GEOSPATIAL THINKING OF UNDERGRADUATE STUDENTS IN PUBLIC UNIVERITIES IN THE UNITED STATES

by

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DEDICATION

To my parents, Vijay Verma and Anupam Verma, my husband, Nikhil Chawla, my son, Aryaveer Chawla, and my siblings, Tanika Verma and Jaideep Verma.

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ABSTRACT

Geospatial thinking and learning are essential components of geography education. The National Research Council's 2006 report, *Learning to Think Spatially,* emphasized that people vary with respect to performance on spatial tasks. Geospatial thinking is a subset of spatial thinking in general. Geospatial thinking is using Earth space at different scales to structure problems, find answers, and express solutions using geospatial concepts, tools of representation, and reasoning processes. Scholars in geography and other disciplines have studied group differences in spatial and geospatial thinking focusing on sex, age, and school grade-level. This dissertation utilized additional demographic variables, such as ethnicity and socioeconomic status, academic variables, such as academic majors and geography academic experience, and geographic locational variables, such as census divisions and urban/suburban/rural locations, to explore group differences in geospatial thinking.

The national study in this dissertation utilized Geospatial Thinking Survey (GTS), based on Spatial Thinking Ability Test (STAT) (Lee and Bednarz 2012), to assess group variances in geospatial thinking abilities of undergraduate students (n = 1479) in 61 public universities in 32 states across nine census divisions of the United States. This mixed-method study investigated whether some groups of students, such as ethnic groups or academic major groups, outperform others in overall geospatial thinking and in separate geospatial thinking domains, such as geospatial association and geospatial overlay, and matched students' performance on the GTS with instructors' perceptions of students' geospatial thinking skills. This dissertation also undertook statistical and data-mining modeling to predict the geospatial thinking score of undergraduate students based on demographic and academic characteristics.

The quantitative findings of this research showed that ethnicity, along with socioeconomic status, and geography courses are the most important variables in understanding, influencing, and predicting undergraduate students' geospatial thinking in the United States. Geography educators must tailor classroom instruction and curricula to help improve geospatial thinking of underperforming ethnic groups, especially blacks and Hispanics. The qualitative findings of this study revealed that college geography educators do not have a clear perception of their students' geospatial thinking, because instructors are not fully utilizing geospatial tools of representation, such as maps, to improve the understanding of geospatial concepts in their students.

CHAPTER I

INTRODUCTION

A groundbreaking publication by the National Research Council (NRC), *Learning to Think Spatially* (NRC 2006), offered a new approach to spatial thinking. The report argued that spatial thinking is universal and malleable. The basic building block for spatial thinking is space, and the operations that humans can perform in space form its foundation. Within his space-time theory of relativity, Albert Einstein conceptualized space as the distance or expanse among objects—relative space (Isaacson 2007).

Spatial thinking—a constructive combination of concepts of space, tools of representation, and processes of reasoning—uses space to structure problems, find answers, and express solutions (NRC 2006). Spatial thinking is a cognitive ability to visualize and interpret location, position, distance, direction, relationships, movement, and change over space, in different situations and at different scales (Sinton et al. 2013). "Spatial thinking means different things at different scales, and within different academic disciplines" (DiBiase 2013). Geospatial thinking, focusing on the geography of human life spaces (spatial thinking at the level of Earth), is a subset of spatial thinking in general (Golledge, Marsh, and Battersby 2008b). Thus, geospatial thinking is using Earth space or geographic space at different scales to frame problems, identify answers, and provide solutions using geospatial concepts, representation tools, and reasoning processes. Spatial thinking is powerful and pervasive in academic disciplines, the workplace, and everyday problem-solving situations. The 2006 NRC report also highlighted that spatial thinking can and should be taught at all levels in the educational system. Skills and strategies for using and applying spatial thinking to solve academic and everyday problems can be learned. “Spatial thinking is a skill or a collection of skills that are all learnable, and can be taught” (Huynh and Sharpe 2013, 4). The NRC report, thus, strongly recommended that a systematic research program into the nature, characteristics, and operations of spatial thinking should be undertaken. A national commitment should undergird the systematic educational efforts necessary to meet the goal of spatial literacy (NRC 2006). Spatial thinking is an important part of any curriculum. Liben (2006) emphasized the importance and pervasiveness of spatial thinking and its value in a wide range of disciplines, concepts, tasks, and settings. Spatial thinking plays fundamental roles in scientific and educational research (Newcombe 2010). Spatial thinking is critical in theory-building (e.g., central place theory) and scientific visualization (e.g., sea floor mapping) (NRC 2006).

The inherent link among the elements of space, representation, and reasoning provides power, versatility, and applicability to the process of spatial thinking. Myriad ways exist to approach spatial thinking and to think spatially. The ability to use and apply spatial concepts, representations, and reasoning intelligently and critically is becoming more crucial when participating in academic, workplace, and everyday settings of the modern society. Various spatial thinking modes are connected to brain locations that undertake verbal and mathematical reasoning (Gersmehl and Gersmehl 2007b). Spatial training has been found to improve educational outcomes, such as helping college students complete engineering degrees (Newcombe 2010). Spatial thinking training in education will increase student participation in mathematics, science, and engineering careers (Uttal et al. 2013). The information technology sector is continuously demanding skilled workers with spatial skills (NRC 2006). Neurosurgeons, for example, draw on magnetic resonance imaging (MRI) to visualize specific brain areas that may determine the outcomes of surgical procedures (Newcombe 2010). The U.S. Department of Labor has required geospatial talents in their career opportunities (Baker 2012).

People think spatially in many everyday situations: when rearranging clothes in a luggage bag, assembling a piece of furniture using a diagram, buying a new home, placing dishes on a dinner table, or consulting a map for directions. "We understand things by looking at their spatial patterns" (Sinton et al. 2013, 11). Geospatial knowledge helps us to make sense of chaotic and diversified environments (Golledge 2002). Geospatial thinking is important for significant everyday life exercises such as remembering a specific map, route planning, following directions to a location, calculating distances and directions, determining spatial patterns among different features on land, visualizing 3-D topography from an alternative perspective, or choosing the best location based on given geographical criteria. Geographic behavior in day-to-day human actions is an essential part of geospatial thinking. Blaut (1991) describes geographic behavior as macro-environmental behavior or place behavior, involving human interaction with the environment or the place, observed in all cultures. "As spatial thinking abilities become increasingly recognized as important for understanding geography, math, science, engineering, and many aspects of everyday life, it is clear that the understanding of these concepts, no matter how simple they seem, must no longer be taken for granted" (Marsh, Golledge, and Battersby 2007, 711).

Despite its crucial role underpinning the National Standards for Science, Mathematics, and Geography, spatial thinking is currently not systematically incorporated into the educational curricula at the K-12 and post-secondary levels. “The development of spatial thinking is not an explicit goal of any school curriculum as literacy and numeracy are” (Sinton et al. 2013, 63). Spatial thinking must be recognized as a fundamental part of the educational system and as a means of facilitating problem-solving and better performance across the academic, professional, and day-to-day activities. Our school systems emphasize reading, writing, math, and science (Sword 2001; Wai 2012; Uttal et al. 2013). Absence of explicit spatial thinking content in the school curriculum will not recognize, support, and challenge the talents of students with strong spatial thinking skills (Sword 2001; Sinton et al. 2013; Uttal et al. 2013). Wai (2012) stressed that some school children are good at numbers and words, while others are better at thinking spatially or visualizing shapes and figures in their minds. All great inventors of the world were not necessarily good at writing essays or solving mathematical equations, they rather imagined spatial models in their minds and made important discoveries (Wai 2012). If school education continues to ignore and undermine students with spatial intelligence, then society will marginalize exceptional spatial talents that can design and build maps, geospatial models, art, buildings, bridges, mechanical devices, engineered tools, electronic devices, smart toys and gadgets. The 2006 NRC report identified its predominant goal as fostering “a generation of students (1) who have the habit of mind of thinking spatially, (2) who can practice spatial thinking in an informed way, and (3) who adopt a critical stance to spatial thinking” (NRC 2006, 3-4). To find ways to facilitate students’ application of spatial thinking and to encourage spatial literacy in students is thus imperative. However, the NRC report made it very clear that spatial thinking is not an add-on to an already crowded school curricula, but rather a missing link across curricula. “Integration and infusion of spatial thinking can help to achieve existing curricular objectives. Spatial thinking is another level to enable students to achieve a deeper and more insightful understanding of subjects across the curriculum” (NRC 2006, 26). Hespanha, Goodchild, and Janelle (2009) observed that explicit practice of spatial thinking in undergraduate social science courses is lacking. The researchers discussed insights and strategies emerging from National Science Foundation (NSF)-sponsored SPACE (Spatial Perspectives on Analysis for Curriculum Enhancement) workshops on spatial thinking in undergraduate education. Sinton et al. (2013) recognized the importance of spatial thinking both as a horizontal thread across the curriculum (learning to understand and practice spatial thinking in all school subjects) and a vertical thread up through the curriculum (from kindergarten through college).

The BRAIN Initiative (2013) is President Obama’s recent call to the science community to undertake research in human brain functioning. BRAIN stands for Brain Research through Advancing Innovative Neurotechnologies. One of the many goals of this program is to understand how brain activity leads to perception, decision-making, and ultimately action. The complex and dynamic nature of human brain calls for uncovering truths and trends about how people think spatially and use spatial thinking strategies in everyday life (Sinton et al. 2013). Gersmehl (2012) presented recent trends in neuroscience research asserting that the human brain seems to be “hard-wired” for spatial thinking, mathematics, and language. Gersmehl (2012) referred to Immanuel Kant’s monumental work “Critique of Pure Reason” (1781) to rationalize that the brain is predisposed to think in certain ways and postulated that people have three *a priori* ways of organizing information from experience—temporally, spatially, and causally

(Gersmehl 2012). Gersmehl (2012) conceptualized that different regions of the brain perform distinct spatial thinking skills, based on more than 3000 research studies. fMRI (functional MRI) and other brain-scanning technologies clearly show that the typical human brain has as many as 8-10 distinct areas that take part in thinking in, about, and with space, such as comparing conditions in different places, grouping places into regions, arranging places in sequences, and finding positions in spatial hierarchies (Sinton et al. 2013). Thus, ignoring spatial and geospatial thinking education directly implies neglecting one of the key ways with which human brain organizes knowledge.

Spatial thinking is an important life-skill that also improves overall academic performance. Spatial thinking skills are an essential component of an array of skills that are required for problem solving to assist durable learning (Gersmehl and Gersmehl 2006). Providing a more prominent place for spatial thinking skills in the curricula and assessment programs of American schools (Gersmehl and Gersmehl 2006), starting in kindergarten and first grade (Gersmehl and Gersmehl 2007a), is favorable for student performance. Understanding spatial and geospatial thinking is, thus, an important part of the BRAIN Initiative (2013). Spatial and geospatial thinking research will reveal new agendas about human cognition that now can only be imagined (Sinton et al. 2013).

The Rediscovering Geography Committee (1997) recommended undertaking research that improves the understanding of geographic literacy and learning. “Geographical learning requires a geographical lens, an approach that is grounded in spatial thinking” (Sinton et al. 2013, 13). Cutter, Golledge, and Graf (2002, 315) structured ten questions important for the geographic community to address: the tenth question was “what is the nature of spatial thinking, reasoning, and abilities?” They declared that geographic knowledge is the product of spatial thinking and reasoning requiring the ability to comprehend such concepts as scale changes, distance and direction variations, and location identification. Spatial thinking concepts are most closely associated with the discipline of geography and geographic knowledge (Tate, Jarvis, and Moore 2005). The concepts, representations, and processes used by spatial thinkers are also used by geographers to study the characteristics, features, and spatial relationships within the natural and social world (Sinton et al. 2013). Battersby, Golledge, and Marsh (2006) reasoned that, because geography relies on many aspects of spatial thinking, reasoning, and visualization, lessons in the subject should provide an excellent way to improve geospatial knowledge. Important for the geography academic community is to address and undertake research in geospatial thinking. The two commonly accepted goals of the geography discipline are the enhancement of spatial thinking and reduction of geographic illiteracy (Golledge, Marsh, and Battersby 2008a). Understanding conceptual structure and reasoning processes of geospatial thinking is crucial in strengthening the learning and education of geography (Ishikawa 2013). Although geography is a subject that is inherently spatial, but it is largely absent in the United States from the school curricula, incorporated within the social studies curricula, frequently taught by underprepared teachers, or not well taught as a spatially rich experience lacking "where" and "why there" analysis (Sinton et al. 2013). Sinton et al. (2013) recommended the use of *Geography for Life: National Geography Standards* (2012) in classroom instruction to support spatial thinking learning through geography.

Significant differences occur among people as to how, how quickly, and how well they understand and do something. It is important to understand "how individuals are able to mentally encode, process, store, and retrieve geographic information and why certain individuals are better or worse in these activities" (Albert and Golledge 1999, 8). Being aware of differences in the levels of spatial abilities among people is essential in understanding completely the nature of geographic knowledge (Golledge 2002). Gersmehl (2012) underscored that various domains/modes of spatial reasoning are not correlated. Different people undertake various spatial thinking tasks in dissimilar ways, levels of skill, and rates of development. People may be better with some types of spatial thinking and not with others (Sinton et al. 2013). For example, a student may be good at map navigation but may not understand very well spatial correlation. To design effectively lessons and assessments, Anthamatten (2010) and Gersmehl (2012) urged the geographic community to pay attention to such differences in spatial thinking.

Like different levels of performance in spatial thinking exist as a function of age, sex, and experience (NRC 2006), certain groups of people from various ethnic, socioeconomic, academic, and geographic backgrounds should demonstrate differences in how people approach and incorporate spatial thinking. "These variations might reflect different progress rates through developmental spatial achievements, different developmental end points, differential access to nonspatial component skills that are needed for spatial processing (e.g. working memory), or differential success in activating competencies in a given test environment (e.g. as a consequence of test anxiety)" (Liben 2006, 208). Investigating the nature of group differences based on variables such as age, sex, ethnicity, socioeconomic status, academic context, geography academic experience, and geographic location can lead to a better understanding of the comprehension and use of geospatial thinking.

Few studies to date have examined the role that factors unrelated to sex typing may play in accounting for differences in spatial thinking behavior. Individual and group differences in spatial thinking development imply the need for observational and experimental research that goes beyond descriptions of age-linked differences in spatial thinking (Liben 2006). Designing effective geography teaching tools, e.g. geographic information systems (GIS), must take into account cognitive factors such as differences in individual spatial skill levels, varying academic disciplines, and cross-cultural differences (Albert and Golledge 1999). Discerning group differences in geospatial thinking would open many avenues to address the appropriate ways for interfacing formal and informal learning about geospatial concepts, tools of representation, and processes of reasoning for different groups. Using appropriately designed support systems tailored to specific groups, geospatial thinking can be taught formally to students belonging to those groups. School curricula at all levels and society in general need to incorporate greater understanding in the awareness, acceptance, and implementation of spatial and geospatial thinking. Consciously thinking about the neurological underpinnings of spatial thinking, such as individual and group differences, may help geographers design better educational materials, deliver more meaningful classes, and assess student mastery more effectively (Gersmehl and Gersmehl 2006). It is important to develop effective and targeted instructional materials for training good geospatial thinkers (Ishikawa 2013). For example, based on their research on geospatial thinking expertise across grade-levels, Huynh and Sharpe (2009) recommended the development of an age-appropriate curriculum and pedagogy for geography and GIS teaching. Uttal et al. (2013) showed that spatial thinking skills are malleable, and training can improve spatial reasoning with targeted instruction in population sub-groups, such as males and females, and children and adults.

For spatial thinking, various terms are used interchangeably or without clear definitions in the literature, such as spatial ability, spatial cognition, or spatial intelligence. However, Ishikawa (2013) empirically concluded that geospatial thinking cannot be considered equivalent to spatial ability. Geospatial is in essence equivalent to geographic, but it includes the application of geographic contents or properties to general space (Ishikawa 2013). In this dissertation, I used the terms spatial thinking and geospatial thinking to refer to human cognition of space and geospace, respectively, i.e. cognition in space/geospace, cognition of/about space/geospace, and cognition with space/geospace. This study employs the term spatial when referring to general spatial thinking (any space from microscopic to cosmic/universal scale) and geospatial when referring to specific spatial thinking using Earth's surface and near-surface as its space.

Significance of the Study

My research assesses geospatial thinking of undergraduate students in public universities in the United States. The study aims to understand the fundamental aspects of the geospatial thinking abilities of undergraduate students—how undergraduate students utilize their cognitive functioning to make informed decisions in their everyday lives using geospatial conceptual knowledge and reasoning processes. Cognitive processes are inseparable from behavior (Blaut 1991). Thus, it is imperative to understand how people with varying cultural and academic backgrounds use dissimilar, noncorrelated geospatial thinking domains differently. My research thus strives to understand how undergraduate students from different backgrounds think geospatially. My study helps in understanding variables that influence cognitive abilities required in thinking geospatially and in contributing to more effective and efficient geography teaching by acknowledging geospatial thinking differences in certain sub-populations. For example, do differences exist in the way white and Hispanic students or urban and rural students mentally visualize maps and geospatial patterns?

With this research, I aim to contribute toward informing the literature about the demographic, academic, and geographic differences in geospatial thinking, thereby targeting the errors of omission that currently exist in the literature. Further, the study will be useful in higher education policymaking. Educational policies must reflect and address the nature of group differences in geospatial thinking and geospatial learning needs of diverse student groups having different demographic and academic contexts. Scholars may use the research work to conduct further inquiries about geospatial thinking and to strengthen student standardized testing regarding geospatial thinking. "The discipline of geography might benefit by using scientific research on spatial thinking ability and related concepts to guide its curriculum" (Anthamatten 2010, 178). My dissertation in geospatial thinking research will help guide geography curriculum. Based on the foregoing group differences, my research findings will assist in refining and restructuring geography undergraduate teaching, including curriculum, textbooks, classroom modules, and assessments. "From an educational perspective, what is most important is whether the experiences (e.g., different levels of play with spatial toys) that have been linked to higher spatial performance in correlational research can be exploited as educational interventions to enhance spatial skills" (Liben 2006, 209).

My data and research will add to the body of scarce geospatial thinking research in higher education geography and will answer the call from such scholars as Downs (1994), Anthamatten (2010), Lambert (2010), and Huynh and Sharpe (2009, 2013) to gather empirical data based on reliable and valid assessments. Data collection in the field of geography education is also important in aiding the development of coherent learning theories and predictions about students' geospatial knowledge and thinking.

Problem Statement

The purpose of this research is to investigate the fundamental question: Do undergraduate students in public universities in the United States differ in geospatial thinking? To understand differences in geospatial thinking, I propose a mixed-method—quantitative and qualitative—analysis of geospatial thinking of undergraduate students to identify trends in public universities across the U.S. While scholars in geography and other disciplines have researched extensively about group differences in spatial thinking, the studies have largely focused on sex and age differences in children (Newcombe and Huttenlocher 2006). Few studies have addressed the issue from a perspective of ethnic groups, socioeconomic status, academic context, geography academic experience, and geographic location to discern differences in geospatial thinking and even fewer have conducted research at the undergraduate level. My research focuses on these variables and their effects on the geospatial thinking of undergraduate students: sex, age, ethnicity, educational attainment of parents (socioeconomic status), annual income of parents (socioeconomic status), academic major, academic classification, geography academic experience at high school level, geography academic experience at college level, census division (geographic location), urban/suburban/rural pattern (geographic location). In the qualitative analysis, the research identifies and explores, from the perspective of teachers, geospatial concepts that undergraduate students have difficulty in comprehending. The qualitative data from faculty interviews will serve as a check for quantitative data gathered from students to identify trends in students' geospatial thinking. My research will thus offer a contribution to the understanding of spatial thinking in general and geospatial thinking in particular.

Huynh and Sharpe (2013) lamented about their work: "Education research is hard to generalize due to the large number of uncontrolled variables, a small sample size, and one study site" (10). The researchers call for more geography education data from a large geographical area, such as at state or country level, to make stronger and more reliable conclusions related to demographic variables such as age and ethnicity, formal learning of geography, and cultural influences relating to spatial thinking. My research aims to collect data about geospatial thinking from university undergraduate students at a national level, collecting information on cultural variables, including age, ethnicity, location, and geography learning.

CHAPTER II

LITERATURE REVIEW

Long before geographers began to focus on spatial thinking, psychologists and other scholars sought to identify and measure spatial ability. Spatial ability—typically defined as spatial perception, visualization, and orientation—is seen as a narrower concept than spatial thinking (NRC 2006). Ishikawa (2013) empirically examined the relationship between spatial ability and geospatial thinking, concluding that students' spatial abilities do not sufficiently explain their performance on geospatial thinking tasks. Spatial thinking is not a new idea in geography education and research; spatial analysis has long been fundamental to geography but the use of the term "geospatial thinking" is novel and only beginning to be widely used. Spatial thinking means to conceptualize and solve problems through the use of spatial concepts such as distance, direction, and region and the tools of representation like maps and graphs, along with the appropriate thinking processes (Jo, Bednarz, and Metoyer 2010).

Research concerning the importance and impact of spatial and geospatial thinking in academic, professional, and everyday life is substantial and diverse. Literature that strives to evolve knowledge and education about spatial and geospatial thinking is continuously advancing methods, techniques, approaches, and factors affecting the underlying cognitive processes. These research trends have identified three pivotal areas of inquiry:

1. Frameworks for understanding spatial and geospatial thinking;
2. Group differences in spatial and geospatial thinking; and

3. Effects of interventions on spatial and geospatial thinking

Frameworks for Understanding Spatial and Geospatial Thinking

Spatial thinking refers to identifying, explaining, and finding meaning in spatial patterns and relationships (Solem, Cheung, and Schlemper 2008). Geospatial knowledge is the knowledge of or about space in the context of geography (Huynh and Sharpe 2009). "Because geographers explore patterns and processes of phenomena on the Earth's surface at a variety of scales, the concept of space is important to their work" (Huynh and Sharpe 2013, 3). The application of geospatial knowledge in a sequential cognitive process to solve a problem is called geospatial thinking (Huynh and Sharpe 2009).

Geospatial thinking is a core component of geography (Golledge 2002; Bednarz 2004; Huynh and Sharpe 2009). Golledge (2002) confirmed that geography is a spatially enabled discipline studying geospatial phenomena and their interrelationships. He explained that the entire geographic thinking and reasoning revolves around spatial concepts (e.g. scale transformation; frames of reference; spatial association, classification, diffusion, hierarchy, and aggregation). Such spatial concepts help in understanding and employing the concept of geographical space or geospace—the area or expanse among objects on the Earth, at varying scales. "In geography, spatial relationships form the fundamental basis upon which geographic theories are developed, issues discussed, and concepts imparted" (Huynh and Sharpe 2009, 120).

Blaut (1991) proposed that features in any macro-environment or geographic place must be described with a minimum of three characteristics: nature or semantic meaning; distance; and direction from some reference point. Golledge (1995) presented basic "primitives" for building sets of spatial concepts. He recognized identity (tags an occurrence with a name or label), location (where an occurrence exists within the totality of an environment), magnitude (a measure of the number, size, amount, degree, intensity, extent, strength, or volume of an occurrence), and time (reports when an occurrence exists) as the four first-order spatial concepts or "primitives of spatial knowledge." An occurrence can thus be defined in terms of its identity, location, magnitude, and temporal existence. The simple spatial concepts (class, category, frequency, periodicity, growth, development, change, distance, angle and direction, sequence and order, connection and linkage, boundary, density, dispersion, and pattern and shape) and complex spatial concepts (correlation, overlay, network, and hierarchy) of higher order are derived from the four spatial primitives. Similarly, Golledge, Marsh, and Battersby (2008a) classified geospatial concepts into a five-level framework: primitive (identity, location, magnitude, and space-time), simple (e.g., arrangement, direction, distribution), difficult (e.g., polygon, area, reference frame), complicated (e.g., scale, surface, buffer, profile), and complex (e.g., interpolation, projection).

Jo and Bednarz (2009) built a three-dimensional taxonomy of spatial thinking. Using the taxonomy, they evaluated questions in four high school geography textbooks on the basis of the three components of spatial thinking. The categories of their spatial thinking taxonomy are: First Primary Category—Concepts of Space (four sub-categories are nonspatial concepts, spatial primitives, simple spatial concepts, and complex spatial concepts); Second Primary Category—Tools of Representation (two sub-categories are use and nonuse of representations); and Third Primary Category—Processes of Reasoning (three sub-categories are input level, processing level, and output level). Jo and Bednarz identified thirty-one concepts as essential in spatial thinking. "Spatial primitives represent basic and fundamental characteristics of an existence in space, such as place-specific identity, location, or magnitude. Simple-spatial concepts are concepts established by sets of spatial primitives (e.g. distance is the interval between locations); complex spatial are those established by assemblies of sets of simple spatial concepts (e.g. network is expressed as sets of connected locations) or from combinations of spatial primitives and simple spatial concepts (e.g. concept of hierarchy can be derived by combining location and magnitude with connectivity)" (Jo and Bednarz 2009, 5). The first level of thinking, the input level, exhibits cognitive processes employed to capture information from the senses or to recall information from memories, e.g. define, identify, recognize, describe. The second level, the processing level, requires making sense of collected information and thus analyzing, classifying, explaining, comparing, or categorizing information obtained at the input level. The third level of thinking, the output level, attributes to creating new knowledge or products from the information received from the first two levels through the processes of evaluation, generalization, application, prediction, and creation. The researchers provided insightful suggestions on the design and use of textbook questions to foster learning to think spatially.

Gersmehl and Gersmehl (2006) inductively developed the taxonomy of spatial thinking skills based on three basic concepts of spatial thinking:

1. Location is the notion that makes a question geographic. The ability to conceptualize and articulate location is a foundational spatial concept.

2. Site/Conditions, also called attributes, traits, or characteristics, are observable features at a particular location—soil, rocks, weather, vegetation, social relations, clothing, religion, food, for instance. The listing of conditions at a place, a cognitive

process of making explicit mental links between "what" and "where" facts about the place, is a very concrete form of spatial thinking. Conditions describe and explain relationships within places.

3. Situation/Connections, also termed links, edges, paths, or routes, are processes or structures that link two or more places together. Spatial connections include identifying the connected places, describing the nature of connections, tracing the route of the connections, and describing the other landscape features that may help facilitate the connection, e.g. slope, flow, trade, movement, migration. Connections describe and explain relationships between/among places.

Based on these three basic concepts, Gersmehl and Gersmehl (2006) built their taxonomy that included eight distinct domains/modes/elements/types/skills of spatial thinking:

1. Making a Spatial Comparison: How are places similar or different?
2. Inferring a Spatial Aura (Area/Zone of Influence): What effect(s) does a feature have on nearby areas?
3. Delimiting a Region: What places are similar to each other and can be grouped together?
4. Fitting a Place into a Spatial Hierarchy: Where does this place fit into a graded or ranked order of areas?
5. Graphing a Spatial Transition: What is the nature of change between two places?
6. Identifying a Spatial Analog: What places at other locations have situations similar to a particular place and therefore may have similar conditions?

7. Discerning Spatial Patterns: Are features arranged in clusters, straight lines, areas, rings, or other nonrandom ways?

8. Assessing a Spatial Association (Correlation): Do specific features tend to occur together?

Gersmehl and Gersmehl (2006) also presented three kinds of spatio-temporal thinking important for geographic understanding:

1. Change: How does a place alter through time?
2. Movement: How do things vary in location through time?
3. Diffusion: How do things fluctuate in extent through time?

Table 2.1 summarizes the foregoing authors' spatial thinking classifications.

Table 2.1. Classification of Spatial Thinking Concepts, Components, and Domains.

Divisions	**Golledge (2002)**	**Golledge, Marsh, Battersby (2008a)**	**National Research Council (2006)**	**Jo and Bednarz (2009)**	**Gersmehl and Gersmehl (2006)**	**Gersmehl and Gersmehl (2006)**
1	Primitive	Primitive	Concepts of Space	Concepts of Space: Nonspatial; Spatial Primitive; Simple Spatial; Complex Spatial	Location	Spatial Comparison
2	Simple-Spatial	Simple	Tools of Representation	Tools of Representation: Use; Nonuse	Site/ Condition	Spatial Aura (Zone of Influence)
3	Complex -Spatial	Difficult	Processes of Reasoning	Processes of Reasoning: Input Level; Processing Level; Output Level	Situation/ Connection	Region
4		Complicated				Spatial Hierarchy
5		Complex				Spatial Transition
6						Spatial Analog
7						Spatial Pattern
8						Spatial Association

Newcombe and Huttenlocher (2006) illustrated two ways in which spatial locations can be coded:

1. With respect to external frameworks, spatial learning can be of two types. Cue learning or route learning occurs when coding location entails the simple and direct use of external landmarks as markers (called beacons). Cues include relations among multiple beacons. Place learning occurs when external features of the environment (such as the shapes of enclosing spaces, or sets of separated landmarks) provide a set of fixed reference points for marking distance and direction, and mapping desired locations.
2. With respect to the viewer, spatial learning can be of two types. Response learning (or egocentric learning) is remembering actions required to get to a desired location, such as where to walk to get to school. Dead reckoning (or inertial navigation) is adjusting an initial location memory by taking the direction and distance of one's own movement into account.

Scholars have also discussed spatial scale typologies. Significant disagreement exists about the scale (from tabletop scale to geographic scale) and dimensions (thinking in, about, and with space) of spatial thinking (Lee and Bednarz 2012, 16). Mark and Freundschuh (1995) suggested that human spatial cognition and interaction operate differently at two levels: geographic (large-scale) spaces and manipulable (small-scale) spaces. Both maps and geographic information systems (GIS) represent geographic spaces, but users interact with maps and GIS as if they were manipulable spaces.

Blaut (1991) suggested two types of human behavior: micro-environmental behavior or object behavior that orients around objects; and macro-environmental behavior or place behavior or geographic behavior that orients around places. Macro-environments are generally larger than people, and micro-environments are smaller. Montello (1993) proposed four scales of spatial thinking: Micro Scale (spatial examination from the microscopic level to the arrangement of body parts, e.g. nanotechnology operates at this level); Figural Scale (the personal domain in the immediate vicinity of the human body); Environmental Scale (the activity space as defined by Goodchild in 2009 or the immediate area in which a person lives and behaves or the environment that can be visually perceived); and Geographic Scale (areas and places that cannot be perceived from a single vantage point on earth). Gersmehl and Gersmehl (2006) observed that people use distinct kinds of spatial thinking to deal with phenomena at three scales: Personal Scale (spatial thinking at a micro scale, e.g. when human beings manipulate objects around their bodies, orient themselves in space, and navigate through space), Geographical Scale (e.g. when studying a map or photograph of, or making observations in, a community, a country, or the globe), and Astronomical Scale (spatial thinking of extremely large areas, e.g. when people contemplate the ultra-macro scale of Einsteinian space-time). The NRC 2006 report presented three contexts for spatial thinking:

1. Geography of life spaces includes the everyday or physical geographic world of four-dimensional space-time where spatial thinking is a means of coming to grips with the static and dynamic spatial relations between and among self and other objects in the physical environment. These relationships represent cognition *in* space and involve thinking about the world in which we live, e.g. people think *in* space when they move about within their homes or communities, or orient themselves around other people or

objects. Location, distance, direction, regions, and sequences are basic spatial concepts people use while thinking in space (Sinton et al. 2013).

2. Geography of physical and social spaces focuses on scientific understandings of the nature, structure, and function of phenomena that range from the microscopic to the astronomical scales. This knowledge represents cognition *of/about* space and involves thinking about the ways in which the world works, e.g. people study maps or pictures to analyze spatial relationships among phenomena.

3. Geography of intellectual spaces is in relationship to concepts and objects—the focus of thoughts—that are not themselves necessarily spatial but can be assigned location via space-time coordinates and therefore can be spatialized. This type of reasoning represents cognition *with* space and involves thinking with or through the medium of space to understand abstract information and organize knowledge, e.g. people think *with* space when they construct a graph, a concept map, or a knitting pattern.

Table 2.2 showcases various classifications of spatial scales conceptualized by different researchers.

Table 2.2. Classification of Spatial Scales.

Researchers	**Divisions**	**Categories**			
Blaut (1991)	2	Micro-environmental Spaces (orient around objects)		Macro-environmental Spaces (orient around places)	
Mark and Freundschuh (1995)	2	Manipulable (small-scale) Spaces		Geographic (large-scale) Spaces	
Montello (1993)	4	Micro Scale	Figural Scale	Environmental Scale	Geographic Scale
Gersmehl and Gersmehl (2006)	3	Personal Scale (Micro Scale)		Geographical Scale	Astronomical Scale
National Research Council (2006)	3	Geography of Life Spaces (Cognition in space)		Geography of Physical and Social Spaces (Cognition of/about space)	Geography of Intellectual Spaces (Cognition with space)

Spatial ability is not a unitary construct, but a collection of specific skills (Voyer, Voyer, and Bryden 1995). The foregoing taxonomies and typologies of spatial thinking also suggest that spatial thinking is a combination of distinct and overlapping skills that are affected differently by demographic, geographic, and academic differences of people. Spatial thinking skills are nonlinear and interconnected (Smith 2007). Different components of spatial and geospatial thinking are not correlated, so people good at one type of spatial thinking task may not be good at other spatial thinking activities (Gersmehl and Gersmehl 2006; Gersmehl 2012; Lee and Bednarz 2012; Huynh and Sharpe 2013; Ishikawa 2013; Sinton et al. 2013). Newcombe and Huttenlocher (2006) urged scholars to undertake research in one such practically important spatial skill—navigation (or moving between locations).

Group Differences in Spatial and Geospatial Thinking

Important are suggestive differences among people as to how, how quickly, and how well they understand and do something, particularly regarding different levels of performance in spatial thinking as a function of age, sex, and experience (NRC 2006). To search for reasons behind spatial variation that occurs among people, places, events, and environments is essential (Golledge 1996). Liben (2006) and Newcombe (2010) noted that people from different sexes, ages, or cultures vary with respect to performance on spatial tasks. Understanding individual differences is valuable in formulating educational curricula to help students maximize spatial skill performance that guide many essential real world activities, such as finding the way to a store or office, and also higher-level challenges such as reasoning in mathematics and the physical sciences (Newcombe and Huttenlocher 2006).

Research on sex differences in spatial abilities has been ongoing since 1930s, especially in the field of psychology. Spatial thinking is a holistic term that emerged relatively recently in late 1990s. "Before the term spatial thinking was introduced, cognitive scientists, psychologists, and science education researchers defined and studied spatial abilities" (Bodzin 2011, 282). Gilmartin and Patton (1984) reviewed psychological research findings on gender-based differences in spatial skills and suggested males are more proficient than females in spatial visualization and spatial orientation but no sex differences exist for other spatial tasks. However, they opined that psychological research generalizations must not be directly applied to geography. Spatial thinking research in the field of geography, i.e. geospatial thinking, is fairly new. This research gained momentum after the NRC published its report *Learning to Think Spatially* in 2006.

Allen (1974) studied the performance of university students on a battery of six spatial tests (card rotation, cube comparison, path choosing, map planning, paper folding, and surface development) and found significant sex differences in problem-solving strategies used for three of the tests. She suggested that women were less proficient than men in their use of frequently used spatial strategies. Women used more guessing and concrete solution styles, rather than relying on mental images to solve the spatial problems.

Gilmartin and Patton (1984) reported the results of five map-use experiments conducted with school (first, third, and fourth grade) and college (undergraduate) students to analyze sex-based differences in students' ability to use cartographic illustrations as geography learning aids and perform map-use tasks (route planning, symbol identification, visual search and estimation, and right/left orientation). The authors observed significant differences in the younger age groups where boys outperformed girls. Map-use scores for female and male college students were similar. Franeck et al. (1993) found significant variances in favor of males at the junior high school level on a similar task, but these differences decreased in high school and essentially disappeared at the college level. However, Voyer, Voyer, and Bryden (1995) meta-analyzed the magnitude of sex differences in spatial abilities and discovered different results. They examined magnitude, consistency, and stability across time regarding sex differences in spatial abilities and observed that the age of emergence of sex differences depends on the test used. For six distinct spatial tests, the researchers found no major sex differences in early childhood. Sex differences increased significantly with age. Voyer, Voyer, and Bryden suggested sex differences in favor of males in tests that assess mental rotation and spatial perception skills.

Henrie et al. (1997) studied sex differences among students from junior high through undergraduate levels. Males consistently outperformed females on a test covering four major aspects of geography: (1) map skills (an important geospatial thinking component), (2) physical geography, (3) human geography, and (4) regional geography. Geographic knowledge increased from junior high through students taking advanced college courses in geography.

Cochran and Wheatley (1988) investigated individual differences of undergraduates in cognitive strategies and their relationships to spatial ability and sex, using two spatial ability tests and a Spatial Strategy Questionnaire (problem-solving strategies on the spatial relations test). Males scored significantly higher than females on only one spatial test. Using a meta-analysis approach, Baenninger and Newcombe (1989) reviewed two strands of research: (1) sex differences in spatial experience (spatial activity participation) can explain sex differences in spatial ability, and (2) environment has an impact on spatial skills and sex differences in ability. Their research revealed a weak but reliable relationship between spatial activity participation and spatial ability that was similar for males and females. The researchers also explained that the appearance of sex differences at various ages on different tests is due to the effect of cumulative experience.

Cherry (1991) reported that males generally score better than females when asked to locate places on a map. Lawton (1994) examined gender differences in way-finding strategies in a sample of primarily white middle to lower middle class undergraduate students. Women were more likely to use a route strategy (attending to instructions on how to get from place to place), whereas men were more prone to employ an orientation strategy (maintaining a sense of their own position in relation to environmental reference points). Women also reported higher levels of geospatial anxiety, or anxiety about environmental navigation, than did men.

Albert and Golledge (1999) studied spatial cognitive abilities in the use of GIS. They administered three map overlay tests to 134 undergraduate students. The tests included selecting the correct input map layer, logical operator, and output map layer. The researchers found no statistically significant differences between males and females, or between GIS-users and GIS nonusers for any of the test conditions or two-way interactions.

LeVasseur (1999) studied 23 geography classes in grades 6 and 9 on the skills and tools of geography using the National Council for Geographic Education (NCGE) Competency-Based Geography Test (1980). The sample included 359 sixth-grade students (173 females, 186 males; 87% white, 11% African American, 1% Hispanic, 1% Asian) and 170 ninth-grade students (92 females, 78 males; 81% white, 15% African American, 2% Hispanic, 2% Asian). Based on the NCGE test scores, no sex differences were noted for the total sample for geography knowledge. More males than females in both the sixth and ninth grades were in the above average group and more females were in the average group. More ninth-grade females than males were in the below average group. Sixth-grade male and female students scored equally well in their ability to interpret direction, distance, and symbols on a map. Males and females also performed equally well when interpreting line graphs. Females outperformed males on interpreting bar graphs. More females than males were also able to use a grid to locate places on a map. LeVasseur (1999) also reported that ninth-grade African-American males scored significantly higher than ninth-grade African-American females. The higher score of sixth-grade African-American males was not significant statistically. White females outperformed white males, but the difference was not significant either at grade six or grade nine.

Montello et al. (1999) analyzed sex-related differences and similarities in geographic and environmental spatial abilities with a sample of 43 females and 36 males. The scale included psychometric tests; tests of directly acquired spatial knowledge from a campus walk; map-learning tests; tests of current geographic knowledge at local, regional, national, and international scales; tests of object-location memory; a verbal spatial task; and various self-report measures of spatial competence and style. The researchers outlined that females performed better at static object-location memory task, while males excelled at tests of newly acquired spatial knowledge of places from direct experience.

Hardwick et al. (2000) investigated gender differences influencing performance on a standardized test of geography knowledge. The study of 109 undergraduate students in an introductory physical geography course and 85 students in a world geography class had the students complete a standardized inventory of gender differences and then take a test of their geographical knowledge, understanding, and skills (based on location exercises, mental mapping, and patterns and processes in physical and human geography). The research exposed complexities of gender identification—all men were not masculine and all women were not feminine. Generally, the results indicated that masculinity and geography major positively affected test performance. The other gender categories (feminine and androgynous) did not have a significant impact on predicting test performance. Even though masculine males and females slightly outperformed others in the geography tests, the results were not statistically significant. Students majoring in geography did better on the test than did those having other academic majors across all gender categories.

Butt (2001) explored a complex set of issues related to a persistent gap in the academic achievement between boys and girls in many school subjects, with a focus on the assessment of geography in secondary schools in the United Kingdom from key stage 3 to post-16. His study revealed that at almost all levels boys consistently performed less well than girls in formal assessments. This assessment gap, however, was reversed between the sexes later in life, as evidenced by research among geography undergraduates (Butt 2001). Lee (2005) administered pre- and post-spatial skills tests to 80 undergraduate students at Texas A&M University. He found that spatial ability improvement linked to GIS learning was not statistically significant regarding differences in gender or academic major (geography majors vs. science and engineering majors). Although male students scored significantly higher than females on both the pre- and post-test, females displayed more improvement. Geography majors scored higher on the pre- and post-test than science and engineering majors, but the difference was not statistically significant. Analysis of paired sample t-test for pre- and post-tests showed that students of both groups increased their scores significantly after completing a GIS course. From the results of 64 participants who enrolled in GIS and cartography courses and undertook a cognitive mapping test, Lee (2005) observed no significant differences in students' choice of map-drawing strategies between male and female students. Also, academic major did not influence map-drawing strategies.

Levine et al. (2005) examined whether the male spatial advantage varies across children from different socioeconomic groups. The researchers studied a sample of 547 students (276 boys, 271 girls) from 15 schools in the greater Chicago area. Boys outperformed females from middle and high socioeconomic backgrounds on spatial tasks. Boys and girls from low socioeconomic group did not differ in their performance level on spatial tasks.

Gilmartin and Patton (1984) purported that, with increasing age and grade-levels, individuals become better spatial thinkers because they experience greater spatial independence and range, exposure to educational media, and general intellectual maturation. In an experiment involving route planning and symbol identification on maps with planimetric and planoblique representations, third graders scored higher than first graders (Gilmartin and Patton 1984). Blaut (1991) concluded that preschoolers and young children naturally engage in simple mapping behavior, including map-reading, map-using, and map-making. Newcombe and Huttenlocher (2006) discussed that although infants possess certain spatial abilities, higher-level spatial cognition used in navigation, such as coding spatial locations, spatial inference, and understanding maps, improves with age and increasing school years. Gersmehl and Gersmehl (2007a) highlighted young children's developmental readiness for geospatial thinking, but struggled to answer precisely at what age children can begin to understand and learn different spatial thinking modes. For example, the researchers suggested that kindergarten children can and do use multiple frames of reference for location.

Lee and Bednarz (2012) administered the Spatial Thinking Ability Test (STAT) to a sample of 532 junior-high, high school, and university students. The researchers observed that as students advanced from junior-high to high school to university, their performance improved. They also concluded that two universities with more geography majors scored higher than two universities with fewer geography majors. Kim and Bednarz (2013) evaluated the effect of GIS learning on five sub-dimensions of spatial habits of mind (SHOM)—pattern recognition, spatial description, visualization, spatial concept use, and spatial tool use. They conducted pre- and post-tests of SHOM across three groups of students: GIS, geography (without GIS content), and education (nongeography). They concluded that the GIS group improved significantly from pre- to the post-test. Geography and education courses did not positively affect students' SHOM.

Battersby, Golledge, and Marsh (2006) explored when students learn to understand and use the concept of map overlay, a key concept behind many geospatial thinking tasks. The investigators reviewed innate geospatial conceptual knowledge of 52 sixth grade, 41 high school, and 48 university undergraduate students—attempting to comprehend when these age/grade groups can illustrate that specific complex geospatial concepts are understood without formal learning of the concept. The study included paper and pencil map overlay tasks and determined that the university and high school students had a significantly better grasp on the concept and application of map overlay than the middle school students. The researchers explained that not only were the high school and university students more likely to use map overlay, they were also significantly more likely to answer correctly questions associated with its use. Map overlay, thus, becomes conceptually easier to grasp and utilize effectively as educational level increases. Marsh, Golledge, and Battersby (2007) illuminated grade-related differences in geospatial concept recognition and understanding. The researchers presented simple paper and pencil tasks to sixth-grade, high school, and undergraduate students to provide insight into grade-related abilities to comprehend descriptions of geospatial relationships. The results indicated significant differences in geospatial concept recognition, understanding, and use among grade-based participants. The understandings students have of geospatial relationship terms builds in complexity as grade-level increases. Golledge, Marsh, and Battersby (2008a) conceptualized and developed a geospatial task-based framework to enhance geospatial thinking vocabulary and concept usage in a grade-related context (third and sixth grade students). In the first experiment with third graders, the researchers found that as complexity of geospatial vocabulary and concepts increased, ability to understand and solve geospatial tasks diminished. Golledge, Marsh, and Battersby (2008a) also reported statistically significant differences between the task-related performances of third-grade and sixth-grade participants on selected geospatial tasks with increasing complexity. The researchers highlighted that an increase in geospatial conceptual awareness was related with school grade level.

Huynh and Sharpe (2009) suggested that geospatial thinking is important to understand geography and geographical concepts and assist problem solving using GIS. Their study developed a geospatial scale (2009) and a geospatial thinking assessment (2013) primarily to address the paucity of valid and reliable assessments for spatial thinking (Walker et al. 2005; NRC 2006); to measure geospatial thinking; and to identify and classify participants into expertise levels (novice, intermediate, or expert) based on their geospatial knowledge. In 2009, Huynh and Sharpe administered the geospatial scale to 104 geography students from four educational levels: grade 9, first-year university undergraduates, third- and fourth-year university undergraduate geography majors, and geography graduate students. Students were then given a simple geographic problem (search for two housing residences based on mandatory and optional criteria) to solve using GIS. The quality of response to the GIS problem was evaluated along three components: geospatial knowledge, strategic problem-solving knowledge (GIS operations), and outcome and explanation. Scores on both the geospatial scale and GIS problem solving showed an increase in geospatial reasoning and expertise with level of education. Huynh and Sharpe (2009) concluded that in general students with lower scores were inclined to use basic visualization or buffer operations, while those with higher scores used a combination of buffers, intersection, and spatial queries.

Moreover, Huynh and Sharpe (2013) developed and evaluated a 30-item geospatial thinking assessment instrument to measure student performance in geospatial thinking. They classified students into geospatial expertise levels (novice, intermediate, or expert) on the basis of their understanding of spatial relations within a geographic context. They observed that generally graduate students performed at the expert level and grade nine students were at the novice level.

The specific language, math, and spatial skills people learn depend on culture—parenting, play, and education (Gersmehl 2012). Child-rearing practices and individual social roles in different cultures influence the development of spatial abilities (Gilmartin and Patton 1984). Ardila and Moreno (2001) administered a neuropsychological battery to the Aruaco Amerindians of Colombia in South America. The battery included verbal and nonverbal tests, including drawing a map of the room. The group performed very poorly in drawing a map, whereas their verbal fluency test performance was in the normal range. Recognition of overlapped figures was virtually perfect in Aruaco Indians when using elements from their environment. Mulenga, Ahonen, and Aro (2001) found that Zambian children performed better in visuo-spatial tests (design copying) than children in the United States. Spatial test scores may be lower or higher in diverse cultural groups, but the important point is they may vary. Rosselli and Ardila (2003) reviewed the cross-cultural differences in performance on spatial ability tasks and analyzed the impact of education and culture on nonverbal neuropsychological measurements. Their findings revealed that performance on nonverbal tests such as copying figures or drawing maps are influenced by the individual's culture.

Table 2.3 presents a list of research works done by various scholars in the field of geography and other disciplines on group differences in spatial and geospatial thinking. The table also presents the sample sizes for studies that utilized empirical data. The table also underscores that substantial research needs to be done for variables other than age and sex.

Table 2.3. Selected Research Works about Group Differences in Spatial and Geospatial Thinking in Geography and Other Disciplines: 1970-2013.

Variable	Geography (Sample Size)	Other Disciplines (Sample Size)
Sex/Gender	Gilmartin and Patton 1984 (397) Cherry 1991 Franeck et al. 1993 Self and Golledge 1994 Henrie et al. 1997 (1564) Albert and Golledge 1999 (134) LeVasseur 1999 (529) Montello et al. 1999 (79) Hardwick et al. 2000 (194) Butt 2001 Lee 2005 (80)	Allen 1974 (93) Cochran and Wheatley 1988 (165) Baenninger and Newcombe 1989 Lawton 1994 (426) Voyer, Voyer, and Bryden 1995 (286) Levine et al. 2005 (547) Liben 2006 NRC 2006 Newcombe and Huttenlocher 2006 Spence et al. 2009 Newcombe 2010
Age/Grade Level	Gilmartin and Patton 1984 (397) Henrie et al. 1997 (1564) Battersby, Golledge, and Marsh 2006 (148) Marsh, Golledge and Battersby 2007 (208) Golledge, Marsh, and Battersby 2008a (169) Huynh and Sharpe 2009 (104); 2013 (104) Lee and Bednarz 2012 (532)	Newcombe and Huttenlocher 2006 NRC 2006
Ethnicity	LeVasseur 1999 (529)	
Culture	Gersmehl 2012	Ardila and Moreno 2001 (20) Mulenga, Ahonen, and Aro 2001 Rosselli and Ardila 2003 Liben 2006
Socio-economic Status		Levine et al. 2005 (547)
Academic Major	Albert and Golledge 1999 (134) Hardwick et al. 2000 (194) Lee 2005 (80) Lee and Bednarz 2009 (80) Kim and Bednarz 2013 (168)	

Effects of Interventions on Spatial and Geospatial Thinking

Geospatial thinking includes geospatial knowledge and reasoning, accounting for specific instruction or education for different levels of learning from basic conceptual knowledge to higher level reasoning (Ishikawa 2013). Spatial thinking skills and abilities can be improved through training, instruction, and practice (Gilmartin and Patton 1984; Baenninger and Newcombe 1989; Newcombe 2010; Bodzin 2011; Sinton et al. 2013; Uttal et al. 2013). The 2006 NRC report stressed that spatial thinking can be learned and taught formally to students using appropriately designed tools, technologies, and curricula. The NRC Committee recommended GIS as one example of a support system that, with pedagogical redesigns, can foster spatial and geospatial thinking.

Blaut (1991) highlighted formal teaching of geography and map skills to young children to improve their spatial knowledge. Uttal (2000) emphasized the influences of maps on the development of spatial cognition. He argued that using and thinking about maps may help children to acquire abstract concepts of space and the ability to think systematically about spatial relations not experienced directly. Exposure to maps may help children to think about multiple spatial relations among multiple locations. Liben (2006), a psychologist, demonstrated, illustrating laboratory and classroom situations, that spatial skills can be improved through interventions like training. She recognized geography as the most viable school subject in which to teach spatial skills. A fundamental fraction of geography education is map education, which she identified as a paramount tool to enhance spatial thinking. “Geography education provides an entrée into spatial thinking. At its core, geographic thinking is spatial thinking” (Liben 2006, 215). Kemp (2008) emphasized the importance of being spatially literate and of teaching spatial literacy to students. He considered maps to be the ideal tools to teach concepts of spatial literacy. He employed insightful map exercises to instill spatial thinking in students.

Marsh, Golledge, and Battersby (2007) recommended utilizing “Minimal GIS”—a pedagogic tool in purpose rather than analytical like traditional GIS—to enable the teaching and learning of geospatial concepts at grade appropriate levels. The incorporation of minimal and low-tech procedures in GIS suited to K-12 grades would make it an effective support system for teaching, learning, and analyzing a variety of both simple and complex spatial problems. Minimal GIS is based primarily on learning concepts.

Lee (2005) used spatial skills pre- and post-tests administered to 80 undergraduate students to show that GIS learning could help students improve their spatial ability, based on an analysis of changes in the students’ test scores. Strong correlations existed between the students’ spatial ability and their performance in the GIS course. Lee (2005) reported that after completion of a GIS course, about half of 64 participants changed their map-drawing strategies for a cognitive mapping test. Lee and Bednarz (2009) employed a spatial-skills test to examine the effect of GIS learning on the spatial thinking ability of college students. They revealed that GIS learning helped students think spatially and observed strong correlations between students’ spatial thinking and their success in the GIS course. Kim and Bednarz (2013) studied the outcomes of GIS learning on five sub-dimensions of spatial habits of mind (SHOM)—pattern recognition, spatial description, visualization, spatial concept use, and spatial tool use. The investigation revealed that completion of GIS course strengthened students’ SHOM, conducted through self-evaluation of spatial habits. Perkins et al. (2010) designed a curriculum to promote spatial thinking using GIS in the context of a middle school class on ecological succession. The researchers utilized a place-based introductory GIS/GPS middle school curriculum unit in which students used measuring tools, GPS units, and My World GIS software to collect physical and spatial data of trees to create a schoolyard tree inventory. From this intervention strategy, the researchers documented a statistically significant increase in students' spatial awareness.

Madsen and Rump (2012) elaborated that the process of learning GIS involves and develops three types of spatial thinking: thinking in space, thinking about space, and thinking with space. Sinton et al. (2013), however, believed that using GIS alone does not guarantee better spatial thinking. To understand, analyze, and explore reasoning behind datasets used and maps produced in the GIS is important. "Just as using calculators, word processors, and the Internet does not automatically generate competency with numbers, words, or information, so using GIS does not necessarily lead directly or automatically to someone becoming a more spatially or geographically literate person" (Sinton et al. 2013, 60).

Hooey and Bailey (2005) suggested active learning methods that increase spatial thinking in students, such as world regional geography courses, informal journal writing in geography, and practicing creative writing in geography classes. Jo, Bednarz, and Metoyer (2010) asserted students could learn to think spatially through questions attuned to the key components of spatial thinking—concepts of space, tools of representation, and processes of reasoning. They encouraged geography teachers to facilitate students' practice of spatial thinking by using questions that can stimulate their spatial thinking.

Gersmehl and Gersmehl (2007a) underscored that "brain structures for spatial reasoning are fully functional at a very early age" (181) and advised that adult intervention (e.g., classroom teachers) may enhance both spatial thinking use and representational ability. The researchers advocated various classroom lessons for young children to improve their spatial thinking abilities. For example, they recommended teachers asking young children to remember and describe things (including arranging pictures of prominent landmarks into proper order) they observe on their route to school to develop their spatial sequencing ability to understand spatial transition.

Newcombe (2010) stressed the importance of spatial thinking for success in Science, Technology, Engineering, and Mathematics (STEM) fields. She discussed the "Project Talent" study to demonstrate the types of questions that assess spatial thinking skills. She emphasized that spatial learning is malleable and durable and suggested various activities for practicing spatial thinking, e.g. using symbolic representation, analogies, gestures, and spatial words (such as inside, between, north, near). Newcombe emphasized that spatial and verbal thinking are intertwined and support each other. She declared that spatial language is a powerful tool for spatial learning and encouraged the use of spatial words in both children and adults.

Sinton et al. (2013) and Uttal et al. (2013) pointed out that games and video-games such as Tetris, Lego blocks, puzzles, and first-person shooter games help improve spatial thinking in certain domains like mental rotation and visual-spatial patterns. Huynh et al. (2013) examined the explicit intervention of games as a way to support student learning of geospatial concepts and skills. The scholars observed improvement in students' learning through games in three geospatial skills: geospatial vocabulary, latitude and longitude extraction from the Universal Transverse Mercator (UTM) coordinate system, and map projection by estimating shortest distance between cities.

Bodzin (2011) demonstrated that spatial thinking can be learned, can be taught formally to students, and can be supported by appropriately designed tools, technologies, and curriculum. He investigated the role of geospatial information technology (GIT)-supported science curriculum in enhancing spatial thinking through understanding land use change. Bodzin sampled in an urban school 110 students in five eighth-grade classes from three different ability levels—low, middle, and upper tracks. Data gathering methods included pre- and post-test assessments, daily classroom observations, daily teacher meetings, and examination of student produced artifacts. The curriculum implementation was found effective for enhancing spatial thinking skills involved with remote sensing satellite imagery (a GIT product) interpretation to identify objects and investigate groundcover features.

Linking the Literature Review and Problem Statement

Although scholarly works in geography and other disciplines have revealed some differences in how people engage in spatial and geospatial thinking, these studies have focused mainly on sex/gender, age, and academic levels. Substantial research remains regarding other group variances in spatial and geospatial thinking. Discerning group differences in spatial and geospatial thinking among groups based on sex and age as well as ethnicity, socioeconomic status, academic context, geography academic experience, and geographic locations is of cardinal importance in the field of education in various disciplines. Spatial thinking can be improved with interventions, thus, curricula, classroom tools, course materials, and assessments must be designed to target spatial thinking and particularly geospatial thinking in identified groups with lower geospatial thinking levels. Analyzing the trends of geospatial thinking differences with data drawn from across the nation, rather than two or three local classrooms, should be useful in predicting the levels of geospatial thinking for students possessing permutations of various demographic, academic, and geographic factors.

Thus, through my research problem statement—Do undergraduate students in public universities in the United States differ in geospatial thinking?—I specifically investigate important research lacunae regarding geospatial thinking. My research about geospatial thinking is the first to:

1. examine geospatial thinking variances at the national scale.
2. analyze a battery of variables, including, in addition to sex and age, ethnicity, socioeconomic status, academic context, geography academic experience, and geographic locations.
3. predict the geospatial thinking level of students in general through the Geospatial Thinking Model (GTM). The GTM helps in anticipating geospatial thinking score on the basis of a combination of significant demographic, academic, or geographical characteristics possessed by a student. This score is based on the Geospatial Thinking Survey (GTS) utilized in this dissertation.

Theoretical Framework

Culture is the way of living of a human group and includes behaviors, ways of thinking, feeling, knowledge, values, attitudes, and belief (Harris 1983). "Culture has both abstract and material dimensions: speech, religion, ideology, livelihood, and value systems, but also technology, housing, foods, and music" (Rowntree et al. 2014, 27).

Culture prescribes what is learned and at what age (Ferguson 1954; Irvine and Berry 1988). Thus, in applying the concept to my research, culture is a broad term including sex, age, ethnicity, family background and socioeconomic status, educational context, urban/suburban/rural patterns, and geographic locations. Culture is thus essential in exploring group differences in spatial and geospatial thinking.

The Social Cognition Learning Model (SCLM) emanates from the works of Lev Vygotsky (Educational Theories 2013; Funderstanding 2013; Learning-Theories 2013). The SCLM asserts that culture fundamentally influences individual development. Humans are the creators of culture, and every child develops in the context of a culture. Therefore, children's learning development is strongly moderated by culture—including the culture of family environment—in which they are nurtured. "Socialization results in attitudes, values, and cognitive and linguistic skills that children use as they grow and ultimately become means or tools for development" (Portes and Vadeboncoeur 2003, 371). Cole (1985) reinforced Vygostsky's "Sociocultural Theory of Psychological Process" (STPP) detailing the relation of individual cognitive processes to the cultural products and treating the cognitive development as a process of acquiring culture. Sociocultural theory places culture at the core of human sense-making tasks.

Geospatial thinking is one such task requiring individuals to make sense of geospace (space at geographical scale) around them. "Cognitive education programs aim at developing basic cognitive skills necessary for efficient study in all curricular areas" (Kozulin 2003, 16). Spatial thinking is one such cognitive skill that provides students with psychological tools to shape general and domain-specific cognitive functions. Psychological functions occur first at the sociocultural level (interaction among people) and then at the psychological level (internalization). Different intellectual thought processes are associated with different cultural interactions. "At the heart of Vygotsky's theory lies the understanding of human cognition and learning as social and cultural rather than individual phenomena" (Kozulin et al. 2003, 1).

The SCLM and STPP specify that culture contributes to a child's intellectual development in two ways. First, culture provides children with their maximum knowledge, i.e. content of their thinking. Second, culture also instills the processes or means of thinking into children, what Vygotsky calls the tools of intellectual adaptation. The SCLM and STPP thus postulate that culture teaches children both what to think and how to think. Both socioeconomic and ethno-cultural factors influence the amount and type of mediation in the learning process and cognitive development of children (Kozulin 2003). As an example, Kozulin (2003, 28) explained, "In the traditional environments the child-adult interactions are usually less verbal and more contextual and are aimed at the successful integration of the child in traditional activities. In the modern environments the interactions are more verbal, more child-oriented, and more abstract in the sense of fostering in the children those skills that have no immediate practical value but are perceived as prerequisites for their future integration into rapidly changing technological society." My dissertation research is based on SCLM and STPP, as it evaluates the influence of cultural variables (including demographic, academic, and geographic variables) on students' geospatial thinking.

The SCLM and STPP also advance that cognitive development results from a logical and rational process involving a child to learn through problem-solving experiences shared with someone else, usually a parent or teacher but sometimes a sibling or peer. The More Knowledgeable Other (MKO) refers to anyone who has a better understanding or a higher ability level than the learner with respect to a particular task, process, or concept. The MKO is normally thought of as being a teacher, coach, or older adult, but the MKO could also be peers, younger persons, or even computers (Learning-Theories 2013). "Vygotskian approach emphasizes the importance of sociocultural forces in shaping the situation of a child's development and learning and points to the crucial role played by parents, teachers, peers, and the community in defining the types of interaction occurring between children and their environments" (Kozulin et al. 2003, 2). Sharing experiences with someone proximal to a child also relates to the cultural environment in which she is growing. The person collaborating with the child shoulders most of the responsibility in the beginning for supervising the problem solving, but gradually this responsibility transfers to the child. The role of MKO reinforces the role of interventions in improving students' geospatial thinking, where MKO can be adult/teacher intervention, geography/map/GIS exercises, or games.

Vygotsky also defines the Zone of Proximal Development (ZPD) as the distance between the level of actual development (LAD) as determined by independent problem solving and the level of potential development (LPD) as determined through problem-solving under adult guidance or in collaboration with more capable peers (Vygotsky 1978, 86). ZPD is the difference that exists between what a child is capable of doing on her own and what the child can accomplish with help and guidance. Brown and Ferrara (1985) referred to Vygotsky's theory of cognitive development that addresses internalization. Internalization implies that "the child first experiences active problem-solving activities in the presence of others but gradually comes to perform these functions independently" (Brown and Ferrara 1985, 281). The SCLM and STPP suggest that because a child acquires most of her knowledge from the culture around her and acquires much assistance in problem-solving from people around her, it is incorrect to focus on a child in isolation. Such focus undermines the cultural tools and processes by which children acquire new skills and thinking and reasoning abilities. Interactions with culture and social agents contribute significantly to a child's intellectual development.

Spatial thinking and geospatial thinking (as a subset of spatial thinking) are essential components of intellectual or cognitive development. Spatial thinking is one of the most important ways with which the human brain comprehends and organizes information (Gersmehl 2012). Cognitive functioning is not innate, but a sociocultural formation resulting from the interactions of a child with culture (Lidz and Gindis 2003). The SCLM and the STPP show that culture influences cognitive development, and thus spatial and geospatial thinking of students. Gersmehl (2012) accentuated: explicit language, math, and spatial skills that people learn depend on culture—parenting, play, and education. Cultural differences entail that many children do not develop sound spatial thinking skills in their natural home and school environment, and thus explicit spatial thinking education is required (Liben 2006). "Culture is an important source of independent variables for the study of psychological dependent variables" (Cole 1985, 147).

Brown and Ferrara (1985) called ZPD the map of the child's sphere of readiness, whose lower limit is the child's existing level of competence and the upper limit is the level of competence that the student can achieve under favorable circumstances. Vygotsky insisted education should be aimed at the upper end, rather than confined by the lower (Brown and Ferrara 1985). Thus, the ZPD concept underscores the importance of practice and training in improving spatial and geospatial thinking of students. Students may gradually become better spatial and geospatial thinkers with the assistance of specifically designed curricula, course materials, and assessments by the instructor, the potential MKO. Using data gathered via the Geospatial Thinking Survey (GTS) based on cultural variables, my research determines what the students' independent problem-solving capability, or the level of actual development (LAD) is in the field of geospatial thinking. The implications of my research include the need of explicit instruction in spatial and geospatial thinking by designing suitable curricula and course materials to address better the level of potential development (LPD) of students' geospatial thinking. Figure 2.1 charts the cognitive flows in the application of Vygotsky's STPP to the learning process of geospatial thinking.

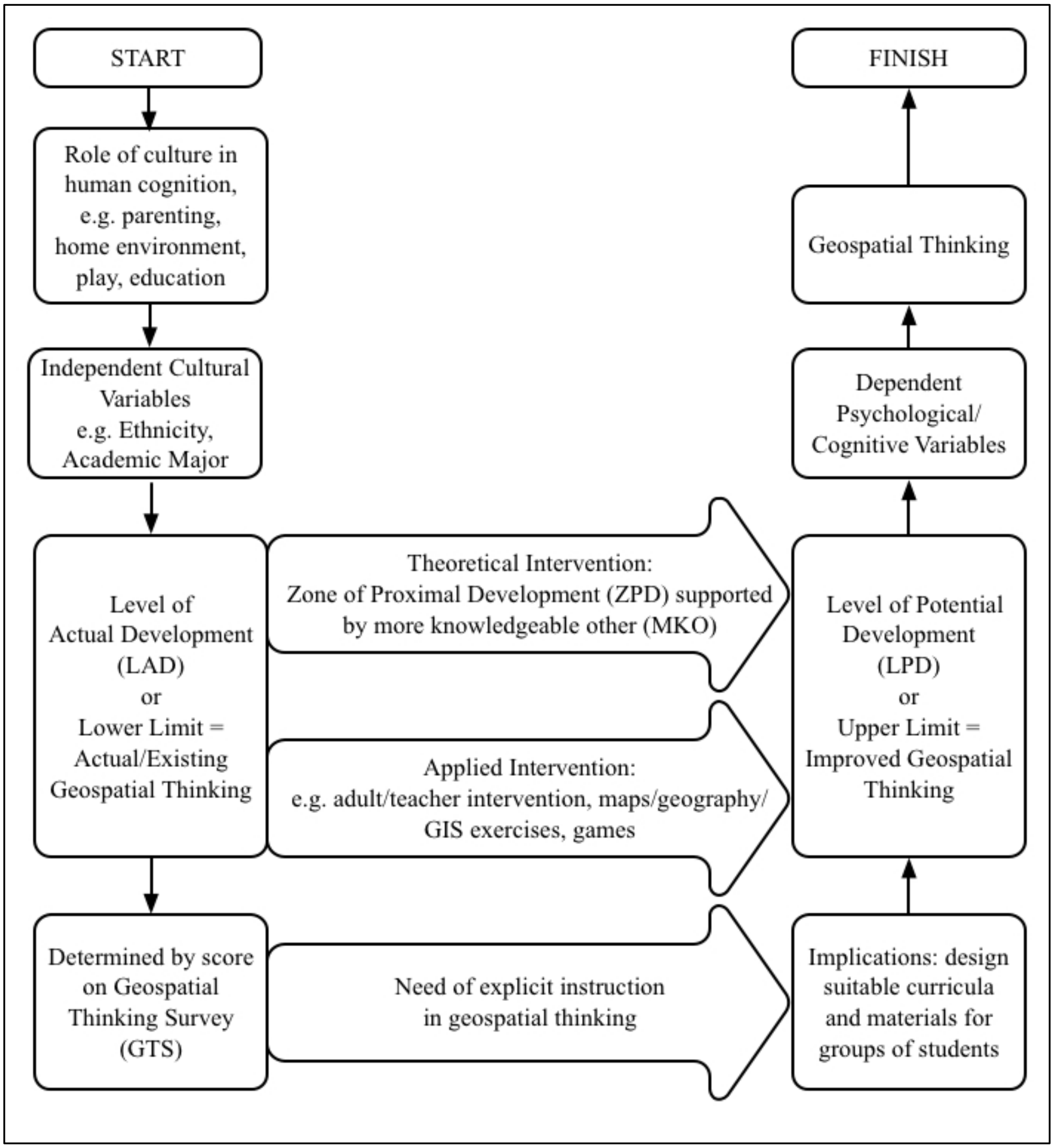


Figure 2.1. Application of Vygotsky's (1978) Sociocultural Theory of Psychological Process (STPP) to geospatial thinking and its learning by students.

CHAPTER III

METHOD

My fundamental research question is: Do undergraduate students in public universities in the United States differ in geospatial thinking?

Research Hypotheses and Questions

This study assesses the nature of age, sex, ethnicity, socioeconomic status, academic context, geography academic experience, and geographic locations as key variables with respect to geospatial thinking.

Quantitative Research Question

The research question for the quantitative study explores geospatial thinking level of undergraduate students in the United States. The quantitative research question of this dissertation is: What is the geospatial thinking level of undergraduate students in the United States?

Quantitative Research Hypotheses

Twelve working hypotheses for quantitative analyses that guide this research and serve as its basic framework are that undergraduate students will vary in geospatial thinking depending on their:

1. sex,
2. age,
3. ethnicity,
4. socioeconomic status (parents' annual income),

5. socioeconomic status (highest educational attainment of parents),
6. academic major (academic context),
7. academic classification (academic context),
8. high school geography academic experience (number of geography courses studied at high school level),
9. college geography academic experience (number of geography courses studied at college level),
10. geography department level (academic context),
11. geographic location (urban/suburban/rural patterns), and
12. geographic location (census divisions).

The null hypothesis for each of these variables is that no significant difference exists in geospatial thinking of students belonging to the different groups. The alternative research hypothesis, therefore, entails that the geospatial thinking of students belonging to these different groups vary.

Qualitative Research Questions

The research questions of the qualitative study explore students' understanding of geospatial concepts from the perspective of geography faculty. Based on faculty interviews, my research explores difficult and easy geospatial concepts for students and cross-validates them with students' performance on the GTS to identify any trends. The primary qualitative research questions are:

1. From instructors' perspective, what geospatial concepts do the students find difficult to understand?

2. From instructors' perspective, what geospatial concepts do the students find easy to understand?

Qualitative Research Hypothesis

1. The instructors' perspective of students' geospatial thinking strengths and weaknesses matches with students' performance in various geospatial thinking domains as measured by the Geospatial Thinking Survey (GTS).

Data Collection

The study area of my research bounds the selected public universities in the United States. I collected quantitative survey data from 61 public universities across the nine census divisions of the United States. I contacted instructors in geography departments at three levels—undergraduate only, master's, and doctoral—to seek their approval to administer Geospatial Thinking Survey (GTS) to their students and provided the Uniform Resource Locator (URL) link for their students to complete the GTS via Survey Monkey.

Following other social science research (Lee and Bednarz 2009, 2012; Huynh and Sharpe 2009, 2013), my sampling process employs a convenience and stratified sample. I contacted instructors in geography departments in more than 65 public universities in the U.S. via telephone calls and email messages. Instructors in 61 departments agreed to encourage their students to participate in the online study (Figure 3.1). Care was taken, however, to select and contact universities for a balanced representation in each census division and in each category of geography department level—undergraduate only, master's, and doctoral (Table 3.1). I contacted the instructors teaching both undergraduate lower-level general education courses and upper-level geography courses in the geography departments in fall 2013 to gain input from their students pursuing both geography and nongeography majors. Students were informed that the participation in the online GTS was voluntary and anonymous. Texas State University's Institutional Review Board (IRB) exempted the GTS because it is a noninvasive and anonymous instrument. The GTS is displayed in Appendix A and was accessible to the students at https://www.surveymonkey.com/s/GeospatialThinkingSurvey.

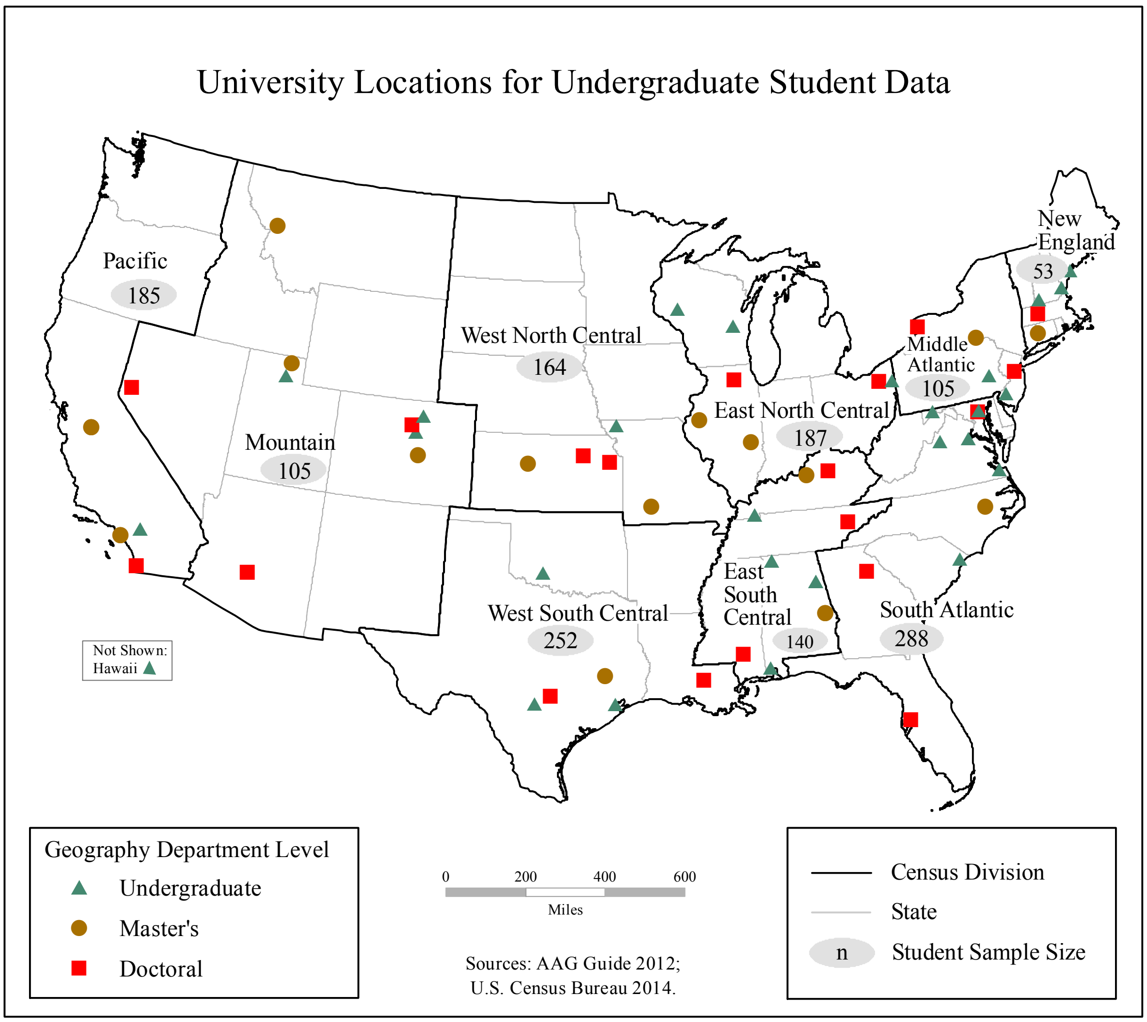


Figure 3.1. Location of sample universities in the U.S. census divisions for student data (n = 61).

Table 3.1. Distribution and Number of Undergraduate Students Who Completed the Geospatial Thinking Survey (GTS) by Census Division (Number of Universities).

Census Divisions	**Geography Department Level**			**Total**
	Doctoral Departments	**Master's Departments**	**Undergraduate Departments**	
South Atlantic	36 (3)	138 (1)	113 (6)	**287 (10)**
West South Central	131 (2)	25 (1)	97 (3)	**253 (6)**
East North Central	22 (2)	36 (2)	133 (3)	**191 (7)**
Pacific	142 (1)	19 (2)	24 (2)	**185 (5)**
West North Central	113 (2)	38 (2)	13 (1)	**164 (5)**
East South Central	41 (3)	19 (2)	76 (4)	**136 (9)**
Mountain	41 (3)	43 (3)	21 (3)	**105 (9)**
Middle Atlantic	9 (2)	70 (1)	26 (2)	**105 (5)**
New England	9 (1)	17 (1)	27 (3)	**53 (5)**
Total	**544 (19)**	**405 (15)**	**530 (27)**	**1479 (61)**

From across the country, 1573 students in 32 states completed the GTS online in the fall 2013 semester. The sample included a few graduate, international, private university, or community college students, and also some invalid responses. So, such cases were not included in the analyses as the focus of this dissertation research is undergraduate students in public universities in the United States. After discarding the 94 unusable cases from the sample, the total sample size became 1479 (Table 3.1).

<u>Characteristics of the Test Instrument</u>

A dearth of standardized tests of geospatial thinking exists in the literature (NRC 2006; Lee and Bednarz 2009; Huynh and Sharpe 2009, 2013). As the basis of the GTS, I used questions from the Spatial Thinking Ability Test (STAT) developed and used by Lee (2005), endorsed by the Association of American Geographers (AAG 2006), and employed by Lee and Bednarz (2009, 2012). The STAT has 16 spatial thinking questions. I omitted the four geometric spatial thinking questions as they are not geospatial. I excluded a map navigation or way-finding question because of repetition and a question on 3-D image visualization because it resulted in low reliability in the pilot study conducted in fall 2012. Therefore, ten geospatial thinking questions, some modified for syntax and better student understanding, from the STAT were included in the GTS. Geospatial thinking consists of several different components. Table 3.2 outlines the

Table 3.2. Geospatial Thinking Domains in the Geospatial Thinking Survey (GTS): Based on Golledge (1995, 2002); Gersmehl and Gersmehl (2006); Jo and Bednarz (2009); and Lee and Bednarz (2012).

Geospatial Thinking Domain/ Component	**Description**	**NRC (2006); Jo and Bednarz (2009) Taxonomy**	**GTS Question**
1. Geospatial Pattern and Transition	Discerning geospatial patterns; graphing geospatial transitions; comparing and transferring map information to graphic information	Cell 23: Complex-spatial concept; using tool of representation; reasoning at processing level	1
2. Direction and Orientation	Map navigation; way-finding; route planning; comprehending orientation and direction	Cell 17: Simple-spatial concept; using tool of representation; reasoning at processing level	2
3. Geospatial Profile and Transition	Recognizing geospatial form; imagining a slope profile based on a topographic/contour map; transforming perceptions, representations, and images from one dimension to another; graphing a geospatial transition	Cell 24: Complex-spatial concept; using tool of representation; reasoning at output level	3
4. Geospatial Association and Transition	Correlating geospatially distributed phenomena; identifying geospatial correlation between maps; assessing geospatial association; making geospatial comparisons; graphing geospatial transitions	Cell 23: Complex-spatial concept; using tool of representation; reasoning at processing level	4 (Geospatial Association and Transition), 5 (Geospatial Assoc.)
5. Geospatial Shapes	Identifying and comprehending integration of geographic features represented as points, lines (networks), areas/polygons (regions)	Cell 17: Simple-spatial concept; using tool of representation; reason-ing at processing level	6, 7, 8, 9
6. Geospatial Overlay	Comprehending overlaying, aggregating, and dissolving map layers to choose the best location based on various spatial/ geographical conditions, connections, distance; inferring a geospatial aura (influence)	Cell 23: Complex-spatial concept; using tool of representation; reasoning at processing level	10

geospatial thinking domains encompassed by the GTS. These domains are based on the components given by such scholars as Golledge (1995, 2002), Gersmehl and Gersmehl (2006), Jo and Bednarz (2009), and Lee and Bednarz (2012). The GTS also included demographic, geographic, and academic background questions.

Reliability and Validity

To identify flaws in the instrument, I conducted a pilot study with undergraduate students in geography undergraduate general education courses at Texas State University in the fall 2012 semester. I invited pilot study participation to undergraduate students by visiting five geography undergraduate level classes. Participation was voluntary and anonymous. Using the Survey Monkey program, 77 undergraduate students completed the GTS online in the pilot study. The pilot study showed that students took about ten-fifteen minutes, on average, to complete the GTS, thereby demonstrating that students did not need an inordinate amount of time to complete the GTS. The results of the pilot study revealed statistically significant differences among the mean scores of the various categories of ethnicity, academic major, academic classification, and academic experience in geography (number of college geography courses taken). No statistically significant differences were found among the mean scores of the various categories of age, sex, highest educational attainment of parents (socioeconomic status), annual income of parents (socioeconomic status), and urban/rural location (geographic location). Thus, ethnicity and academic background influenced geospatial thinking of students, while age, sex, socioeconomic status, and geographic location did not influence geospatial thinking of students in the exploratory study with a small sample of size of 77 undergraduate students at one university.

To establish the internal consistency of the GTS, I calculated the Cronbach's Alpha statistic that measures the intercorrelation of items, that is, the extent to which item responses obtained at the same time correlate with each other (Lee and Bednarz 2012). The Cronbach's Alpha for the GTS was 0.679, which signifies a low level of internal consistency in social science research. However, the results of the pilot study indicated that if one particular question (3-d terrain question) were removed from the GTS, the Cronbach's Alpha would increase to 0.708, a value indicating an acceptable level of internal consistency among the items. Out of a total of 77 students in the pilot study, only 20 answered the 3-d terrain question correctly. I, therefore, deleted this question from the GTS in the final administration for this dissertation. Spatial thinking consists of multiple components/domains that are not correlated to each other (Voyer, Voyer, and Bryden 1995; Gersmehl and Gersmehl 2006; Smith 2007; Lee and Bednarz 2012; Gersmehl 2012; Huynh and Sharpe 2013; Ishikawa 2013; Sinton et al. 2013), leading to lower internal consistency among the test items.

Validity is considered to be the degree to which the test measures what it claims to measure. Validity shows how well the test instrument reflects the real meaning of the investigated concepts, examined through face and content validity (Huynh and Sharpe 2013). The GTS has face validity because it measures geospatial thinking skills using maps and geographic information. Content validity relates to what extent the test items represent the concepts of interest (Huynh and Sharpe 2013). The GTS has content validity as it covers a representative sample of the geospatial thinking skills discussed in the literature. Thus, GTS is a reliable and valid test of geospatial thinking skills; of course, as mentioned, the GTS drew its questions from the AAG's STAT (2006).

Domains of Geospatial Thinking

I employed principal components analysis (PCA) to group GTS questions into distinct geospatial thinking domains. PCA analysis verified the grouping of GTS questions into different components with the domains identified in the literature.

Quantitative Analyses

Variables

The dependent variable in my study is geospatial thinking, measured by score on the GTS. The maximum possible score on the GTS is ten for a total of ten geospatial thinking questions. The minimum score on the GTS is zero, if a student answered all the questions incorrectly.

The 12 independent/predictor variables are grouped into three broad categories:

1. Demographic variables: sex, age, ethnicity, parents' annual income (a measure of socioeconomic status), and highest educational attainment of parents (a measure of socioeconomic status)
2. Academic variables: academic classification, academic major, number of geography courses taken at the high school level (a measure of formal academic experience in geography), number of geography courses taken at the college level (a measure of formal academic experience in geography), and geography department level (at a student's current university)
3. Geographic location variables: urban/suburban/rural patterns (where the students grew up), and census division (in which the student's current university is located)

Students with non-geography majors are the control group, and the students who are geography majors are the experimental group. Taking geography courses is expected to act as an intervention to improve geospatial thinking. The research therefore examines whether geography courses improve geospatial thinking in students.

Student Performance Measured by GTS Score: Geospatial Thinking Index (GTI)

I assigned students a level on Geospatial Thinking Index (GTI), based on GTS score. This index assigned students into three categories with an overall geospatial thinking level based on competency on the GTS, using standard deviation method. The three categories identified are:

1. Low Geospatial Thinking Level
2. Medium Geospatial Thinking Level
3. High Geospatial Thinking Level

Group Differences on GTS Score Means

I employed a t-test and a one-way analysis of variance (ANOVA) to interpret group differences in geospatial thinking of students from various backgrounds. The t-test and ANOVA are parametric tests that assume the data being analyzed are normally distributed (Monday, Klein, and Lee 2005). The GTS scores are approximately normally distributed.

The t-test determines if two categories of data are significantly different from each other. I used the t-test for only one independent variable—sex—to compare mean scores of female and male students. ANOVA analyzes means on a quantitative Y dependent variable across two or more groups of X independent variables (Explorable 2013; Park 2009). I ran 11 ANOVAs for 11 independent variables to compare the means of categories of different variables for statistical significance. I used the Games-Howell test (a post-hoc comparison method that does not assume homogeneity of variances or equal sample sizes) to find internal group differences for significant ANOVA runs, thereby determining which groups differ and by which degree (Laerd Statistics 2014).

Geospatial Thinking Score Prediction

I employed multiple regression model to explain which independent variables are significant predictors of the dependent variable—geospatial thinking. Multiple regression, concerning the association of two or more independent variables (taken together) with one dependent variable, compares one group to another to show which variables contribute best to explain/predict the dependent variable (Brace, Kemp, and Snelgar 2012).

To predict the level of geospatial thinking of a student from a particular background (a combination of different demographic, academic, or geographic variables), I applied a predictive model in the analyses. This model, called the Geospatial Thinking Model (GTM), along with the regression model, is helpful in anticipating geospatial thinking acumen of students who do not take the GTS. These predicted GTS scores are based on such student background information as belonging to a particular ethnic group or undertaking an academic major. For this predictive model, I employed the Cubist software, a data mining and artificial intelligence tool for generating rule-based predictive models from data.

Student Performance on Individual Questions of the GTS

I analyzed the performance of all students on individual GTS questions based on the percentage of students answering a particular question correctly. I divided the GTS questions into three categories—Less Difficult, Difficult, and More Difficult, based on what percentage of students answered the question correctly and incorrectly.

Group Differences on Individual Questions of the GTS

The chi-square test of independence is a non-parametric method used to determine whether there is an evidence of a significant association between two categorical variables (Daniel 1990; Stat Trek 2014). I used the chi-square test of independence to investigate the relationship between each independent variable (categorical variable) and each geospatial thinking domain (distinct GTS questions with students' responses coded dichotomously, i.e. categorical), and to interpret group differences in different geospatial thinking domains of students from various backgrounds. I ran chi-square to analyze whether differences in one variable are associated to understanding a geospatial thinking domain correctly or incorrectly.

Qualitative Analyses

I conducted telephone interviews with 27 geography instructors, three each from nine census divisions, employing convenience and stratified sampling. From each census division, I interviewed geography faculty from three department levels each—doctoral, master's, and undergraduate—to gauge the geospatial concepts that the students find difficult to understand based on the instructors' perception. The interviews were semi-structured with two demographic questions about instructors' sex and ethnicity, two contextual questions about instructor experience, and four open-ended questions about geospatial thinking of undergraduate students and classroom activities. Based on the instructors' responses on the qualitative interviews, I undertook an analysis of the geospatial concepts using content analysis.

Mixed-method Analysis

My dissertation research brought together the quantitative and qualitative datasets to determine if the two matched. Student performance on the GTS provided the quantitative data (GTS scores), and instructor perception in the interviews contributed the qualitative data. I searched for trends in the two datasets, to confirm if the instructors' perceptions about students' understanding of different geospatial concepts verify student performance on various geospatial thinking domains. I also looked for mismatches between the two datasets to formulate follow-up questions as to why the datasets do not correspond.

CHAPTER IV

QUANTITATIVE ANALYSES AND FINDINGS

Domains of Geospatial Thinking

Principal component analysis (PCA), a method of factor analysis, was employed to see if GTS questions group into a more coherent set of geospatial thinking components/domains. Factor analysis identifies the minimum underlying factors needed to explain the intercorrelations among the test items (Lee and Bednarz 2012). To verify the skills tested by the six domains as separate components of geospatial thinking (Table 3.2), the PCA results should yield similar components to reflect the six domains. I subjected responses to the 10-item GTS to PCA in Statistical Package for the Social Sciences (SPSS) software. The PCA groupings were based on students' responses to the GTS questions. PCA revealed four components with eigenvalues greater than 1.0, accounting for 48.31 percent of cumulative variance, with component loadings given by varimax rotation (Table 4.1).

GTS questions and corresponding factor loadings are presented in Table 4.1. In interpreting the rotated factor pattern, a question was said to load on a given component if the factor loading was 0.40 or greater for that component, and was less than 0.40 for the other (Stevens 1986; Lee and Bednarz 2012; SAS 2014). Using this criterion, four questions were found to load on Component I, two questions each on Components II and III, and one question on Component IV.

Table 4.1 Results of Principal Component Analysis (PCA) for the GTS.

GTS Question Number and Geospatial Thinking Domain	**Components**			
	I	**II**	**III**	**IV**
1 (Geospatial Pattern and Transition)	**-0.593**	0.051	0.143	0.136
2 (Geospatial Direction and Orientation)	-0.144	0.031	**0.782**	0.045
3 (Geospatial Profile and Transition)	0.386	-0.322	0.185	0.263
4 (Geospatial Association and Transition)	0.035	**0.775**	0.138	-0.148
5 (Geospatial Association)	0.146	-0.180	**0.545**	-0.016
6 (Geospatial Shapes)	**0.720**	-0.097	0.057	0.146
7 (Geospatial Shapes)	**0.480**	0.338	-0.017	0.241
8 (Geospatial Shapes)	**0.563**	0.001	0.159	-0.194
9 (Geospatial Shapes)	0.187	**-0.499**	0.205	-0.364
10 (Geospatial Overlay)	-0.011	-0.049	0.043	**0.829**
Eigenvalues	1.701	1.079	1.038	1.012
% of variance	17.007	10.792	10.384	10.123
Cumulative % of variance	17.007	27.800	38.184	48.307

Table 4.1 shows that Q6 (question 6), Q7, and Q8 loaded on Component I, all three questions representing Geospatial Shapes, identified in the literature as a distinct domain (Table 3.2), and a discrete component in the PCA results (Table 4.1). However, Q9 is also part of the same Geospatial Shapes domain in Table 3.2, but was not identified by the PCA for Component I. Q1 (Geospatial Pattern and Transition domain) is also loaded on component I but is not part of the same Geospatial Shapes domain. The PCA thus produced partially meaningful results in relation to component I. Also, Q1 has an inverse relationship with questions 6, 7, and 8. For example, students answering Q1 correctly are more likely to answer questions 6, 7, and 8 incorrectly, and vice-versa.

Q4 represents the Geospatial Association and Transition domain in the literature and a discrete Component II by PCA results. Although both Q4 and Q5 are part of the Geospatial Association domain, the PCA found only Q4 as distinct in Component II. However, Q4 assesses both Geospatial Association and Transition, while Q5 only focuses on Geospatial Association. Q9 that loaded on component II is in the Geospatial Shapes domain. However, questions 4 and 9 are inversely related to each other based on students' responses.

Q2 loaded on component III, identified in the Direction and Orientation domain and a distinct component III in the PCA results. Q5 representing the Geospatial Association domain, also loaded on Component III. Q2 and Q5 are therefore not part of the same domain, but they loaded on Component III.

Q10, characterizing the Geospatial Overlay domain, loaded on component IV in the PCA results. The PCA did not select Q3 as a separate Geospatial Profile and Transition domain.

Thus, the four components produced by PCA do represent four distinct geospatial thinking domains—Geospatial Shapes, Geospatial Association and Transition, Direction and Orientation, and Geospatial Overlay. Although Geospatial Shapes and Geospatial Association and Transition were separate components, they did not include all representative questions.

Lee and Bednarz (2012) presented similar question grouping results for STAT, where group inclusion for some questions were not clear and meaningful as were those not selected for any group. These outcomes demonstrate some questions may not be adequately worded. Some questions represent more than one domain of geospatial thinking. Ten questions, further, covered by six domains (in the case of GTS) are not sufficient to capture the entire range of geospatial thinking skills. Researchers thus need to develop more comprehensive assessments and tests to measure geospatial thinking. Indeed, both the STAT and GTS omit such fundamental geospatial thinking skills as scale, frames of reference, regionalization (spatial classification), spatial diffusion, spatial hierarchy, and spatial analog. Huynh and Sharpe's (2013) geospatial thinking assessment includes questions on scale, frames of reference (latitude and longitude), spatial enclosure, and spatial diffusion. Their 30-question instrument, however, was very long requiring about 45 minutes for completion. The instrument also included drawing and short answer writing questions, which are not feasible for a national survey conducted online. Scoring drawing and writing questions is subjective and complicated. A geospatial thinking test that comprehensively measures a wide range of skills within a reasonable number of objective questions for a national online administration remains elusive.

Student Performance Measured by GTS score: Geospatial Thinking Index (GTI)

Students' score on the GTS is a measure of their geospatial thinking. Based on the ten geospatial thinking questions, a student's score may vary between 0 and 10 on the GTS. The mean score of students on the GTS was 6.57, with a standard deviation of 2.00, and the mode score was 8. Table 4.2 displays the number of students obtaining GTS scores from 0 to 10.

Table 4.2. GTS Scores and Student Frequencies.

GTS Score	Number of Students	Percent of Students	Cumulative Percentage
0	5	0.3	0.3
1	13	0.9	1.2
2	49	3.3	4.5
3	75	5.1	9.6
4	94	6.4	16.0
5	147	9.9	25.9
6	225	15.2	41.1
7	314	21.2	62.3
8	324	21.9	84.2
9	203	13.7	97.9
10	30	2.1	100.0
Total	1479	100.0	

The distribution of the GTS scores is approximately normal, though slightly negatively skewed (Figure 4.1). This implies that the majority of students performed at a similar level, and most students answered over half of the questions correctly. A sizeable proportion of students performed both above and below average. Thus, the GTS as an assessment instrument appropriately differentiates levels of geospatial thinking from basic through intermediate to an advanced level of performance. Huynh and Sharpe (2013) found similar results for 104 students as assessed via geospatial thinking assessment.

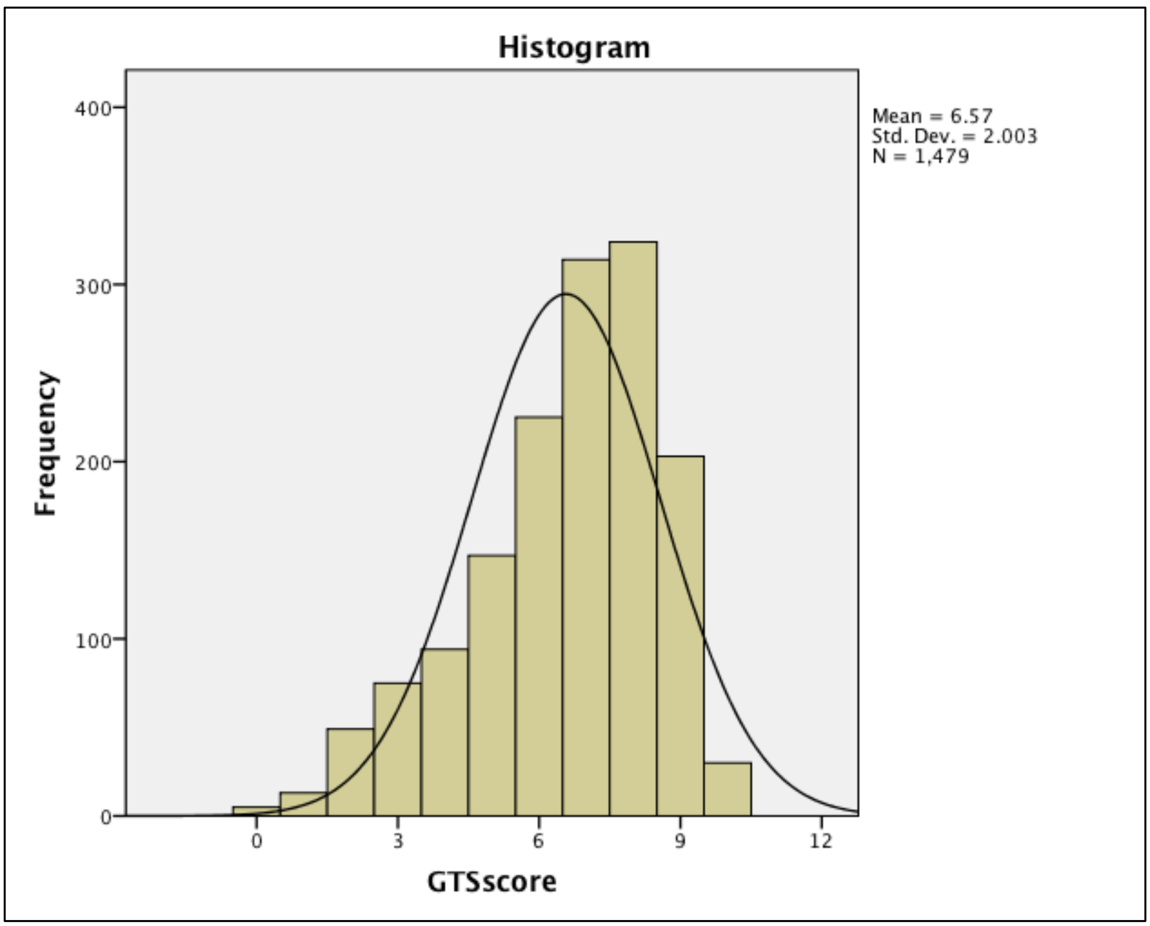


Figure 4.1. Histogram of student performance on the GTS.

Huynh and Sharpe (2013) categorized the students into novice, intermediate, and expert levels to investigate a measurable or identifiable development of mature geospatial thinking, utilizing a standard deviation method to assign students to one of the three expertise levels on the geospatial thinking assessment. The researchers used standard scores of one standard deviation above and below the mean for the critical values between different expertise levels.

Following Huynh and Sharpe (2013), I also categorized students into three levels of geospatial thinking using the standard deviation technique. I grouped students relative to the mean of the distribution (6.57), with the standard scores of one standard deviation (2.00) above and below the mean producing the three class intervals. Students with GTS scores greater than one standard deviation above the mean (greater than 8.6) were classified as students with high geospatial thinking level, those with GTS scores one standard deviation less than the mean (less than 4.6) were classified as students with low geospatial thinking level, and those within standard deviation of the mean (from 4.6 to 8.6) were classified as students with medium geospatial thinking level (Table 4.3). Using the 1479 student scores, ANOVA confirmed differences among three levels of performance were significant (F = 2465.46, p <0.001).

Table 4.3. Geospatial Thinking Index.

Geospatial Thinking Level	**GTS Score Range**	**Number of Students (%)**	**Mean Score**
Low	0-4	236 (16.0)	3.02
Medium	5-8	1010 (68.3)	6.81
High	9-10	233 (15.7)	9.13
Total	0-10	1479 (100)	6.57

Group Differences on GTS Score Means

I used t-test (alpha = 0.05) in SPSS to interpret group differences in geospatial thinking for only one independent variable—sex. I ran 11 ANOVAs (alpha = 0.05) for each of the 11 predictor variables to compare the means of categories of different variables (e.g. white, Hispanic, black, and Asian for ethnicity) for statistical significance. After running the ANOVA tests, I used the Games-Howell test (a post-hoc comparison method that does not assume homogeneity of variances or equal sample sizes) to find internal group differences, thereby determining which groups differ and by which degree (Laerd Statistics 2014).

Table 4.4 presents the distribution of GTS score means for females and males. The t-test found a statistically significant difference between the mean scores of females and males in which the mean score of male students is higher than the mean score of female students. Sex thus influences the geospatial thinking of students.

Table 4.4. GTS Score Means for Sex.

Sex	Number of Students (%)	Total Possible Score	Highest Score	Lowest Score	Mean Score	t-test	p Value
Female	804 (54.4)	10	10	0	6.33	-4.955	<0.001
Male	675 (45.6)	10	10	0	6.85		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Age generally reflects growing life experiences. Table 4.5 summarizes the distribution of students in three age groups. The ANOVA found a statistically significant difference among the mean scores of three age categories. The mean score of students 21-24 years old and more than 24 years old is highest, while that of 18-20 years old students is lowest. Increasing age thus has a positive effect on students' geospatial thinking.

Table 4.5. GTS Score Means for Age Categories.

Age	Number of Students (%)	Total Possible Score	Highest Score	Lowest Score	Mean Score	F	p Value
18-20	751 (50.8)	10	10	0	6.28	15.988	<0.001
21-24	473 (32.0)	10	10	0	6.87		
> 24	255 (17.2)	10	10	0	6.86		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Post-hoc comparisons (alpha = 0.05) in Table 4.6 show that 18-20 year old students scored significantly lower than both students 21-24 years old and more than 24 years old. Older students therefore perform better in geospatial thinking skills.

Table 4.6. Post-hoc Comparisons (Games-Howell) of GTS Score by Age Categories (p Value in Parentheses).

Age	**18-20**	**21-24**
21-24	**-0.586 (<0.001)**	
> 24	**-0.578 (<0.001)**	0.008 (0.998)

Table 4.7 presents the distribution of four ethnic groups in the data. The ANOVA found a statistically significant difference among the mean scores of four ethnic categories. The mean score of white students is highest, while that of black students is lowest. Ethnicity affects the geospatial thinking of students.

Table 4.7. GTS Score Means for Ethnic Groups.

Ethnicity	**Number of Students (%)**	**Total Possible Score**	**Highest Score**	**Lowest Score**	**Mean Score**	**F**	**p Value**
White	1103 (74.6)	10	10	0	6.89	51.732	<0.001
Hispanic	136 (9.2)	10	10	1	5.86		
Black	127 (8.6)	10	10	0	4.87		
Asian	113 (7.6)	10	10	1	6.20		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Post-hoc comparisons in Table 4.8 shows white students scored significantly higher than Hispanic, black, and Asian students. Both Hispanic and Asian students scored significantly higher than black students. But the difference between the scores of Hispanic and Asian students is not statistically significant. Ethnicity therefore affects students' geospatial thinking.

Table 4.8. Post-hoc Comparisons (Games-Howell) of GTS Score by Ethnic Groups (p Value in Parentheses).

Ethnicity	**White**	**Hispanic**	**Black**
Hispanic	**1.028 (<0.001)**		
Black	**2.022 (<0.001)**	**0.994 (0.002)**	
Asian	**0.685 (0.004)**	-0.343 (0.577)	**-1.337 (<0.001)**

The ANOVA found a statistically significant difference among the mean scores of four categories of the annual income of parents (Table 4.9). The mean score of students from high-income groups (>$75,000) is highest. Socioeconomic status (annual income of parents) influences geospatial thinking of students.

Table 4.9. GTS Score Means for Parents' Annual Income Categories.

Annual Income of Parents	**Number of Students (%)**	**Total Possible Score**	**Highest Score**	**Lowest Score**	**Mean Score**	**F**	**p Value**
<$25,000	223 (15.1)	10	10	1	6.38	7.679	<0.001
$25,000-$50,000	351 (23.7)	10	10	0	6.21		
$51,000-$75,000	333 (22.5)	10	10	0	6.65		
>$75,000	572 (38.7)	10	10	0	6.81		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Post-hoc comparisons (Table 4.10) for income groups showed that the students from the second income category ($25,000-$50,000) scored significantly lower than students from third ($51,000-$75,000) and fourth (>$75,000) categories, yet the third and fourth income groups were not significantly different. Higher income groups may mean higher geospatial thinking but not necessarily across all income categories. Post-hoc comparison does not reveal any pattern or important decreasing or increasing differences in geospatial thinking across income categories.

Table 4.10. Post-hoc Comparisons (Games-Howell) of GTS Score by Parents' Annual Income Categories (p Value in Parentheses).

Parents' Annual Income	**<$25,000**	**$25,000-$50,000**	**$51,000-$75,000**
$25,000-$50,000	0.176 (0.781)		
$51,000-$75,000	-0.270 (0.450)	**-0.447 (0.013)**	
>$75,000	-0.434 (0.060)	**-0.610 (<0.001)**	-0.163 (0.588)

The highest educational attainment of parents is also a measure of socioeconomic background and relates to the home environment of students. Table 4.11 outlines the distribution of five parents' educational attainment groups. The ANOVA found a statistically significant difference among the mean scores of five categories of parents' education. The mean score of students with highly educated parents (graduate degrees) is highest. Socioeconomic status (parents' education) affects geospatial thinking of students.

Table 4.11. GTS Score Means for Parents' Education Categories.

Educational Attainment of Parents	**Number of Students (%)**	**Total Possible Score**	**Highest Score**	**Lowest Score**	**Mean Score**	**F**	**p Value**
Less than High School	61 (4.1)	10	10	2	6.67	7.615	<0.001
High School	400 (27.1)	10	10	0	6.13		
Associate Degree	168 (11.3)	10	10	0	6.51		
Bachelor Degree	508 (34.3)	10	10	0	6.75		
Graduate Degree	342 (23.2)	10	10	1	6.83		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Post-hoc comparisons (Table 4.12) for parents' education groups demonstrated that the students having parents with high school degrees scored significantly lower than the students having parents with bachelor and graduate degrees. Higher education of parents may mean higher geospatial thinking of students but not necessarily across all categories. Post-hoc comparison does not reveal any pattern or important decreasing or increasing differences in geospatial thinking across parents' education categories.

Table 4.12. Post-hoc Comparisons (Games-Howell) of GTS Score by Parents' Education Categories (p Value in Parentheses).

Parents' Education	Less than High School	High School	Associate Degree	Bachelor Degree
High School	0.547 (0.311)			
Associate Degree	0.166 (0.983)	-0.381 (0.280)		
Bachelor Degree	-0.074 (0.999)	**-0.621 (<0.001)**	-0.240 (0.670)	
Graduate Degree	-0.161 (0.979)	**-0.708 (<0.001)**	-0.327 (0.436)	-0.087 (0.966)

Increasing academic classification reflects higher-level formal classroom instruction. Table 4.13 displays the distribution of students in four academic classifications. The ANOVA found a statistically significant difference among the mean scores of four academic classifications. The mean score of senior (fourth-year) students is highest, while that of freshmen (first-year) is lowest. Similar to age, higher academic classification thus positively affects students' geospatial thinking.

Table 4.13. GTS Score Means for Academic Classifications.

Academic Classification	Number of Students (%)	Total Possible Score	Highest Score	Lowest Score	Mean Score	F	p Value
Freshman (First Year)	268 (18.1)	10	10	0	6.19	22.023	<0.001
Sophomore (Second Year)	366 (24.7)	10	10	1	6.23		
Junior (Third Year)	401 (27.1)	10	10	0	6.44		
Senior (Fourth Year)	444 (30.1)	10	10	0	7.18		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Post-hoc comparisons (Table 4.14) for academic classifications revealed that senior students scored significantly higher than freshman, sophomore, or junior students. Similar to the oldest age group, the highest level of academic classification affects the level of geospatial thinking.

Table 4.14. Post-hoc Comparisons (Games-Howell) of GTS Score by Academic Classifications (p Value in Parentheses).

Academic Classification	Freshman	Sophomore	Junior
Sophomore	-0.045 (0.993)		
Junior	-0.251 (0.410)	-0.206 (0.515)	
Senior	**-0.994 (<0.001)**	**-0.950 (<0.001)**	**-0.743 (<0.001)**

For academic major question on the GTS, students responded with more than 100 academic majors. I categorized the academic majors into categories of related majors to make comparisons easier. An academic major category with more than 30 respondents kept its distinct category. I grouped academic majors with less than 30 respondents into larger groups based on academic college affiliation. For example, 37 students reported history as their academic major; history was then identified as a separate major. However, both anthropology and sociology had less than 30 respondents each, thereby placing them into the category termed Other Social Science Majors. Some of the other academic majors grouped into the Other Social Science Majors category included economics, international studies, political science, social work, public administration, and philosophy. Some of the academic majors categorized in the Other Science Majors category included chemistry, physics, mathematics, meteorology, neuroscience, radiology, forestry, and astronomy. Art, music, theatre, film, dance, photography, interior design, linguistics, English, French, Japanese, and Spanish are some of the academic majors grouped into the Humanities Majors category.

Table 4.15 exhibits the distribution of students in 18 academic major groups, arranged according to decreasing mean scores. The ANOVA found a statistically significant difference among the mean scores of different academic majors. The mean score of geography majors is the highest, while that of criminal justice majors is the lowest. Academic major thus shapes students' geospatial thinking.

Table 4.15. GTS Score Means for Academic Majors.

Academic Major	Number of Students (%)	Total Possible Score	Highest Score	Lowest Score	Mean Score	F	p Value
Geography	367 (24.8)	10	10	2	7.57	15.10	<0.001
Geology	31 (2.1)	10	10	5	7.48		
Environmental Science	59 (4.0)	10	10	1	7.20		
Other Science Majors	66 (4.5)	10	10	4	7.15		
Biology	57 (3.8)	10	10	3	7.02		
Engineering	50 (3.4)	10	10	1	6.96		
History	37 (2.5)	10	9	2	6.81		
Computer Science	36 (2.4)	10	9	2	6.58		
Humanities Majors	50 (3.4)	10	9	1	6.56		
Psychology	46 (3.1)	10	9	1	6.15		
Other Social Science Majors	138 (9.3)	10	10	0	6.07		
No Major	45 (3.1)	10	9	0	6.02		
Business	165 (11.2)	10	10	2	6.00		
Health	51 (3.4)	10	10	1	5.82		
Nursing	40 (2.7)	10	9	0	5.70		
Education	136 (9.2)	10	10	0	5.62		
Communication	67 (4.5)	10	9	1	5.54		
Criminal Justice	38 (2.6)	10	10	1	5.29		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Table 4.16 displays the significant post-hoc comparisons for 18 academic major groups. Both geography and geology students scored higher than nursing, health, psychology, criminal justice, education, communication, business, Other Social Science

Majors, and No Major students. Students in Other Science Majors scored higher than education, communication, business, criminal justice, nursing, health, and Other Social Science Majors students. Biology students scored higher than education, communication, business, and criminal justice students. Engineering students scored higher than education, communication, and criminal justice students. Environmental science students scored higher than education, communication, business, criminal justice, and Other Social Science Majors students. Education, communication, and criminal justice students scored lower than geography, geology, engineering, environmental science, biology, and Other Science Majors students. Business students scored lower than geography, geology, environmental science, biology, and Other Science Majors students. Other Social Science

Table 4.16. Significant Post-hoc Comparisons (Games-Howell) of GTS Score by Academic Majors (p Value in Parentheses).

Academic Majors	Geog-raphy	Geol-ogy	Envt. Sci.	Other Science	Biology	Engine-ering	Health	Nursing
Other Science							-1.328 (.041)	-1.452 (.039)
Psycho-logy	1.417 (.001)	1.332 (.029)						
Other Social Science	1.504 (<.01)	1.419 (.001)	1.138 (.029)	1.086 (.008)				
No Major	1.547 (.001)	1.462 (.023)						
Business	1.569 (<.01)	1.484 (<.01)	1.203 (.006)	1.152 (.001)	1.018 (.012)			
Health	1.746 (<.01)	1.660 (.005)		1.328 (.041)				
Nursing	1.869 (<.01)	1.784 (.005)		1.452 (.039)				
Educa-tion	1.952 (<.01)	1.866 (.<01)	1.586 (<.01)	1.534 (<.01)	1.400 (<.01)	1.342 (.004)		
Commun-ication	2.032 (<.01)	1.947 (<.01)	1.666 (.001)	1.614 (<.01)	1.480 (.002)	1.423 (.018)		
Criminal Justice	2.280 (<.01)	2.194 (.001)	1.914 (.006)	1.862 (.004)	1.728 (.013)	1.671 (.037)		

Majors students scored lower than geography, geology, environmental science, and Other Science Majors. Nursing and health students scored lower than geography, geology, and Other Science Majors students.

Table 4.17 presents the distribution of students with different academic experience in high school geography, measured by number of geography courses studied in high school. The ANOVA found a statistically significant difference among the mean scores of different high school geography levels. The mean score of students who studied no geography course at the high school level is the highest, while that of students who studied two geography courses is the lowest. This outcome is certainly perplexing.

Table 4.17. GTS Score Means for Number of High School Geography Courses.

Number of High School Geography Courses	**Number of Students (%)**	**Total Possible Score**	**Highest Score**	**Lowest Score**	**Mean Score**	**F**	**p Value**
No Geography Course	507 (34.3)	10	10	1	6.79	3.639	0.012
1 Geography Course	656 (44.3)	10	10	0	6.51		
2 Geography Courses	210 (14.2)	10	10	1	6.33		
>2 Geography Courses	106 (7.2)	10	10	0	6.37		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Post-hoc comparisons (Table 4.18) for the number of high school geography courses taken showed that students who never studied a geography course in high school scored significantly higher than students who studied two geography courses. All other differences were not statistically significant. This outcome may add to the general assertion by some scholars (Sinton et al. 2013) and educational policymakers that geography is not properly taught in high schools in the U.S., in this case regarding geospatial thinking skills.

Table 4.18. Post-hoc Comparisons (Games-Howell) of GTS Score by Number of High School Geography Courses (p Value in Parentheses).

High School Geography	No Geography Course	1 Geography Course	2 Geography Courses
1 Geography Course	0.283 (0.071)		
2 Geography Courses	**0.460 (0.031)**	0.178 (0.694)	
>2 Geography Courses	0.421 (0.248)	0.138 (0.925)	-0.039 (0.999)

Table 4.19 shows the distribution of students with different academic experience in college geography, measured by number of geography courses studied. The ANOVA found a statistically significant difference among the mean scores of students who had taken various numbers of college geography courses. The mean score of students who had taken more than five college geography courses is the highest, while those students who had taken no college geography scored the lowest. College geography courses bolster students' geospatial thinking, thereby corroborating that geography academic majors have the highest level of geospatial thinking (Tables 4.15 and 4.16).

Table 4.19. GTS Score Means for the Number of College Geography Courses.

Number of College Geography Courses	Number of Students (%)	Total Possible Score	Highest Score	Lowest Score	Mean Score	F	p Value
No Geography Course	253 (17.1)	10	10	0	6.10	44.932	<0.001
1-2 Geography Courses	812 (54.9)	10	10	0	6.27		
3-5 Geography Courses	161 (10.9)	10	10	2	7.00		
>5 Geography Courses)	253 (17.1)	10	10	4	7.72		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Post-hoc comparisons (Table 4.20) for the number of college geography courses taken showed students with no experience in college geography courses scored significantly lower than students who had taken three or more college geography courses. Students who had taken more than five college geography courses scored significantly higher than students who had taken no, 1-2, or 3-5 college geography courses. Studying geography in college is thus very important in improving geospatial thinking.

Table 4.20. Post-hoc Comparisons (Games-Howell) of GTS Score by Number of College Geography Courses (p Value in Parentheses).

Number of College Geography Courses	**No Geography Course**	**1-2 Geography Courses**	**3-5 Geography Courses**
1-2 Geography Courses	-0.170 (0.672)		
3-5 Geography Courses	**-0.901 (<0.001)**	**-0.732 (<0.001)**	
>5 Geography Courses	**-1.625 (<0.001)**	**-1.455 (<0.001)**	**-0.723 (<0.001)**

Undergraduate students responding in this study were from geography departments granting highest degree at three levels—undergraduate, master's, and doctoral. Table 4.21 displays the distribution of students in three geography department degree levels. The ANOVA revealed no statistically significant difference among the

Table 4.21. GTS Score Means for Geography Department Degree Levels.

Geography Department Level	**Number of Students (%)**	**Total Possible Score**	**Highest Score**	**Lowest Score**	**Mean Score**	**F**	**p Value**
Doctoral	544 (36.8)	10	10	1	6.50	0.895	0.409
Master's	405 (27.4)	10	10	0	6.68		
Undergraduate	530 (35.8)	10	10	0	6.55		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

mean scores of students from the three geography department degree levels. Although geography studied at the college level makes a positive difference in undergraduate students' geospatial thinking, undergraduate student performance is similar regardless of whether geography departments offer graduate degrees.

Urban, suburban, or rural patterns reflect geographic locations where the students grew up. The role of the structure of cities, suburbs, and rural areas in shaping students' spatial and geospatial thinking has not been expressed in the literature. Table 4.22 outlines the distribution of students who grew up in urban/suburban/rural areas. The ANOVA found a statistically significant difference among the mean scores of students from urban/suburban/rural areas. The mean score of rural students is highest, and that of urban students is lowest. Urban/suburban/rural patterns steer students' geospatial thinking.

Table 4.22. GTS Score Means for Urban/Suburban/Rural Patterns.

Urban/ Suburban/ Rural Patterns	**Number of Students (%)**	**Total Possible Score**	**Highest Score**	**Lowest Score**	**Mean Score**	**F**	**p Value**
Urban	475 (32.1)	10	10	0	6.15	16.157	<0.001
Suburban	636 (43.0)	10	10	0	6.73		
Rural	368 (24.9)	10	10	1	6.83		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Post-hoc comparisons (Table 4.23) revealed that urban students scored significantly lower than both suburban and rural students. However, the difference between the scores of suburban and rural students was not statistically significant.

Table 4.23. Post-hoc Comparisons (Games-Howell) of GTS Score by Urban/Suburban/Rural Patterns (p Value in Parentheses).

Urban/Suburban/Rural Patterns	**Urban**	**Suburban**
Suburban	**-0.589 (<0.001)**	
Rural	**-0.681 (<0.001)**	-0.092 (0.729)

Census divisions of the U.S. reflect locations where the students reside. Table 4.24 presents the distribution of students in nine census divisions, based on students' current university location. The ANOVA found a statistically significant difference among the mean scores of students from nine census divisions. The mean score of students in the Mountain division is highest, and that of students in the Pacific division is lowest. Geographic location influences students' geospatial thinking.

Table 4.24. GTS Score Means for Census Divisions.

Census Divisions	**Number of Students (%)**	**Total Possible Score**	**Highest Score**	**Lowest Score**	**Mean Score**	**F**	**p Value**
Mountain	105 (7.1)	10	10	2	7.44	8.375	<0.001
New England	53 (3.6)	10	10	3	7.34		
East South Central	136 (9.2)	10	10	0	6.90		
Middle Atlantic	105 (7.1)	10	9	0	6.90		
East North Central	191 (12.9)	10	10	0	6.72		
West North Central	164 (11.1)	10	10	1	6.60		
West South Central	253 (17.1)	10	9	1	6.49		
South Atlantic	287 (19.4)	10	10	0	6.16		
Pacific	185 (12.5)	10	10	1	5.97		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Post-hoc comparisons (Table 4.25) revealed that students in the Mountain Division scored higher than students from East North Central, West North Central, West South Central, South Atlantic, and Pacific divisions. Students in the New England Division scored higher than students in West South Central, South Atlantic, and Pacific divisions. Students in East South Central and Middle Atlantic divisions scored higher than students from the South Atlantic and Pacific. Students in the Pacific Division scored lower than students in the Mountain, New England, East South Central, Middle Atlantic, and East North Central divisions. Students in the South Atlantic Division scored lower than students from Mountain, New England, East South Central, and Middle Atlantic divisions. Students in the West South Central Division scored lower than students from New England and Mountain divisions. Students in the East North Central and West North Central divisions scored lower than students from the Mountain Division.

Table 4.25. Post-hoc Comparisons (Games-Howell) of GTS Score by Census Divisions (p Value in Parentheses).

Census Division	**Mountain**	**New England**	**East South Central**	**Middle Atlantic**	**East North Central**	**West North Central**	**West South Central**	**South Atlantic**
New England	0.098 (1.000)							
East South Central	0.534 (0.276)	0.435 (0.774)						
Middle Atlantic	0.533 (0.344)	0.435 (0.807)	0.000 (1.000)					
East North Central	**0.721 (0.015)**	0.622 (0.254)	0.187 (0.995)	0.187 (0.996)				
West North Central	**0.834 (0.002)**	0.736 (0.095)	0.301 (0.904)	0.301 (0.926)	0.114 (1.000)			
West South Central	**0.948 (<0.001)**	**0.850 (0.016)**	0.414 (0.509)	0.415 (0.590)	0.227 (0.951)	0.114 (1.000)		
South Atlantic	**1.281 (<0.001)**	**1.183 (<0.01)**	**0.748 (0.012)**	**0.748 (0.024)**	0.560 (0.092)	0.447 (0.347)	0.333 (0.625)	
Pacific	**1.465 (<0.001)**	**1.367 (<0.01)**	**0.931 (0.002)**	**0.932 (0.004)**	**0.744 (0.017)**	0.631 (0.087)	0.517 (0.195)	0.184 (0.994)

The combination of student backgrounds in the Mountain Division accounts for the high geospatial thinking mean score of 7.44. Explaining the high geospatial thinking scores in the Mountain Division are: (1) more than 86% of students were white, (2) about 60% were geography majors, (3) 65% of students had taken three or more college geography courses, and (4) 77% of students were seniors and juniors. On the other end of the GTS performance spectrum with a GTS mean score of 5.97 was the Pacific Division where: (1) 61% of students were female, (2) 47% of students were non-white, (3) only 16% were geography majors, (4) 37% were either in business or in the category of other social science majors, and (5) 78% had studied two or less college geography courses. Similar data disaggregation can assist in explaining the mean GTS scores for other census divisions.

Table 4.26 summarizes the highest and lowest GTS mean scores for statistically significant variables. The most important variables influencing geospatial thinking of students were ethnicity, college geography courses, academic classification, age, urban/suburban/rural locations, and academic major. University educators should consider these significant explanatory variables in designing geography curricula, textbooks, classroom materials, and assessments. Instructors should work toward improving geospatial thinking of groups of students with low mean scores on the GTS. Geospatial thinking activities should be included in undergraduate classrooms across different academic classifications and majors to improve geospatial thinking of such groups of students as female, black, younger, freshman, urban students, and students with less educated parents and lower income households. Non-geography students should be encouraged to take foundational geography courses to strengthen their geospatial thinking skills. Geography is indeed a valuable intervention in improving undergraduate student geospatial thinking skills.

Table 4.26. Summary of Highest and Lowest GTS Mean Scores for Significant Variables.

Variable	t/F	p Value	Groups with Highest Mean Score	Groups with Lowest Mean Score
Sex	-4.955	<0.001	Male (6.85)	Female (6.33)
Age	15.988	<0.001	21-24 (6.87); >24 (6.86)	18-20 (6.28)
Ethnicity	51.732	<0.001	White (6.89)	Black (4.87)
Parents' Annual Income	7.679	<0.001	>$75,000 (6.81)	$25,000-$50,000 (6.21)
Parents' Education	7.615	<0.001	Graduate Degree (6.83)	High School (6.13)
Academic Classification	22.023	<0.001	Senior (7.18)	Freshman (6.19)
Academic Major	15.100	<0.001	Geography (7.57)	Criminal Justice (5.29)
College Geography Courses	44.932	<0.001	>5 (7.72)	None (6.10)
Urban/Suburban/Rural Patterns	16.157	<0.001	Rural (6.83)	Urban (6.15)
Census Division	8.375	<0.001	Mountain (7.44)	Pacific (5.97)

Geospatial Thinking Score Prediction: Regression Model

I employed multiple regression to determine which variables (demographic, academic, geographic) are useful in predicting geospatial thinking scores of students who have not taken the GTS. Multiple regression, concerning the association of two or more independent variables (taken together) with one dependent variable, compares one group to another to show which variables are operating best to explain/predict the dependent variable (Brace, Kemp, and Snelgar 2012). Stepwise multiple regression explains which independent variables are significant predictors of the dependent variable—geospatial thinking.

In multivariate statistics, it is common to do a factor analysis or principal component analysis (PCA) prior to multiple regression. PCA is used to reduce a large number of variables to obtain a smaller set of variables (called principal components) that account for most of the variance in the observed variables. The principal components can then be used as predictor or criterion variables in subsequent analyses; such principal component scores can be used for multiple regression. Each significant principal component represents independent variable(s) that load strongly on that component. Thus, PCA reduces many independent variables into a few important variable components that account for most of the variance in the observed variables. In this way, the multicollinearity among many independent variables is also minimized when highly correlated variables are grouped and turned into one component (Stevens 1986; SAS 2014).

I ran Categorical Principal Component Analysis (CATPCA), a type of PCA analysis that deals with categorical variables at a nominal or ordinal scale, in SPSS to group the most important independent variables into meaningful components or dimensions. The independent variables included in CATCPCA were sex, age, ethnicity, parents' annual income, parents' education, urban/suburban/rural pattern, census division, academic classification, and college level geography academic experience. CATPCA revealed four components with eigenvalues of 1.0 or more, accounting for 65.54 percent of cumulative variance (Table 4.27). However, only the first two components with high internal consistency (measured by Cronbach's Alpha), i.e. 0.562 and 0.461 respectively, were meaningful (Table 4.27). The first two components accounted for 41.03 percent of cumulative variance.

Table 4.27 Results of CATPCA of the Independent Variables.

Independent Variable	**Components**			
	1	**2**	**3**	**4**
Sex	0.307	0.169	0.125	0.761
Age	**0.758**	-0.277	-0.050	0.067
Ethnicity	-0.222	**-0.602**	0.394	0.165
Parents' Annual Income	0.029	**0.734**	0.373	0.034
Parents' Education	0.043	**0.685**	0.449	-0.112
Urban/Rural Patterns	0.186	0.349	-0.598	-0.298
Census Division	0.110	-0.278	0.554	-0.527
Academic Classification	**0.833**	-0.124	0.133	-0.046
College Geography	**0.732**	0.058	-0.005	-0.126
Cronbach's Alpha	0.562	0.461	0.185	0.011
Eigenvalues	1.998	1.695	1.196	1.009
% of variance	22.199	18.831	13.293	11.216
Cumulative % of variance	22.199	41.030	54.323	65.539

Table 4.27 shows that age, academic classification, and college level geography academic experience load heavily (component loading ≥0.6) on component one. Ethnicity, parents' annual income, and parents' education load strongly (component loading ≥0.6) on component two. The two essential components regarding students' geospatial thinking are:

1. Academic Component: age, academic classification, college geography
2. Socioeconomic Component: ethnicity, parents' annual income, parents' education

Age categories of undergraduate students used in this research generally correspond to academic classifications, with the exception of above 24-year-old category. In most cases, increasing age signifies increasing academic experience. Ethnicity, parents' income and parents' educational background are key cultural variables that relate to the home environment in which the students grew up.

I then applied multiple regression to be able to predict students' geospatial thinking score based on the academic and socioeconomic components. I ran multiple regression with the object scores of the two components obtained by CATPCA. The dependent variable was the geospatial thinking scores for 1479 students, and object scores of academic and socioeconomic components for the 1479 students were independent variables.

A significant model emerged using the backward method of multiple regression, with F = 103.295, $p < 0.001$, and adjusted $R^2 = 0.122$ (Table 4.28). Although the model explains only 12 percent of the total variance in the data, the model predicts robustly within the 12 percent of variability. The regression model identified academic and socioeconomic components as significant in predicting students' geospatial thinking (Table 4.29). Based on the values of standardized coefficients and the t statistic, academic component is the stronger variable in predicting students' geospatial thinking than the socioeconomic component.

Table 4.28. Multiple Regression Model for Predicting Geospatial Thinking Scores.

Dependent Variable	Geospatial Thinking	
Independent Variables	Academic Component, Socioeconomic Component	
Method, Model	Backward, Model 1	
R	0.350	
R^2	0.123	
Adjusted R^2	0.122	
Standard Error of the Estimate	1.877	
ANOVA	F	103. 295
	Sig.	<0.001

Table 4.29. Coefficients of the Multiple Regression Model for Predicting Geospatial Thinking Scores.

Model 1	**Unstandardized Coefficients**		**Standardized Coefficients**	**t Stat.**	**Sig. Value**
	B	**Standard Error**	**Beta**		
Constant	6.568	0.049		134.583	<0.001
Academic Component	0.580	0.049	0.290	11.880	<0.001
Socioeconomic Component	0.395	0.049	0.197	8.091	<0.001

Based on the unstandardized coefficients shown in Table 4.29, the regression equation to predict students' geospatial thinking score (GT Score) is:

GT Score = 6.568 + (0.580)(academic component) + (0.395)(socioeconomic component)

This regression equation can be used to predict students' geospatial thinking score (1-10 on GTS) for undergraduate students who have not taken the GTS. However, the values of academic component and socioeconomic component are dependent on three independent variables each: academic component (age, academic classification, and college geography), and socioeconomic component (ethnicity, parents' annual income, and parents' education). To predict the values of academic component and socioeconomic component, I ran two more multiple regressions.

For the academic component multiple regression, I drew from the academic component object scores produced by the foregoing CATPCA for the 1479 students as the dependent variable, with age, academic classification, and college geography as independent variables. The categories in these three independent variables are ordinal, so I encoded the variables into eight dummy variables (18-20 year old; 21-24 years old; freshman; sophomore; junior; no college geography courses; 1-2 college geography courses; and 3-5 college geography courses). A strong model emerged using the backward method of multiple regression, with $F = 3417.477$, $p < 0.001$, and adjusted $R^2 = 0.949$ (Table 4.30), accounting for 94 percent of the total variance in the data. Table 4.31 displays the coefficients of the regression model for the academic component.

Table 4.30. Multiple Regression Model for Predicting Academic Component Values.

Dependent Variable	Academic Component	
Independent Variables	Age Academic Classification College Geography	
Method, Model	Backward, Model 1	
R	0.974	
R^2	0.949	
Adjusted R^2	0.949	
Standard Error of the Estimate	0.227	
ANOVA	F	3417.477
	Sig.	<0.001

Table 4.31. Coefficients of the Multiple Regression Model for Predicting Academic Component Values.

Model 1	**Unstandardized Coefficients**		**Standardized Coefficients**	**t Stat.**	**Sig. Value**
	B	**Standard Error**	**Beta**		
Constant	1.968	0.019		101.445	<0.001
18-20 Years	-1.007	0.019	-0.503	-52.078	<0.001
21-24 Years	-0.510	0.018	-0.238	-28.441	<0.001
Freshman	-1.180	0.024	-0.455	-48.630	<0.001
Sophomore	-0.809	0.022	-0.349	-36.646	<0.001
Junior	-0.417	0.018	-0.185	-23.388	<0.001
No College Geography	-1.313	0.022	-0.494	-58.835	<0.001
1-2 College Geography	-0.898	0.018	-0.447	-49.106	<0.001
3-5 College Geography	-0.448	0.023	-0.139	-19.196	<0.001

Based on the unstandardized coefficients shown in Table 4.31, the regression equation to predict the academic component value is:

Academic Component = 1.968 + (-1.007)(18-20 age group) + (-0.510)(21-24 age group) + (-1.180)(freshman) + (-0.809)(sophomore) + (-0.417)(junior) + (-1.313)(no college geography course) + (-0.898)(1-2 college geography courses) + (-0.448)(3-5 college geography courses)

In the equation, the presence of a characteristic in student data equals 1, and the absence of any characteristic equals 0. For example, if a student belongs to the age group 18-20, 1 is used in the equation, and the student does not automatically belong to the age group 21-24, thus the value is 0. Similarly, if a student is senior, then all three values in the equation for freshman, sophomore, and junior are 0.

For the socioeconomic component multiple regression, I incorporated the socioeconomic component object scores produced by CATPCA for 1479 students as the dependent variable, and ethnicity, parents' annual income, and parents' education became the independent variables. The categories in these three independent variables are nominal and ordinal, so I encoded these three variables into ten dummy variables: white, Hispanic. Black, <$25,000, $25,000-$50,000, $51,000-$75,000, less than high school, high school, associate degree, and bachelor degree. Once again, a strong model resulted from the backward method of multiple regression, with $F = 1121.995$, $p < 0.001$, and adjusted $R^2 = 0.884$ (Table 4.32), accounting for 88 percent of the total variance in the data. Table 4.33 displays the coefficients for the socioeconomic component regression model.

Table 4.32. Multiple Regression Model for Predicting Socioeconomic Component Values.

Dependent Variable	Socioeconomic Component	
Independent Variables	Ethnicity Parents' Annual Income Parents' Education	
Method, Model	Backward, Model 1	
R	0.940	
R^2	0.884	
Adjusted R^2	0.884	
Standard Error of the Estimate	0.341	
ANOVA	F	1121.995
	Sig.	<0.001

Table 4.33. Coefficients of the Multiple Regression Model for Predicting Socioeconomic Component Values.

Model 1	Unstandardized Coefficients		Standardized Coefficients	T Stat.	Sig. Value
	B	Standard Error	Beta		
Constant	-0.142	0.038		-3.734	<0.001
Ethnicity: White	1.357	0.034	0.591	39.612	<0.001
Ethnicity: Hispanic	0.778	0.044	0.225	17.659	<0.001
Ethnicity: Black	0.431	0.044	0.121	9.700	<0.001
Parents' Income: <$25K	-1.279	0.030	-0.458	-43.305	<0.001
Parents' Income: $25K-50K	-0.821	0.025	-0.349	-32.834	<0.001
Parents' Income: $51K-75K	-0.366	0.024	-0.153	-15.217	<0.001
Parents' Education: <HS	-1.300	0.052	-0.258	-24.827	<0.001
Parents' Education: HS	-0.982	0.027	-0.436	-35.955	<0.001
Parents' Education: AA	-0.690	0.033	-0.219	-20.906	<0.001
Parents' Education: BA/BS	-0.325	0.024	-0.154	-13.394	<0.001

Based on the unstandardized coefficients shown in Table 4.33, the regression equation predicting the socioeconomic component value is:

Socioeconomic Component = -0.142 + (1.357)(white) + (0.778)(Hispanic) +
(0.431)(black) + (-1.279)(parents' income <$25,000) +
(-0.821)(parents' income $25,000-$50,000) +
(-0.366)(parents' income $51,000-$75,000) +
(-1.300)(parents' education less than high school) +
(-0.982)(parents' education high school) +
(-0.690)(parents' education associate degree) +
(-0.325)(parents' education bachelor degree)

In the equation and as with the academic component, the presence of a characteristic for a student equals 1, and the absence of any characteristic equals 0. For example, if a student is white, 1 is used in the equation in place of white, and the student does not automatically belong to Hispanic or black category, so these values are 0. Similarly, if parents' annual income for a student is above $75,000, then all three values in the equation for parents' annual income of <$25,000, $25,000-$50,000, and $51,000-$75,000 are 0.

In sum, the values of the academic and socioeconomic components for a student can predict student's geospatial thinking score using this equation:

GT Score = 6.568 + (0.580)(academic component) + (0.395)(socioeconomic component)

Geospatial Thinking Score Prediction: Data Mining Model

To predict the outcome of geospatial thinking of a student based on certain independent variables, I also employed a data mining predictive model, which I call the Geospatial Thinking Model (GTM). The Cubist software constructed the GTM. Cubist is an artificial intelligence tool for generating rule-based predictive models (Cubist 2014). Artificial intelligence includes expert system or a computer system that can simulate human reasoning and decision-making ability. Cubist models predict numeric values, in this case geospatial thinking scores. The elements of an expert system include:

1. Fact: an evidence (or value) of an attribute relevant to the phenomenon (geospatial thinking score).
2. Rule: conditional statement(s) that relate a given circumstance to an outcome (e.g., a student's score on the GTS is predicted based on sex, ethnicity, and academic classification) (Chow 2012; Cubist 2014).

Cubist estimates a case's target value in terms of its attribute values by building a model containing one or more rules, where each rule is a conjunction of conditions associated with a linear expression. The meaning of a rule is that, if a case satisfies all the conditions, then the linear expression is appropriate for predicting the target value. A Cubist model thus resembles a piecewise linear model, except that the rules can overlap (Cubist 2014).

Cubist employs heuristics that try to simplify models without substantially reducing their predictive accuracy (Cubist 2014). However, Cubist includes different methods for combining rule-based and instance-based models. After running several iterations of model selections using different options, I chose only rule-based models as recommended by the Cubist software based on the data analyzed by selecting the option: Let Cubist Decide. This option derives from the training data a heuristic estimate of the accuracy of each type of model and chooses the form that performs more accurately (Cubist 2014). For model building, I first used geospatial thinking scores of 1479 students as the dependent variable, termed the target attribute in Cubist, and nine independent variables (attributes): age, sex, ethnicity, parents' annual income, parents' education, urban/suburban/rural patterns, academic classification, academic major, and college geography courses.

The first-run Cubist model produced five rules as shown in Table 4.34. Although the order of the rules does not affect the value predicted by a model, Cubist presents them in decreasing order of importance. The first rule makes the greatest contribution to the model's accuracy on the training data, and the last rule has the least impact (Cubist 2014). Thus, rule 1 in Table 4.34 is the most important, and rule 5 is the least. Expert systems, like Cubist, select only the most important variables to generate rules that can predict most cases. Ethnicity and academic major stand out as contributing variables in predicting geospatial thinking of most cases.

Each rule also carries some descriptive information: the number of training cases that satisfy the rule's conditions, their target values' mean, and a rough estimate of the expected error magnitude of predictions made by the rule (Table 4.34).

Table 4.34. Cubist First-Run Model to Predict Students' Geospatial Thinking Score (GT Score)

<table>
<tr><td>Dependent Variable</td><td colspan="4">Geospatial Thinking</td></tr>
<tr><td>Independent Variables</td><td colspan="4">Age, Sex, Ethnicity, Parents' Annual Income, Parents' Education, Urban/Suburban/Rural Patterns, Academic Classification, Academic Major, College Geography Courses</td></tr>
<tr><td>Number of Rules</td><td colspan="4">5 (Option: Let Cubist Decide)</td></tr>
<tr><td>Number of Instances</td><td colspan="4">7 nearest neighbors (Option: Let Cubist Decide)</td></tr>
<tr><td>Attribute Usage</td><td colspan="4">100% Ethnicity, 100% Academic Major</td></tr>
<tr><td>Rule #</td><td>Training Cases</td><td>Mean</td><td>Estimated Error</td><td>Rule</td></tr>
<tr><td>1</td><td>179</td><td>4.9</td><td>1.9</td><td>If Ethnicity in Hispanic, Black
Academic Major in Computer Science, Health, Nursing, Psychology, Criminal Justice, Social Science, Business, Education, Communication, Humanities, No Major
then GT score = 5</td></tr>
<tr><td>2</td><td>219</td><td>5.8</td><td>1.6</td><td>If Ethnicity in White, Asian
Academic Major in Criminal Justice, Education, Communication, No Major
then GT score = 6</td></tr>
<tr><td>3</td><td>414</td><td>6.4</td><td>1.5</td><td>If Ethnicity in White, Asian
Academic Major in Computer Science, Health, Nursing, Psychology, Social Science, Business, Humanities
then GT score = 7</td></tr>
<tr><td>4</td><td>131</td><td>6.5</td><td>1.6</td><td>If Ethnicity in Hispanic, Black, Asian
Academic Major in Geography, Geology, Environmental Science, Biology, Engineering, Science, History
then GT score = 7</td></tr>
<tr><td>5</td><td>536</td><td>7.6</td><td>1.1</td><td>If Ethnicity in White
Academic Major in Geography, Geology, Environmental Science, Biology, Engineering, Science, History
then GT score = 8</td></tr>
</table>

Within the linear formula, the attributes are ordered in decreasing relevance to the result (Cubist 2014). In each of the five rules, then, ethnicity is a stronger predictor of geospatial thinking, followed by academic major. A comparative analysis of the first three rules show white and Asian students have higher geospatial thinking scores than

Hispanic and black students across similar academic majors. Rules 4 and 5 clearly imply that all ethnic groups are capable of increasing their geospatial thinking scores with interventions by taking such courses as geography and geology, and science courses. Even with a similar geospatial intervention, however, geospatial thinking scores of white students are predicted to be higher than those of Hispanic, black, and Asian students. Designing appropriate curricular geospatial materials to improve geospatial thinking of Hispanic and black students in particular is critical.

Cubist models are evaluated on the training data from which they were generated. The relative error magnitude is the ratio of the average error magnitude to the error magnitude that would result from always predicting the mean value. Useful models should have a relative error of magnitude less than 1 (Cubist 2014). The first-run model (Table 4.34) had a relative error of 0.86, meaning the model is effective in geospatial thinking score prediction. The correlation coefficient measures the agreement between the cases' actual values of the target attribute and those values predicted by the model (Cubist 2014). The correlation coefficient for the first-run model was 0.44, which implies that the actual and predicted geospatial thinking scores are only moderately correlated.

To consider the effect of independent variable(s) other than academic major in influencing students' geospatial thinking, I ran Cubist again with a different set of independent variables, excluding academic major and including census division (Table 4.35). In the second iteration, I included age, sex, ethnicity, parents' annual income, parents' education, urban/suburban/rural patterns, academic classification, college geography courses, and census division, and the Cubist model generated three rules in the order of importance as shown. Ethnicity and college geography are conspicuous as prime variables in predicting geospatial thinking of most cases in the second run. Rules 1 and 2 emphasize that the geospatial thinking scores of Hispanic and black students are lower than those of white and Asian students who have taken the same number of college geography courses. Rule 3 clearly highlights that higher number of college geography courses improves geospatial thinking.

Table 4.35. Cubist Second-Run Model to Predict Students' Geospatial Thinking Score (GT Score)

<table>
<tr><td colspan="2">Dependent Variable</td><td colspan="3">Geospatial Thinking</td></tr>
<tr><td colspan="2">Independent Variables</td><td colspan="3">Age, Sex, Ethnicity, Parents' Annual Income, Parents' Education, Urban/Suburban/Rural Patterns, Academic Classification, College Geography, Census Division</td></tr>
<tr><td colspan="2">Number of Rules</td><td colspan="3">3 (Option: Let Cubist Decide)</td></tr>
<tr><td colspan="2">Number of Instances</td><td colspan="3">6 nearest neighbors (Option: Let Cubist Decide)</td></tr>
<tr><td colspan="2">Attribute Usage</td><td colspan="3">100% College Geography, 83% Ethnicity</td></tr>
<tr><td>Rule #</td><td>Cases</td><td>Mean</td><td>Estimated Error</td><td>Rule</td></tr>
<tr><td>1</td><td>242</td><td>5.2</td><td>1.9</td><td>If Ethnicity in Hispanic, Black
College Geography in None, 1-2 courses, 3-5 courses
then GT score = 5</td></tr>
<tr><td>2</td><td>984</td><td>6.6</td><td>1.5</td><td>If Ethnicity in White, Asian
College Geography in None, 1-2 courses, 3-5 courses
then GT score = 7</td></tr>
<tr><td>3</td><td>253</td><td>7.7</td><td>0.9</td><td>If College Geography in >5 courses
then GT score = 8</td></tr>
</table>

The second-run model (Table 4.35) had a relative error of 0.88, meaning the model is effective in geospatial thinking score prediction. The correlation coefficient for the second-run model was 0.36, which implies that the actual and predicted geospatial thinking scores are only moderately correlated.

Both regression and data mining models identified ethnicity and academic variables as important in determining students' geospatial thinking. Students can work to improve their geospatial thinking by taking such courses as geography, geology, and environmental science, particularly.

Student Performance on Individual Questions of the GTS

Individual questions of the GTS represent different geospatial thinking domains (Table 3.2). Prior research has demonstrated that different geospatial thinking domains are not correlated. Students may perform well at one component of geospatial thinking, and not on another component (Voyer, Voyer, and Bryden 1995; Gersmehl and Gersmehl 2006; Smith 2007; Gersmehl 2012; Lee and Bednarz 2012; Huynh and Sharpe 2013; Ishikawa 2013; Sinton et al. 2013). Each GTS question, therefore, must be examined to assess students' performance in separate geospatial thinking domains.

Figure 4.2 shows the performance of all students on the ten GTS questions. I divided the GTS questions into three categories—less difficult, difficult, and more difficult—based on the percentage of students answering the particular question correctly. The 34th and 67th percentiles separated the three groups of student responses.

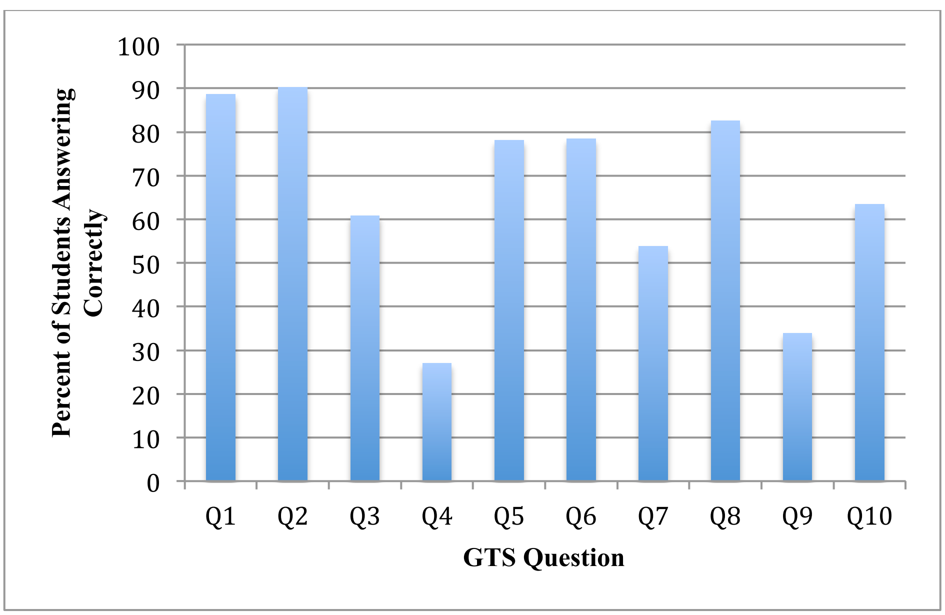


Figure 4.2. Student performance on individual GTS questions.

More than 67 percent students answered correctly questions 1 (geospatial pattern and transition), 2 (direction and orientation), 5 (geospatial association), 6 (geospatial shapes), and 8 (geospatial shapes). These questions were less difficult for a majority of the students. If a question was answered correctly by 34-67 percent of students, then the question was categorized as difficult question. Questions 3 (geospatial profile and transition), 7 (geospatial shapes), and 10 (geospatial overlay) were difficult based on students' correct responses. If a question was answered correctly by less than 34 percent of students, then the question was a more difficult question. Questions 4 (geospatial association and transition) and 9 (geospatial shapes) were more difficult.

Table 4.36 depicts the difficulty level of GTS questions based on correct answers. Interestingly, the four geospatial shapes questions included the three categories: less difficult (Q8, Q6), difficult (Q7), and more difficult (Q9). This outcome can be linked to the varying structures of the questions (see Appendix A). Within the geospatial shapes domain, questions that were less difficult (Q8, Q6) involve analyzing points and lines (networks) in terms of geographical data. The difficult question (Q7) requires the analysis

Table 4.36. Difficulty Level of GTS Questions Based on Students' Responses (From Less Difficult to More Difficult).

Question Difficulty Level	**GTS Question**	**Geospatial Thinking Domain**	**Percent of Students Answering Correctly**
Less Difficult	Q2	Direction and Orientation	90.3
	Q1	Geospatial Pattern and Transition	88.6
	Q8	Geospatial Shapes	82.6
	Q6	Geospatial Shapes	78.4
	Q5	Geospatial Association	78.1
Difficult	Q10	Geospatial Overlay	63.4
	Q3	Geospatial Profile and Transition	60.8
	Q7	Geospatial Shapes	53.8
More Difficult	Q9	Geospatial Shapes	33.9
	Q4	Geospatial Association and Transition	27.0

of lines and areas (polygons and regions), and more difficult question (Q9) entails analyzing points and areas. Within a single geospatial thinking domain, therefore, students understand and analyze geospatial shapes differently.

Q5 from geospatial association and transition domain was less difficult, while Q4 from the same domain was more difficult (Table 4.36). Q5 requires students to search for geospatial association (similar patterns) between two maps. Q4 compels students to first discern geospatial association between two maps, and then transfer the information to a graph. More complex geospatial reasoning processes make questions more difficult even within similar geospatial domains.

Direction and orientation (Q2) was the easiest question on the GTS for most of the students (Table 4.36). Undergraduate students seem to be good at map navigation, way finding, and route planning. Geospatial pattern and transition (Q1) was also very easy for students, underscoring that undergraduate students appear to be comfortable in discerning geospatial patterns, transferring map information to graphic information, and graphing geospatial transitions. Results for Q10 (geospatial overlay) suggest that students are also fairly good at comprehending overlaying and dissolving map layers to choose the best location based on various geographical conditions, connections, and distance. Students find geospatial profile and transition difficult in comprehension than other questions. Student understanding of geospatial shapes vary from being less difficult to more difficult, depending on the number and level of concepts, and reasoning processes involved in the analysis. Geospatial association with transition is difficult for undergraduate students.

The analysis of difficulty level of GTS questions in Table 4.36 demonstrates that students comprehend and apply geospatial thinking domains differently. The division of spatial concepts and spatial reasoning processes into hierarchies (Golledge 1995; Jo and Bednarz 2009) seem to be inconsequential, because responses from the GTS show students answering questions from similar domains (similar conceptual and reasoning levels) at the two ends of the range of difficulty. Both direction and shape are simple-spatial concepts, according to Jo and Bednarz (2009), but students found the direction question less difficult, and geospatial shapes questions at all three levels of difficulty. Spatial association is a complex-spatial concept, according to Jo and Bednarz (2009), yet student responses were at both ends of the difficulty range in different questions. Although spatial pattern, profile, association, and overlay are higher-order complex-spatial concepts (Jo and Bednarz 2009), students do not necessarily find them as more difficult than lower-order simple-spatial concepts of direction and shape. Q3 requires students to visualize topographic profile and orient themselves in situ, thereby entailing higher order spatial reasoning process at the output level (Jo and Bednarz 2009). All other questions on the GTS are at the processing level, which is the mid-level of spatial reasoning, according to Jo and Bednarz (2009). However, students did not perceive Q3 to be more difficult than other questions. The theoretical assumptions of the difficulty level of questions based on spatial conceptual and reasoning hierarchy do not necessarily apply to undergraduate students' understanding and comprehension of different geospatial thinking domains.

Different spatial and geospatial thinking domains are not correlated but interconnected, as postulated by Gersmehl and Gersmehl (2006). Understanding group and individual differences in students' understanding of distinct geospatial thinking domains is critical. An effective geography curriculum must comprehend student strengths and weaknesses in various geospatial domains and then tailor teaching materials to target improvement.

Group Differences on Individual Questions of the GTS

To substantiate statistically the foregoing generalizations regarding the difficulty of individual GTS questions, I applied the chi-square test of independence (alpha = 0.05) to investigate the relationships among the categories of each independent variable with each GTS question, thereby inferring group differences. The chi-square test of independence is a nonparametric method used to determine whether a significant association exists between two categorical variables (Daniel 1990; Agresti 2002; Bearden 2014; Boduszek 2014). Each analysis of the chi-square test of independence included each demographic, academic, or geographic variable as one variable, and each GTS question as another variable. The students' responses on individual questions were categorical, as they were coded dichotomously, i.e. correct or incorrect. The six independent variables—sex, age, ethnicity, academic classification, college geography, and urban/suburban/rural patterns—were also categorical. To analyze whether a variable and a particular GTS question were associated, I ran the chi-square test 60 times (six independent variables by ten geospatial thinking questions). For example, one chi-square run tested if understanding the geospatial thinking domain regarding geospatial overlay in Q10 was independent of student ethnicity.

For Q1 representing geospatial pattern and transition domain, I ran a chi-square for the six variables (Table 4.37). The understanding of geospatial pattern and transition ability was independent of sex and age, yet the domain was associated with differences in ethnicity, academic classification, college geography, and urban/suburban/rural locations.

Table 4.37. Association of Q1 (Geospatial Pattern and Transition) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	**Categories**	**Number of Student Responses (%)**		**Chi-Square**	**p Value**	**Result**
		Correct	**Incorrect**			
Sex	Female	703 (87.4)	101 (12.6)	2.244	0.134	No difference exists in the responses of females and males to Q1
	Male	607 (89.9)	68 (10.1)			
Age	18-20	659 (87.7)	92 (12.3)	1.086	0.581	No differences exist in the responses of age groups to Q1
	21-24	424 (89.6)	49 (10.4)			
	>24	227 (89.0)	28 (11.0)			
Ethnicity	White	1009 (91.5)	94 (8.5)	41.346	<0.01	Differences exist in the responses of ethnic groups to Q1
	Hispanic	109 (80.1)	27 (19.9)			
	Black	96 (75.6)	31 (24.4)			
	Asian	96 (85.0)	17 (15.0)			
Academic Classification	Freshman	233 (86.9)	35 (13.1)	9.461	0.024	Differences exist in the responses of academic classification groups to Q1
	Sophomore	315 (86.1)	51 (13.9)			
	Junior	352 (87.8)	49 (12.2)			
	Senior	410 (92.3)	34 (7.7)			
College Geography Courses	No Geog. Course	206 (81.4)	47 (18.6)	40.589	<0.01	Differences exist in the responses of college geography groups to Q1
	1-2 Geog. Courses	706 (86.9)	106 (13.1)			
	3-5 Geog. Courses	150 (93.2)	11 (6.8)			
	>5 Geog. Courses	248 (98.0)	5 (2.0)			
Urban/ Suburban/ Rural	Urban	401 (84.4)	74 (15.6)	11.949	0.003	Differences exist in the responses of urban/sub-urban/rural groups to Q1
	Suburban	575 (90.4)	61 (9.6)			
	Rural	334 (90.8)	34 (9.2)			

Table 4.38 shows internal comparisons of significant associations between Q1 and different variables. The results suggest undergraduate curriculum needs to cater specifically to Hispanic, black, and urban students, and students who have not taken any college geography courses so their geospatial thinking ability in geospatial pattern and transition can be strengthened. Senior students and students who have taken more than five college geography courses have better understandings of geospatial pattern and transition. Higher educational experience and formal college geography instruction are keys in improving student comprehension of geospatial pattern and transition.

Table 4.38. Internal Comparisons for Association of Q1 (Geospatial Pattern and Transition) with Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	Categories	Standardized Residuals		Significant Contributors to the Association and Internal Comparisons
		Correct	Incorrect	
Ethnicity	White	1.0	**-2.9**	Fewer white students than expected answered Q1 incorrectly, thus outperforming the other ethnic groups. More Hispanic and black students than expected answered Q1 incorrectly, thus underperforming the other ethnic groups.
	Hispanic	-1.0	**2.9**	
	Black	-1.6	**4.3**	
	Asian	-0.4	1.1	
Academic Classification	Freshman	-0.3	0.8	Fewer senior students than expected answered Q1 incorrectly, thus outperforming the other academic classification groups.
	Sophomore	-0.5	1.4	
	Junior	-0.2	0.5	
	Senior	0.8	**-2.3**	
College Geography Courses	No Geog. Course	-1.2	**3.4**	More students with no college geography than expected answered Q1 incorrectly, thus under-performing the other groups. Fewer students with >5 college geography courses than expected answered Q1 incorrectly, thus outperforming the other groups.
	1-2 Geog. Courses	-0.5	1.4	
	3-5 Geog. Courses	0.6	-1.7	
	>5 Geog. Courses	1.6	**-4.4**	
Urban/ Suburban/ Rural	Urban	-1.0	**2.7**	More urban students than expected answered Q1 incorrectly, thus underperforming the other groups.
	Suburban	0.5	-1.4	
	Rural	0.4	-1.2	

The geospatial thinking ability to comprehend direction and orientation (Q2) was related to differences in ethnicity and urban/suburban/rural locations (Table 4.39).

Table 4.39. Association of Q2 (Direction and Orientation) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	Categories	Number of Student Responses (%)		Chi-Square	p Value	Result
		Correct	Incorrect			
Sex	Female	718 (89.3)	86 (10.7)	1.848	0.174	No difference exists in the responses of females and males to Q2
	Male	617 (91.4)	58 (8.6)			
Age	18-20	668 (88.9)	83 (11.1)	3.481	0.175	No differences exist in the responses of age groups to Q2
	21-24	436 (92.2)	37 (7.8)			
	>24	231 (90.6)	24 (9.4)			
Ethnicity	White	1014 (91.9)	89 (8.1)	16.775	0.001	Differences exist in the responses of ethnic groups to Q2
	Hispanic	120 (88.2)	16 (11.8)			
	Black	104 (81.9)	23 (18.1)			
	Asian	97 (85.8)	16 (14.2)			
Academic Classification	Freshman	237 (88.4)	31 (11.6)	4.872	0.181	No differences exist in the responses of academic classification groups to Q2
	Sophomore	328 (89.6)	38 (10.4)			
	Junior	358 (89.3)	43 (10.7)			
	Senior	412 (92.8)	32 (7.2)			
College Geography Courses	No Geog. Course	220 (87.0)	33 (13.0)	7.673	0.053	No differences exist in the responses of college geography groups to Q2
	1-2 Geog. Courses	729 (89.8)	83 (10.2)			
	3-5 Geog. Courses	149 (92.5)	12 (7.5)			
	>5 Geog. Courses	237 (93.7)	16 (6.3)			
Urban/ Suburban/ Rural	Urban	412 (86.7)	63 (13.3)	12.790	0.002	Differences exist in the responses of urban, suburban, rural groups to Q2
	Suburban	577 (90.7)	59 (9.3)			
	Rural	346 (94.0)	22 (6.0)			

Table 4.40 shows the internal comparisons of Q2 with ethnicity and urban/suburban/rural locations. Black and urban students need geospatial instruction that

emphasizes direction and orientation skills. Rural students, when navigating, are apparently more attuned to direction and orientation than urban students.

Table 4.40. Internal Comparisons for Association of Q2 (Direction and Orientation) with Ethnicity, and Urban/Suburban/Rural Patterns.

Variable	Categories	Standardized Residuals		Significant Contributors to the Association and Internal Comparisons
		Correct	Incorrect	
Ethnicity	White	0.6	-1.8	More black students than expected answered Q2 incorrectly, thus underperforming the other ethnic groups.
	Hispanic	-0.2	0.8	
	Black	-1.0	**3.0**	
	Asian	-0.5	1.5	
Urban/ Suburban/ Rural	Urban	-0.8	**2.5**	More urban students than expected answered Q2 incorrectly, thus underperforming the other groups. Fewer rural students than expected answered Q2 incorrectly, thus outperforming the other groups.
	Suburban	0.1	-0.4	
	Rural	0.8	**-2.3**	

Q3, geospatial profile and transition, is related to differences in sex, age, ethnicity, academic classification, college geography, and urban/suburban/rural locations (Table 4.41). In the geospatial profile and transition domain, students who were female, Hispanic, black, urban, younger, freshman, and less exposed to formal geography courses underperformed more than expected (Table 4.42). These groups of students may require additional classroom instruction in geospatial profile and transition thinking ability.

Table 4.41. Association of Q3 (Geospatial Profile and Transition) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	Categories	Number of Student Responses (%)		Chi-Square	p Value	Result
		Correct	Incorrect			
Sex	Female	427 (53.1)	377 (46.9)	43.532	<0.01	Difference exists in the responses of females and males to Q3
	Male	472 (69.9)	203 (30.1)			
Age	18-20	417 (55.5)	334 (44.5)	20.316	<0.01	Differences exist in the responses of age groups to Q3
	21-24	303 (64.1)	170 (35.9)			
	>24	179 (70.2)	76 (29.8)			
Ethnicity	White	731 (66.3)	372 (33.7)	69.968	<0.01	Differences exist in the responses of ethnic groups to Q3
	Hispanic	63 (46.3)	73 (53.7)			
	Black	41 (32.3)	86 (67.7)			
	Asian	64 (56.6)	49 (43.4)			
Academic Classification	Freshman	136 (50.7)	132 (49.3)	25.823	<0.01	Differences exist in the responses of academic classification groups to Q3
	Sophomore	219 (59.8)	147 (40.2)			
	Junior	236 (58.9)	165 (41.1)			
	Senior	308 (69.4)	136 (30.6)			
College Geography Courses	No Geog. Course	134 (53.0)	119 (47.0)	68.577	<0.01	Differences exist in the responses of college geography groups to Q3
	1-2 Geog. Courses	450 (55.4)	362 (44.6)			
	3-5 Geog. Courses	106 (65.8)	55 (34.2)			
	>5 Geog. Courses	209 (82.6)	44 (17.4)			
Urban/ Suburban/ Rural	Urban	256 (53.9)	219 (46.1)	13.965	0.001	Differences exist in the responses of urban, sub-urban, rural groups to Q3
	Suburban	406 (63.8)	230 (36.2)			
	Rural	237 (64.4)	131 (35.6)			

Table 4.42. Internal Comparisons for Association of Q3 (Geospatial Profile and Transition) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/ Suburban/Rural Patterns.

Variable	Categories	Standardized Residuals		Significant Contributors to the Association and Internal Comparisons
		Correct	Incorrect	
Sex	Female	**-2.8**	**3.5**	Fewer female students than expected answered Q3 correctly, and more female students than expected answered Q3 incorrectly. More male students than expected answered Q3 correctly, and fewer male students than expected answered Q3 incorrectly. Thus, males outperformed females.
	Male	**3.0**	**-3.8**	
Age	18-20	-1.8	**2.3**	More 18-20 year old students than expected answered Q3 incorrectly, thus underperforming the other age groups. Fewer >24-year-old students than expected answered Q3 incorrectly, thus outperforming the other age groups.
	21-24	0.9	-1.1	
	>24	1.9	**-2.4**	
Ethnicity	White	**2.3**	**-2.9**	More white students than expected answered Q3 correctly, and fewer white students than expected answered Q3 incorrectly. Thus, whites outperformed the other ethnic groups. Fewer Hispanic and black students than expected answered Q3 correctly, and more Hispanic and black students than expected answered Q3 incorrectly. Thus, Hispanics and blacks underperformed the other ethnic groups.
	Hispanic	**-2.2**	**2.7**	
	Black	**-4.1**	**5.1**	
	Asian	-0.6	0.7	
Academic Classification	Freshman	**-2.1**	**2.6**	Fewer freshmen than expected answered Q3 correctly, and more freshmen than expected answered Q3 incorrectly. Thus, freshmen underperformed the other groups. More senior students than expected answered Q3 correctly, and fewer seniors than expected answered Q3 incorrectly. Thus, seniors outperformed the other groups.
	Sophomore	-0.2	0.3	
	Junior	-0.5	0.6	
	Senior	**2.3**	**-2.9**	
College Geography Courses	No Geography Course	-1.6	**2.0**	More students with no college geography courses than expected answered Q3 incorrectly, thus underperforming the other groups. Fewer students with 1-2 college geography courses than expected answered Q3 correctly, and more students with 1-2 college geography
	1-2 Geography Courses	**-2.0**	**2.4**	

Table 4.42. Continued.

<table>
<tr><th rowspan="2">Variable</th><th rowspan="2">Categories</th><th colspan="2">Standardized Residuals</th><th rowspan="2">Significant Contributors to the Association and Internal Comparisons</th></tr>
<tr><th>Correct</th><th>Incorrect</th></tr>
<tr><td rowspan="2">College Geography Courses</td><td>3-5 Geography Courses</td><td>0.8</td><td>-1.0</td><td rowspan="2">courses than expected answered Q3 incorrectly, thus underperforming the other groups. More students with >5 college geography courses than expected answered Q3 correctly, and fewer students with >5 college geography courses than expected answered Q3 incorrectly, thus outperforming the other groups.</td></tr>
<tr><td>>5 Geography Courses</td><td>4.5</td><td>-5.5</td></tr>
<tr><td rowspan="3">Urban/Sub-urban/Rural</td><td>Urban</td><td>-1.9</td><td>2.4</td><td rowspan="3">More urban students than expected answered Q3 incorrectly, thus underperforming the other groups.</td></tr>
<tr><td>Suburban</td><td>1.0</td><td>-1.2</td></tr>
<tr><td>Rural</td><td>0.9</td><td>-1.1</td></tr>
</table>

Q4, geospatial association and transition, was related to differences in age, and academic classification (Table 4.43), and Table 4.44 displays internal comparisons of significant associations of Q4. In the geospatial association and transition domain, students above 24 years of age underperformed more than expected. Geospatial association and transition was the most difficult geospatial domain according to the performance of students on the GTS. Only 27 percent were able to answer Q4 correctly (Table 4.33). Students need more practice in geospatial association and transition geospatial thinking.

Table 4.43. Association of Q4 (Geospatial Association and Transition) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	**Categories**	**Number of Student Responses (%)**		**Chi-Square**	**p Value**	**Result**
		Correct	**Incorrect**			
Sex	Female	213 (26.5)	591 (73.5)	0.273	0.601	No difference exists in the responses of females and males to Q4
	Male	187 (27.7)	488 (72.3)			
Age	18-20	218 (29.0)	533 (71.0)	17.511	<0.01	Differences exist in the responses of age groups to Q4
	21-24	140 (29.6)	333 (70.4)			
	>24	42 (16.5)	213 (83.5)			
Ethnicity	White	305 (27.7)	798 (72.3)	5.698	0.127	No differences exist in the responses of ethnic groups to Q4
	Hispanic	32 (23.5)	104 (76.5)			
	Black	26 (20.5)	101 (79.5)			
	Asian	37 (32.7)	76 (67.3)			
Academic Classification	Freshman	76 (28.4)	192 (71.6)	9.178	0.027	Differences exist in the responses of academic classification groups to Q4
	Sophomore	87 (23.8)	279 (76.2)			
	Junior	96 (23.9)	305 (76.1)			
	Senior	141 (31.8)	303 (68.2)			
College Geography Courses	No Geog. Course	69 (27.3)	184 (72.7)	2.049	0.562	No differences exist in the responses of college geography groups to Q4
	1-2 Geog. Courses	209 (25.7)	603 (74.3)			
	3-5 Geog. Courses	46 (28.6)	115 (71.4)			
	>5 Geog. Courses	76 (30.0)	177 (70.0)			
Urban/ Suburban/ Rural	Urban	119 (25.1)	356 (74.9)	1.603	0.449	No differences exist in the responses of urban, sub-urban, rural groups to Q4
	Suburban	181 (28.5)	455 (71.5)			
	Rural	100 (27.2)	268 (72.8)			

Table 4.44. Internal Comparisons for Association of Q4 (Geospatial Association and Transition) with Age, and Academic Classification.

Variable	Categories	Standardized Residuals		Significant Contributors to the Association and Internal Comparisons
		Correct	Incorrect	
Age	18-20	1.0	-0.6	Fewer >24 year old students than expected answered Q4 correctly, and more >24 year old students than expected answered Q4 incorrectly, thus underperforming the other age groups.
	21-24	1.1	-0.7	
	>24	**-3.2**	**2.0**	
Academic Classification	Freshman	0.4	-0.3	None
	Sophomore	-1.2	0.7	
	Junior	-1.2	0.7	
	Senior	1.9	-1.2	

Q5, geospatial association, was related to differences in sex, age, ethnicity, academic classification, college geography, and urban/suburban/rural locations (Table 4.45). Hispanic, black, and urban students and students who had taken no college geography courses underperformed more than expected (Table 4.46), consequently pointing to more classroom instruction and practice in geospatial association. Male, senior, and rural students and students who had taken more than five college geography courses performed better than expected.

Table 4.45. Association of Q5 (Geospatial Association) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	Categories	Number of Student Responses (%)		Chi-Square	p Value	Result
		Correct	Incorrect			
Sex	Female	610 (75.9)	194 (24.1)	5.087	0.024	Difference exists in the responses of females and males to Q5
	Male	545 (80.7)	130 (19.3)			
Age	18-20	562 (74.8)	189 (25.2)	9.480	0.009	Differences exist in the responses of age groups to Q5
	21-24	385 (81.4)	88 (18.6)			
	>24	208 (81.6)	47 (18.4)			
Ethnicity	White	918 (83.2)	185 (16.8)	76.159	<0.01	Differences exist in the responses of ethnic groups to Q5
	Hispanic	83 (61.0)	53 (39.0)			
	Black	72 (56.7)	55 (43.3)			
	Asian	82 (72.6)	31 (27.4)			
Academic Classification	Freshman	196 (73.1)	72 (26.9)	13.475	0.004	Differences exist in the responses of academic classification groups to Q5
	Sophomore	275 (75.1)	91 (24.9)			
	Junior	313 (78.1)	88 (21.9)			
	Senior	371 (83.6)	73 (16.4)			
College Geography Courses	No Geog. Course	177 (70.0)	76 (30.0)	31.310	<0.01	Differences exist in the responses of college geography groups to Q5
	1-2 Geog. Courses	620 (76.4)	192 (23.6)			
	3-5 Geog. Courses	132 (82.0)	29 (18.0)			
	>5 Geog. Courses	226 (89.3)	27 (10.7)			
Urban/ Suburban/ Rural	Urban	344 (72.4)	131 (27.6)	15.076	0.001	Differences exist in the responses of urban, suburban, rural groups to Q5
	Suburban	505 (79.4)	131 (20.6)			
	Rural	306 (83.2)	62 (16.8)			

Table 4.46. Internal Comparisons for Association of Q5 (Geospatial Association) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	Categories	Standardized Residuals		Significant Contributors to the Association and Internal Comparisons
		Correct	Incorrect	
Sex	Female	-0.7	1.3	None
	Male	0.8	-1.5	
Age	18-20	-1.0	1.9	None
	21-24	0.8	-1.5	
	>24	0.6	-1.2	
Ethnicity	White	1.9	-3.6	Fewer Hispanic and black students than expected answered Q5 correctly, and more Hispanic and black students than expected answered Q5 incorrectly. Thus, Hispanics and blacks underperformed the other ethnic groups.
	Hispanic	**-2.3**	**4.3**	
	Black	**-2.7**	**5.2**	
	Asian	-0.7	1.3	
Academic Classification	Freshman	-0.9	1.7	Fewer seniors than expected answered Q5 incorrectly, thus outperforming the other groups.
	Sophomore	-0.6	1.2	
	Junior	0.0	0.0	
	Senior	1.3	**-2.5**	
College Geography Courses	No Geog. Course	-1.5	**2.8**	More students with no college geography course than expected answered Q5 incorrectly, thus underperforming the other groups. More students with >5 college geography courses than expected answered Q5 correctly, and fewer students with >5 college geography courses than expected answered Q5 incorrectly, thus outperforming the other groups.
	1-2 Geog. Courses	-0.6	1.1	
	3-5 Geog. Courses	0.6	-1.1	
	>5 Geog. Courses	**2.0**	**-3.8**	
Urban/ Suburban/ Rural	Urban	-1.4	**2.6**	More urban students than expected answered Q5 incorrectly, thus underperforming the other groups. Fewer rural students than expected answered Q5 incorrectly, thus outperforming the other groups.
	Suburban	0.4	-0.7	
	Rural	1.1	**-2.1**	

Q6, geospatial shapes, was related to differences in sex, age, ethnicity, academic classification, college geography, and urban/suburban/rural locations (Table 4.47). Female, younger (18-20 years old), Hispanic, black, Asian, freshman, and urban students, and students with no or 1-2 college geography courses underperformed more than expected (Table 4.48). These groups of students may require supplementary classroom instruction and practice in comprehending geospatial shapes. Male, older (above 24 years old), white, senior, and rural students and students who had taken more than five college geography courses performed better than expected.

Table 4.47. Association of Q6 (Geospatial Shapes) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	**Categories**	**Number of Student Responses (%)**		**Chi-Square**	**p Value**	**Result**
		Correct	**Incorrect**			
Sex	Female	609 (75.7)	195 (24.3)	7.119	0.008	Difference exists in the responses of females and males to Q6
	Male	550 (81.5)	125 (18.5)			
Age	18-20	556 (74.0)	195 (26.0)	19.022	<0.01	Differences exist in the responses of age groups to Q6
	21-24	384 (81.2)	89 (18.8)			
	>24	219 (85.9)	36 (14.1)			
Ethnicity	White	938 (85.0)	165 (15.0)	129.13	<0.01	Differences exist in the responses of ethnic groups to Q6
	Hispanic	88 (64.7)	48 (35.3)			
	Black	60 (47.2)	67 (52.8)			
	Asian	73 (64.6)	40 (35.4)			
Academic Classification	Freshman	189 (70.5)	79 (29.5)	27.867	<0.01	Differences exist in the responses of academic classification groups to Q6
	Sophomore	277 (75.7)	89 (24.3)			
	Junior	310 (77.3)	91 (22.7)			
	Senior	383 (86.3)	61 (13.7)			
College Geography Courses	No Geog. Course	178 (70.4)	75 (29.6)	67.152	<0.01	Differences exist in the responses of college geography groups to Q6
	1-2 Geog. Courses	603 (74.3)	209 (25.7)			
	3-5 Geog. Courses	135 (83.9)	26 (16.1)			
	>5 Geog. Courses	243 (96.0)	10 (4.0)			
Urban/ Suburban/ Rural	Urban	332 (69.9)	143 (30.1)	32.593	<0.01	Differences exist in the responses of urban, sub-urban, rural groups to Q6
	Suburban	513 (80.7)	123 (19.3)			
	Rural	314 (85.3)	54 (14.7)			

Table 4.48. Internal Comparisons for Association of Q6 (Geospatial Shapes) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	**Categories**	**Standardized Residuals**		**Significant Contributors to the Association and Internal Comparisons**
		Correct	**Incorrect**	
Sex	Female	-0.8	1.6	None
	Male	0.9	-1.7	
Age	18-20	-1.3	**2.6**	More 18-20-year-old students than expected answered Q6 incorrectly, thus underperforming the other age groups. Fewer >24 year old students than expected answered Q6 incorrectly, thus outperforming the other age groups.
	21-24	0.7	-1.3	
	>24	1.4	**-2.6**	
Ethnicity	White	**2.5**	**-4.8**	More white students than expected answered Q6 correctly, and fewer white students than expected answered Q6 incorrectly. Thus, whites outperformed the other ethnic groups. More Hispanic, black, and Asian students than expected answered Q6 incorrectly. Thus, Hispanics, blacks, and Asians underperformed the other ethnic groups. Fewer black students than expected answered Q6 correctly, thus underperforming the other groups.
	Hispanic	-1.8	**3.4**	
	Black	**-4.0**	**7.5**	
	Asian	-1.7	**3.1**	
Academic Classification	Freshman	-1.5	**2.8**	More freshmen than expected answered Q6 incorrectly, thus underperforming the other groups. Fewer seniors than expected answered Q6 incorrectly, thus outperforming the other groups.
	Sophomore	-0.6	1.1	
	Junior	-0.2	0.5	
	Senior	1.9	**-3.6**	
College Geography Courses	No Geog. Course	-1.4	**2.7**	More students with no and 1-2 college geography courses than expected answered Q6 incorrectly, thus underperforming the other groups. More students with >5 college geography courses than expected answered Q6 correctly, and fewer students with >5 college courses experience than expected answered Q6 incorrectly, thus outperforming the other groups.
	1-2 Geog. Courses	-1.3	**2.5**	
	3-5 Geog. Courses	0.8	-1.5	
	>5 Geog. Courses	**3.2**	**-6.0**	
Urban/ Suburban/ Rural	Urban	**-2.1**	**4.0**	Fewer urban students than expected answered Q6 correctly, and more urban students than expected answered Q6 incorrectly, thus underperforming the other groups. Fewer rural students than expected answered Q6 incorrectly, thus outperforming the other groups.
	Suburban	0.7	-1.2	
	Rural	1.5	**-2.9**	

Q7, geospatial shapes, was related to differences in age, ethnicity, academic classification, and college geography (Table 4.49).

Table 4.49. Association of Q7 (Geospatial Shapes) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	Categories	Number of Students Responses (%)		Chi-Square	p Value	Result
		Correct	Incorrect			
Sex	Female	422 (52.5)	382 (47.5)	1.259	0.262	No difference exists in the responses of females and males to Q7
	Male	374 (55.4)	301 (44.6)			
Age	18-20	352 (46.9)	399 (53.1)	30.375	<0.01	Differences exist in the responses of age groups to Q7
	21-24	283 (59.8)	190 (40.2)			
	>24	161 (63.1)	94 (36.9)			
Ethnicity	White	631 (57.2)	472 (42.8)	23.815	<0.01	Differences exist in the responses of ethnic groups to Q7
	Hispanic	63 (46.3)	73 (53.7)			
	Black	47 (37.0)	80 (63.0)			
	Asian	55 (48.7)	58 (51.3)			
Academic Classification	Freshman	120 (44.8)	148 (55.2)	39.828	<0.01	Differences exist in the responses of academic classification groups to Q7
	Sophomore	173 (47.3)	193 (52.7)			
	Junior	212 (52.9)	189 (47.1)			
	Senior	291 (65.5)	153 (34.5)			
College Geography Courses	No Geog. Course	118 (46.6)	135 (53.4)	37.373	<0.01	Differences exist in the responses of college geography groups to Q7
	1-2 Geog. Courses	404 (49.8)	408 (50.2)			
	3-5 Geog. Courses	101 (62.7)	60 (37.3)			
	>5 Geog. Courses	173 (68.4)	80 (31.6)			
Urban/ Suburban/ Rural	Urban	239 (50.3)	236 (49.7)	3.917	0.141	No differences exist in the responses of urban, suburban, rural groups to Q7
	Suburban	358 (56.3)	278 (43.7)			
	Rural	199 (54.1)	169 (45.9)			

Younger (18-20 years old), black, and freshman students underperformed more than expected in the geospatial shapes domain (Table 4.50), implying these groups should undergo classroom instruction and practice in comprehending spatial shapes. Older (above 24 years old) and senior students, and students who had taken more than five college geography classes performed better than expected.

Table 4.50. Internal Comparisons for Association of Q7 (Geospatial Shapes) with Age, Ethnicity, Academic Classification, and College Geography.

Variable	Categories	Standardized Residuals		Significant Contributors to the Association
		Correct	Incorrect	
Age	18-20	**-2.6**	**2.8**	Fewer 18-20-year-old students than expected answered Q7 correctly, and more 18-20-year-old students than expected answered Q7 incorrectly, thus underperforming the other age groups. More >24 year old students than expected answered Q7 correctly, and fewer >24-year-old students than expected answered Q7 incorrectly, thus outperforming the other age groups.
	21-24	1.8	-1.9	
	>24	**2.0**	**-2.2**	
Ethnicity	White	1.5	-1.7	Fewer black students than expected answered Q7 correctly, and more black students than expected answered Q7 incorrectly, thus underperforming the other ethnic groups.
	Hispanic	-1.2	1.3	
	Black	**-2.6**	**2.8**	
	Asian	-0.7	0.8	
Academic Classification	Freshman	**-2.0**	**2.2**	Fewer freshmen than expected answered Q7 correctly, and more freshmen than expected answered Q7 incorrectly, thus underperforming the other groups. More seniors than expected answered Q7 correctly, and fewer seniors than expected answered Q7 incorrectly, thus outperforming the other groups.
	Sophomore	-1.7	1.8	
	Junior	-0.3	0.3	
	Senior	**3.4**	**-3.6**	
College Geography Courses	No Geog. Course	-1.6	1.7	More students with >5 college geography courses than expected answered Q7 correctly, and fewer students with >5 college geography courses than expected answered Q7 incorrectly, thus outperforming the other groups.
	1-2 Geog. Courses	-1.6	1.7	
	3-5 Geog. Courses	1.5	-1.7	
	>5 Geog. Courses	**3.2**	**-3.4**	

Q8, geospatial shapes, was related to differences in sex, age, ethnicity, academic classification, college geography, and urban/suburban/rural locations (Table 4.51). Younger (18-20 years old), black, and rural students, and students who had taken one to two college geography courses underperformed more than expected (Table 4.52), perhaps needing additional classroom instruction and practice in comprehending geospatial shapes. White, 21-24-year-old, and senior students, and students who had taken 3-5 or more than five college geography courses performed better than expected.

Table 4.51. Association of Q8 (Geospatial Shapes) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	**Categories**	**Number of Student Responses (%)**		**Chi-Square**	**p Value**	**Result**
		Correct	**Incorrect**			
Sex	Female	646 (80.3)	158 (19.7)	5.961	0.015	Difference exists in the responses of females and males to Q8
	Male	575 (85.2)	100 (14.8)			
Age	18-20	591 (78.7)	160 (21.3)	16.091	<0.01	Differences exist in the responses of age groups to Q8
	21-24	412 (87.1)	61 (12.9)			
	>24	218 (85.5)	37 (14.5)			
Ethnicity	White	949 (86.0)	154 (14.0)	65.883	<0.01	Differences exist in the responses of ethnic groups to Q8
	Hispanic	103 (75.7)	33 (24.3)			
	Black	74 (58.3)	53 (41.7)			
	Asian	95 (84.1)	18 (15.9)			
Academic Classification	Freshman	209 (78.0)	59 (22.0)	24.000	<0.01	Differences exist in the responses of academic classification groups to Q8
	Sophomore	287 (78.4)	79 (21.6)			
	Junior	327 (81.5)	74 (18.5)			
	Senior	398 (89.6)	46 (10.4)			
College Geography Courses	No Geog. Course	205 (81.0)	48 (19.0)	54.929	<0.01	Differences exist in the responses of college geography groups to Q8
	1-2 Geog. Courses	628 (77.3)	184 (22.7)			
	3-5 Geog. Courses	144 (89.4)	17 (10.6)			
	>5 Geog. Courses	244 (96.4)	9 (3.6)			
Urban/ Suburban/ Rural	Urban	373 (78.5)	102 (21.5)	7.909	0.019	Differences exist in the responses of urban, sub-urban, rural groups to Q8
	Suburban	538 (84.6)	98 (15.4)			
	Rural	310 (84.2)	58 (15.8)			

Table 4.52. Internal Comparisons for Association of Q8 (Geospatial Shapes) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	Categories	Standardized Residuals		Significant Contributors to the Association and Internal Comparisons
		Correct	Incorrect	
Sex	Female	-0.7	1.5	None
	Male	0.8	-1.6	
Age	18-20	-1.2	**2.5**	More 18-20-year-old students than expected answered Q8 incorrectly, thus underperforming the other age groups. Fewer 21-24-year-old students than expected answered Q8 incorrectly, thus outperforming the other age groups.
	21-24	1.1	**-2.4**	
	>24	0.5	-1.1	
Ethnicity	White	1.3	**-2.8**	Fewer white students than expected answered Q8 incorrectly, thus outperforming the other ethnic groups. Fewer black students than expected answered Q8 correctly, and more black students than expected answered Q8 incorrectly, thus underperforming the other ethnic groups.
	Hispanic	-0.9	1.9	
	Black	**-3.0**	**6.6**	
	Asian	0.2	-0.4	
Academic Classification	Freshman	-0.8	1.8	Fewer seniors than expected answered Q8 incorrectly, thus outperforming the other groups.
	Sophomore	-0.9	1.9	
	Junior	-0.2	0.5	
	Senior	1.6	**-3.6**	
College Geography Courses	No Geog. Course	-0.3	0.6	More students with 1-2 college geography courses than expected answered Q8 incorrectly, thus underperforming the other groups. Fewer students with 3-5 college geography courses than expected answered Q8 incorrectly, thus outperforming the other groups. More students with >5 college geography courses than expected answered Q8 correctly, and fewer students with >5 college courses than expected answered Q8 incorrectly, thus outperforming the other groups.
	1-2 Geog. Courses	-1.6	**3.6**	
	3-5 Geog. Courses	1.0	**-2.1**	
	>5 Geog. Courses	**2.4**	**-5.3**	
Urban/ Suburban/ Rural	Urban	-1.0	**2.1**	More urban students than expected answered Q8 incorrectly, thus underperforming the other groups.
	Suburban	0.6	-1.2	
	Rural	0.4	-0.8	

Q9, geospatial shapes, was not associated with differences in sex, age, ethnicity, academic classification, college geography, and urban/suburban/rural locations (Table 4.53).

Table 4.53. Association of Q9 (Geospatial Shapes) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	Categories	Number of Students Responses (%)		Chi-Square	p Value	Result
		Correct	Incorrect			
Sex	Female	283 (35.2)	521 (64.8)	1.242	0.265	No difference exists in the responses of females and males to Q9
	Male	219 (32.4)	456 (67.6)			
Age	18-20	261 (34.8)	490 (65.2)	1.238	0.538	No differences exist in the responses of age groups to Q9
	21-24	162 (34.2)	311 (65.8)			
	>24	79 (31.0)	176 (69.0)			
Ethnicity	White	363 (32.9)	740 (67.1)	2.458	0.483	No differences exist in the responses of ethnic groups to Q9
	Hispanic	53 (39.0)	83 (61.0)			
	Black	46 (36.2)	81 (63.8)			
	Asian	40 (35.4)	73 (64.6)			
Academic Classification	Freshman	107 (39.9)	161 (60.1)	5.468	0.141	No differences exist in the responses of academic classification groups to Q9
	Sophomore	116 (31.7)	250 (68.3)			
	Junior	131 (32.7)	270 (67.3)			
	Senior	148 (33.3)	296 (66.7)			
College Geography Courses	No Geog. Course	91 (36.0)	162 (64.0)	0.745	0.862	No differences exist in the responses of college geography groups to Q9
	1-2 Geog. Courses	274 (33.7)	538 (66.3)			
	3-5 Geog. Courses	55 (34.2)	106 (65.8)			
	>5 Geog. Courses	82 (32.4)	171 (67.6)			
Urban/ Suburban/ Rural	Urban	158 (33.3)	317 (66.7)	1.342	0.511	No differences exist in the responses of urban, suburban, rural groups to Q9
	Suburban	210 (33.0)	426 (67.0)			
	Rural	134 (36.4)	234 (63.6)			

Overall, the geospatial shapes domain was represented by questions 6, 7, 8, and 9. The interpretation of the results of all the four questions shows the geospatial shapes domain was associated with sex, age, ethnicity, academic classification, college geography, and urban/suburban/rural locations. Male, older (21-24 and above 24 years old), white, senior, and rural students, and students who had taken 3-5 or more than five college geography courses performed better than expected. These groups of students, therefore, better understand geospatial shapes. Female, younger (18-20 years old), Hispanic, black, Asian, freshman, and urban students, and students who had taken no or only 1-2 college geography courses underperformed, thus implying the need for intervention to improve their geospatial shapes skills.

Q10, geospatial overlay, was related to differences in sex, age, ethnicity, academic classification, and college geography (Table 4.54). Female, younger (18-20 years old), black, and sophomore students, and students who had taken only 1-2 college geography courses underperformed than expected (Table 4.55), indicating the students should have more instruction and practice in comprehending geospatial overlay. Male, white, older (above 24 years old), and senior students, and students who had taken more than five college geography courses performed better than expected.

Table 4.54. Association of Q10 (Geospatial Overlay) with Sex, Age, Ethnicity, Academic Classification, College Geography, and Urban/Suburban/Rural Patterns.

Variable	Categories	Number of Student Responses (%)		Chi-Square	p Value	Result
		Correct	Incorrect			
Sex	Female	462 (57.5)	342 (42.5)	26.332	<0.01	Difference exists in the responses of females and males to Q10
	Male	475 (70.4)	200 (29.6)			
Age	18-20	433 (57.7)	318 (42.3)	23.191	<0.01	Differences exist in the responses of age groups to Q10
	21-24	319 (67.4)	154 (32.6)			
	>24	185 (72.5)	70 (27.5)			
Ethnicity	White	740 (67.1)	363 (32.9)	37.922	<0.01	Differences exist in the responses of ethnic groups to Q10
	Hispanic	83 (61.0)	53 (39.0)			
	Black	52 (40.9)	75 (59.1)			
	Asian	62 (54.9)	51 (45.1)			
Academic Classification	Freshman	156 (58.2)	112 (41.8)	33.113	<0.01	Differences exist in the responses of academic classification groups to Q10
	Sophomore	205 (56.0)	161 (44.0)			
	Junior	248 (61.8)	153 (38.2)			
	Senior	328 (73.9)	116 (26.1)			
College Geography Courses	No Geog. Course	145 (57.3)	108 (42.7)	70.070	<0.01	Differences exist in the responses of college geography groups to Q10
	1-2 Geog. Courses	467 (57.5)	345 (42.5)			
	3-5 Geog. Courses	109 (67.7)	52 (32.3)			
	>5 Geog. Courses	216 (85.4)	37 (14.6)			
Urban/ Suburban/ Rural	Urban	285 (60.0)	190 (40.0)	4.290	0.117	No differences exist in the responses of urban, suburban, rural groups to Q10
	Suburban	420 (66.0)	216 (34.0)			
	Rural	232 (63.0)	136 (37.0)			

Table 4.55. Internal Comparisons for Association of Q10 (Geospatial Overlay) with Sex, Age, Ethnicity, Academic Classification, and College Geography.

<table>
<tr><th rowspan="2">Variable</th><th rowspan="2">Categories</th><th colspan="2">Standardized Residuals</th><th rowspan="2">Significant Contributors to the Association and Internal Comparisons</th></tr>
<tr><th>Correct</th><th>Incorrect</th></tr>
<tr><td rowspan="2">Sex</td><td>Female</td><td>-2.1</td><td>2.8</td><td rowspan="2">Fewer female students than expected answered Q10 correctly, and more female students than expected answered Q10 incorrectly. More male students than expected answered Q10 correctly, and fewer male students than expected answered Q10 incorrectly. Thus, males outperformed females.</td></tr>
<tr><td>Male</td><td>2.3</td><td>-3.0</td></tr>
<tr><td rowspan="3">Age</td><td>18-20</td><td>-2.0</td><td>2.6</td><td rowspan="3">Fewer 18-20-year-old students than expected answered Q10 correctly, and more 18-20-year-old students than expected answered Q10 incorrectly, thus underperforming the other age groups. Fewer >24-year-old students than expected answered Q10 incorrectly, thus outperforming the other age groups.</td></tr>
<tr><td>21-24</td><td>1.1</td><td>-1.5</td></tr>
<tr><td>>24</td><td>1.8</td><td>-2.4</td></tr>
<tr><td rowspan="4">Ethnicity</td><td>White</td><td>1.6</td><td>-2.0</td><td rowspan="4">Fewer white students than expected answered Q10 incorrectly, thus outperforming the other ethnic groups. Fewer black students than expected answered Q10 correctly, and more black students than expected answered Q10 incorrectly, thus underperforming the other ethnic groups.</td></tr>
<tr><td>Hispanic</td><td>-0.3</td><td>0.4</td></tr>
<tr><td>Black</td><td>-3.2</td><td>4.2</td></tr>
<tr><td>Asian</td><td>-1.1</td><td>1.5</td></tr>
<tr><td rowspan="4">Academic Classification</td><td>Freshman</td><td>-1.1</td><td>1.4</td><td rowspan="4">More sophomores than expected answered Q10 incorrectly, thus underperforming the other age groups. More seniors than expected answered Q10 correctly, and fewer seniors than expected answered Q10 incorrectly, thus outperforming the other groups.</td></tr>
<tr><td>Sophomore</td><td>-1.8</td><td>2.3</td></tr>
<tr><td>Junior</td><td>-0.4</td><td>0.5</td></tr>
<tr><td>Senior</td><td>2.8</td><td>-3.7</td></tr>
<tr><td rowspan="4">College Geography Courses</td><td>No Geog. Course</td><td>-1.2</td><td>1.6</td><td rowspan="4">Fewer students with 1-2 college geography courses than expected answered Q10 correctly, and more students with 1-2 college geography colleges than expected answered Q10 incorrectly, thus underperforming the other groups. More students with >5 college geography colleges than expected answered Q10 correctly, and fewer students with >5 college geography colleges than expected answered Q10 incorrectly, thus outperforming the other groups.</td></tr>
<tr><td>1-2 Geog. Courses</td><td>-2.1</td><td>2.7</td></tr>
<tr><td>3-5 Geog. Courses</td><td>0.7</td><td>-0.9</td></tr>
<tr><td>>5 Geog. Courses</td><td>4.4</td><td>-5.8</td></tr>
</table>

Table 4.56 summarizes the statistically significant associations of geospatial thinking domains with six independent variables and displays outperforming and underperforming groups of students in different domains. The main groups of students that seem to need additional classroom instruction and training in various geospatial thinking domains include females, younger students (18-20 years old), Hispanics, blacks, freshmen, urban students, and students who had taken no or only 1-2 college geography courses.

Table 4.56. Summary of Relationship of Geospatial Thinking Domains with Significant Variables.

GTS Question (Geospatial Thinking Domain)	Significant Variables	Outperforming Groups	Underperforming Groups
Q1 (Geospatial Pattern and Transition)	Ethnicity	White	Hispanic and Black
	Academic Classification	Senior	
	College Geography	>5 College Geog. Courses	No College Geog. Course
	Urban/Suburban/ Rural Patterns		Urban
Q2 (Direction and Orientation)	Ethnicity		Black
	Urban/Suburban/ Rural Patterns	Rural	Urban
Q3 (Geospatial Profile and Transition)	Sex	Male	Female
	Age	>24	18-20
	Ethnicity	White	Hispanic and Black
	Academic Classification	Senior	Freshman
	College Geography	>5 College Geog. Courses	No and 1-2 College Geog. Courses
	Urban/Suburban/ Rural Patterns		Urban
Q4 (Geospatial Association and Transition)	Age		>24
Q5 (Geospatial Association)	Ethnicity		Hispanic and Black
	Academic Classification	Senior	
	College Geography	>5 College Geog. Courses	No College Geog. Course
	Urban/Suburban/ Rural Patterns	Rural	Urban

Table 4.56. Continued.

GTS Question (Geospatial Thinking Domain)	Significant Variables	Outperforming Groups	Underperforming Groups
Q6 (Geospatial Shapes)	Age	>24	18-20
	Ethnicity	White	Hispanic, Black, and Asian
	Academic Classification	Senior	Freshman
	College Geography	>5 College Geog. Courses	No and 1-2 College Geog. Courses
	Urban/Suburban/ Rural Patterns	Rural	Urban
Q7 (Geospatial Shapes)	Age	>24	18-20
	Ethnicity		Black
	Academic Classification	Senior	Freshman
	College Geography	>5 College Geog. Courses	
Q8 (Geospatial Shapes)	Age	21-24	18-20
	Ethnicity	White	Black
	Academic Classification	Senior	
	College Geography	>5 and 3-5 College Geog. Courses	1-2 College Geog. Courses
	Urban/Suburban/ Rural Patterns		Urban
Q10 (Geospatial Overlay)	Sex	Male	Female
	Age	>24	18-20
	Ethnicity	White	Black
	Academic Classification	Senior	Sophomore
	College Geography	>5 College Geog. Courses	1-2 College Geog. Courses

Visualization of Responses for Individual GTS Questions

Visually corroborating the tabular chi-square results are six two-dimensional diagrams displaying the results of statistically significant variables. Figure 4.3 shows males performed better than females on most geospatial thinking questions. Males performed significantly better than females in such geospatial thinking domains as geospatial profiles and transition, geospatial association, geospatial shapes, and geospatial overlay.

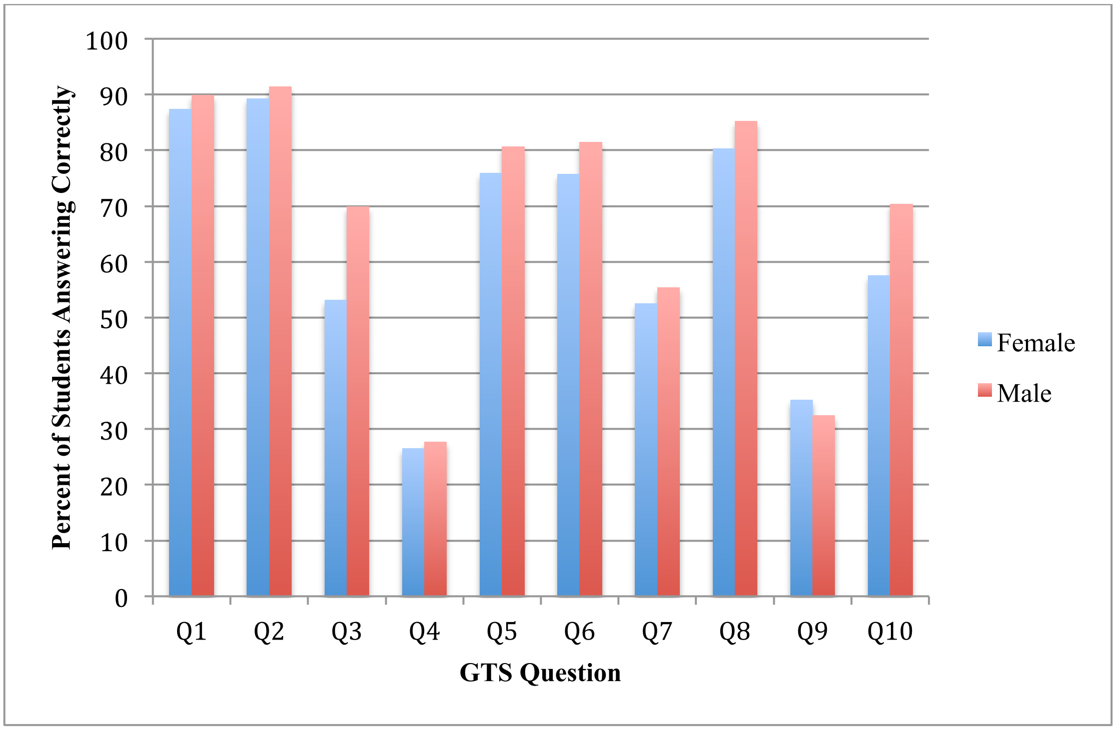


Figure 4.3. Student performance on GTS questions based on sex.

Figure 4.4 underscores that older students (above 24 years old) outperformed younger students (18-20 years old) on most geospatial thinking questions. Older students demonstrated a superior understanding of geospatial profile and transition, geospatial shapes, and geospatial overlay, while younger students underperformed in these domains.

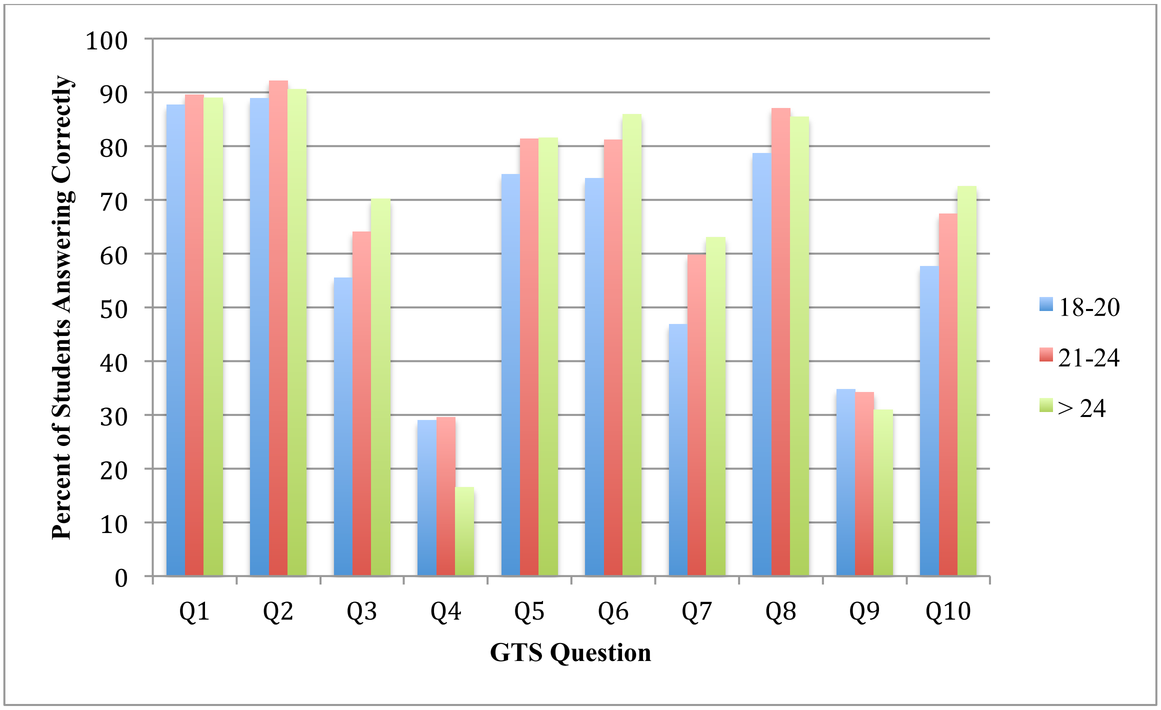


Figure 4.4. Student performance on GTS questions based on age.

Figure 4.5 highlights that white students performed better than Hispanic, black, and Asian students on most geospatial thinking questions. White students outperformed at understanding geospatial pattern and transition, geospatial profile and transition, geospatial shapes, and geospatial overlay. Hispanic and black students underperformed in such geospatial thinking domains as geospatial pattern and transition, geospatial profile and transition, geospatial association, and geospatial shapes. Black students also underperformed in direction and orientation, and geospatial overlay.

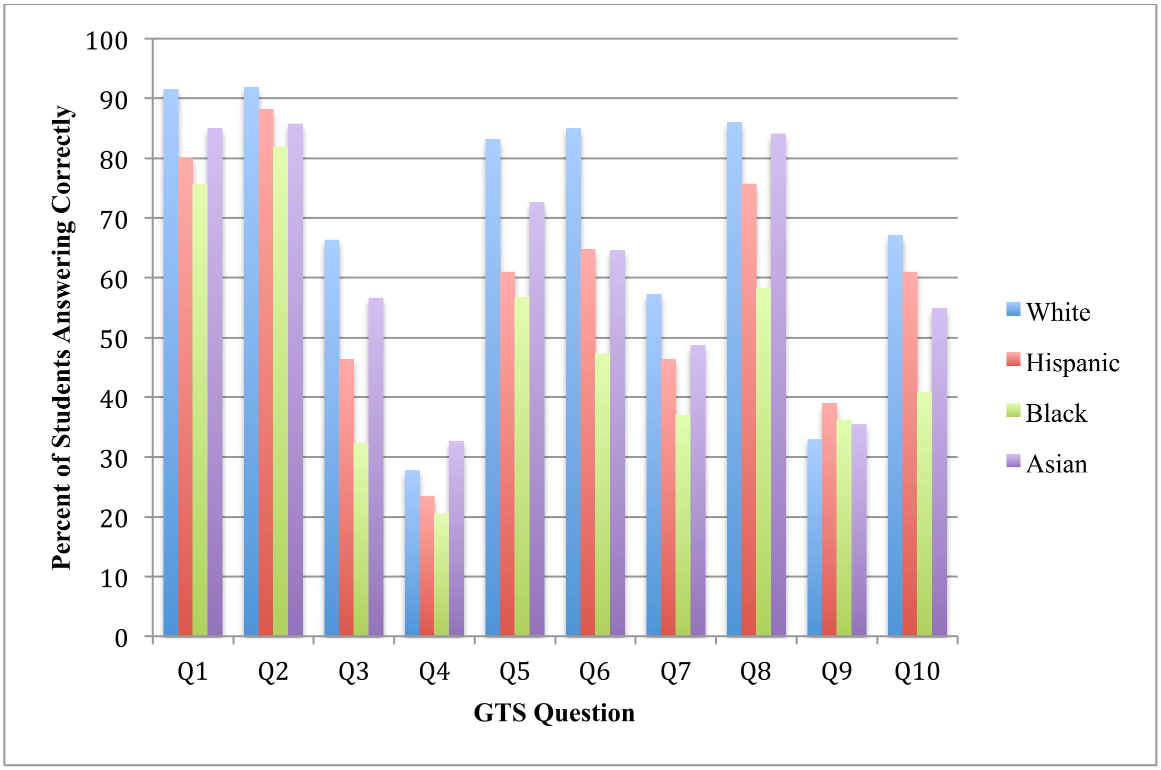


Figure 4.5. Student performance on GTS questions based on ethnicity.

Figure 4.6 accentuates that senior students performed better than freshman students on most geospatial thinking questions. Senior students performed better at understanding geospatial pattern and transition, geospatial profile and transition, geospatial association, geospatial shapes, and geospatial overlay. Freshman students underperformed in geospatial profile and transition, and geospatial shapes. Sophomore students underperformed in geospatial overlay ability.

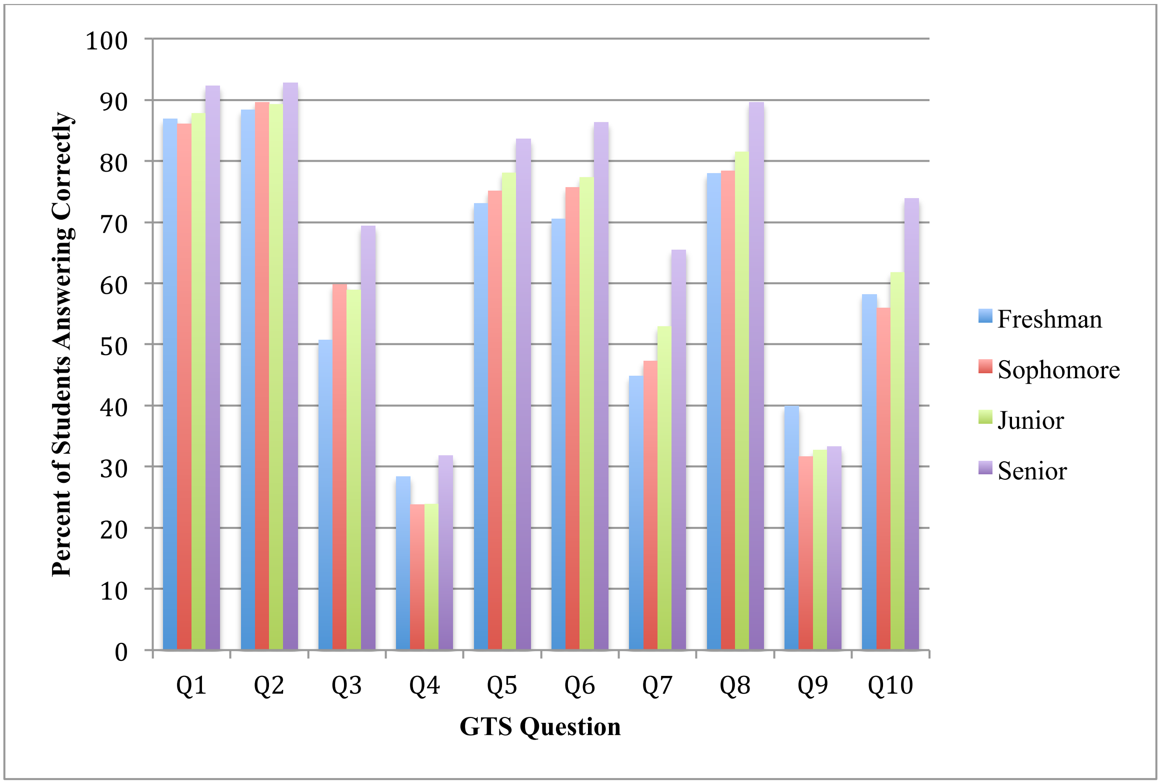


Figure 4.6. Student performance on GTS questions based on academic classification.

Figure 4.7 underlines that students who had taken more than five college geography courses performed better than students who had not taken any geography courses and those who had taken only one or two courses on most geospatial thinking questions. Students who had taken more than five college geography courses demonstrated geospatial thinking proficiency in geospatial pattern and transition, geospatial profile and transition, geospatial association, geospatial shapes, and geospatial overlay. Students who had taken three-five college geography courses demonstrated geospatial thinking competence in geospatial shapes. Students who had taken one-two college geography courses underperformed in geospatial profile and transition, geospatial shapes, and geospatial overlay. Students who had never taken a college geography course underperformed in geospatial pattern and transition, geospatial profile and transition, geospatial association, and geospatial shapes.

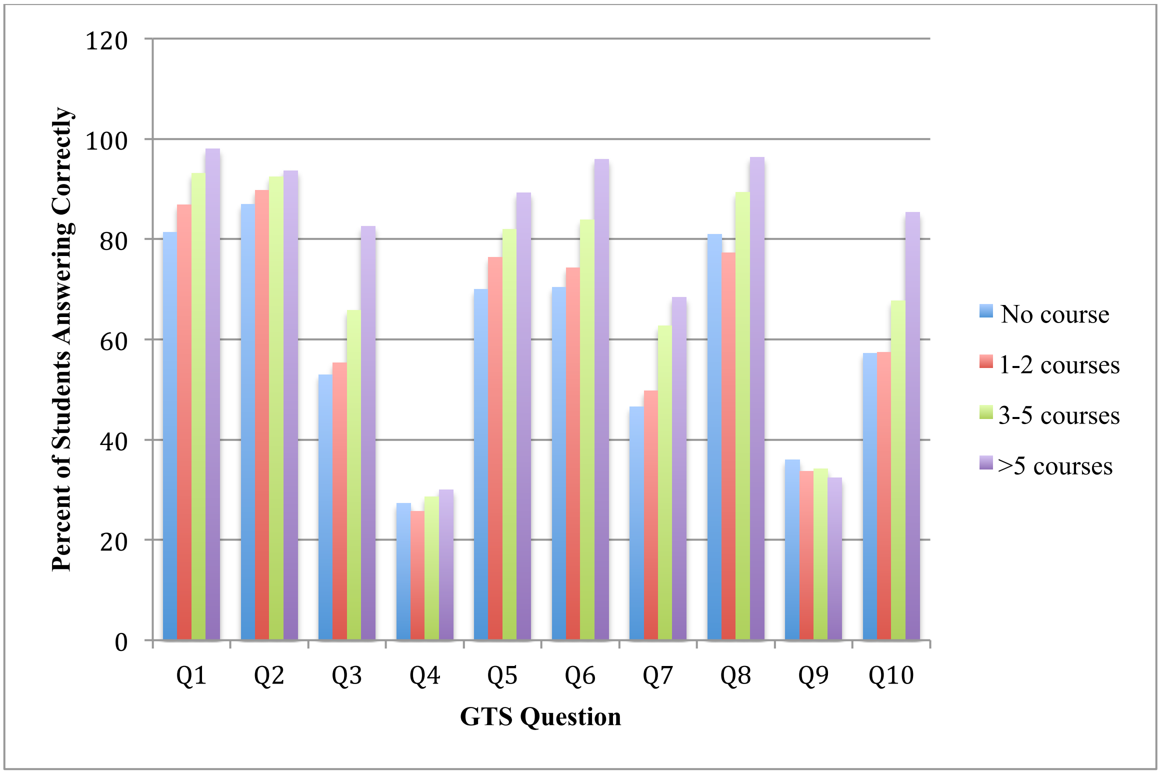


Figure 4.7. Student performance on GTS questions based on number of college geography courses taken.

Figure 4.8 emphasizes that rural students performed better than urban students on most geospatial thinking questions. Rural students performed better at direction and orientation, geospatial association, and geospatial shapes. Urban students underperformed in such geospatial thinking domains as geospatial pattern and transition, direction and orientation, geospatial profile and transition, geospatial association, and geospatial shapes.

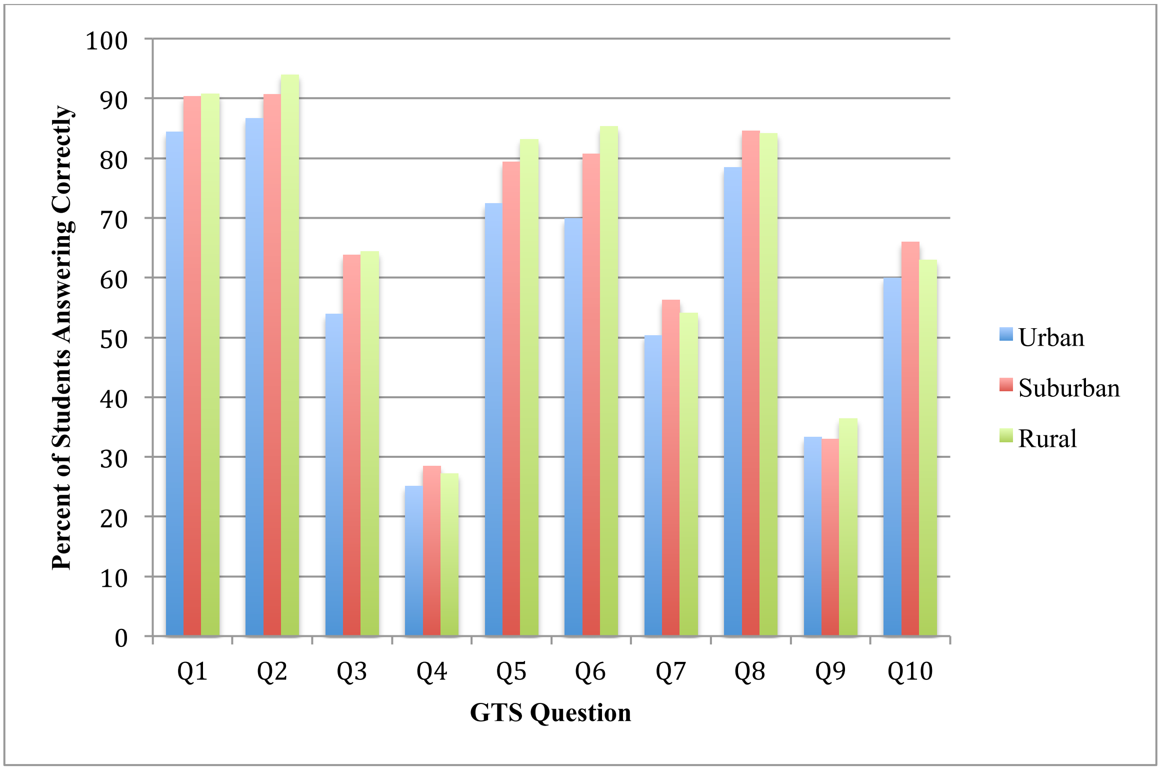


Figure 4.8. Student performance on GTS questions based on urban/suburban/ rural locations.

Quantitative Study Limitations and Discussion of Error

Limitations of time, resources, and method are inherent in any research endeavor. I used Geospatial Thinking Survey (GTS), based on the STAT, as a geospatial thinking test instrument. Both the STAT and GTS have errors of omission with respect to geospatial thinking domains, such as overlooking fundamental geospatial thinking skills of scale, frames of reference, geospatial diffusion, geospatial hierarchy, and geospatial analog. My process for selecting the sample of undergraduate universities was both convenient and stratified. Instructors' approval provided an impetus for encouragement to students in selected universities to participate in the online GTS. This technique had no control over which students specifically took the GTS, the amount of time students took to complete the GTS, or the fair completion of GTS by the students without help from other sources. Although I employed standard statistical practices drawn from the literature, e.g. setting alpha = 0.05, errors are intrinsic to any statistical technique.

Summary of Major Quantitative Findings

The findings of the quantitative analysis of student performance on the GTS supports the theoretical position that geospatial thinking domains are not correlated but are interconnected instead. Students proficient at one geospatial thinking component may not comprehend another geospatial thinking domain. To solve a geospatial task, students may employ multiple geospatial thinking skills. The results of the PCA confirmed that classifying various geospatial thinking skills into well-defined domains is as difficult as measuring geospatial thinking ability of students through a test instrument with limited questions.

Undergraduate students' score on the GTS ranged from 0 to 10, and the scores were normally distributed. The mean score of all the students was 6.57, while 8 was the modal score. Two thirds of students in the sample displayed medium geospatial thinking levels as assessed by the Geospatial Thinking Index (GTI). About 16 percent of students possessed low geospatial thinking levels, and another 16 percent performed at the high end of the GTI scale.

Demographic, academic, and geographic locational variables affect student geospatial thinking. The findings of the ANOVA confirmed that geospatial thinking of undergraduate students vary based on hypothesized independent variables: sex, age, ethnicity, socioeconomic status (parents' annual income and parents' education), academic major, academic classification, college geography academic experience, and geographic location (urban/suburban/rural areas, and census divisions). The most important variables that influenced geospatial thinking of students were ethnicity, college geography courses, academic classification, urban/suburban/rural locations, age, and academic major.

Mirroring the ANOVA findings, multiple regression and Cubist model results corroborated the similar important predictive variables of the academic component, including college geography courses, academic classification, and age; and of the socioeconomic component with ethnicity being highly significant. The multiple regression and Cubist models were useful in predicting student geospatial thinking based on the foregoing academic and demographic variables. Groups of students with higher geospatial thinking performance levels than others were whites, students who studied more than five college geography courses, seniors, rural students, students more than 24-years old, and geography majors.

The majority of the students found such geospatial thinking domains as direction and orientation, geospatial pattern and transition, geospatial overlay, and geospatial profile and transition to be less difficult than geospatial association and transition. Geospatial shapes were confounding as students found them both easy and difficult in different questions. Students did not necessarily find higher-order geospatial concepts and reasoning skills to be difficult or lower-order concepts and reasoning skills to be easier. The performance of students therefore varies within distinct geospatial thinking domains.

The chi-square analysis investigated the relationships between different variables and distinct geospatial thinking domains. Strong evidence exists of associations between:

1. geospatial pattern and transition ability and ethnicity, college geography courses, urban/suburban/rural locations, and academic classification.
2. direction and orientation skill and ethnicity and urban/suburban/rural locations.
3. geospatial profile and transition domain and ethnicity, college geography courses, sex, academic classification, age, and urban/suburban/rural locations.
4. geospatial association and transition ability and age and academic classification.
5. geospatial association skill and ethnicity, college geography courses, urban/suburban/rural locations, academic classification, age, and sex.
6. geospatial shapes domain and ethnicity, college geography courses, urban/suburban/rural locations, academic classification, age, and sex.
7. geospatial overlay ability and college geography courses, ethnicity, academic classification, sex, age, and urban/suburban/rural locations.

Groups of students that significantly performed better than expected on various geospatial thinking domains included whites, students who studied more than five college geography courses, geography majors, seniors, above 24-year old students, rural students, and males. Groups of students who underperformed more than expected were Hispanics, blacks, students who studied two or fewer college geography courses, freshmen, 18-20 year old students, urban students, and females.

CHAPTER V

QUALITATIVE ANALYSES AND FINDINGS

Qualitative Data

Based on convenience and stratified sampling, I interviewed 27 geography instructors, three each from universities in nine census divisions. Faculty participated from three geography department levels—doctoral, master's, and undergraduate. Figure 5.1 displays the locations of the universities of participating instructors.

The semi-structured telephone interviews with geography faculty attempted to gauge the geospatial concepts that the students find difficult to understand based on the instructor perception and experience in the classroom. The faculty interviews (Appendix B) specifically had two questions about instructor sex and ethnicity, two opening contextual questions about instructor experience, and four open-ended questions about geospatial thinking of undergraduate students and classroom activities (Table 5.1). All the instructors had a doctoral degree in geography, except one who had a doctoral degree in urban and public affairs. The 37 percent women in the faculty sample approximated the percentage of women in the *AAG Guide* (2014), and the percentages of faculty from the four ethnic groups—white (77.8%), Hispanic (11.1%), black (3.7%), and Asian (7.4%)—roughly reflected the percentages in the *AAG Guide* (2014), with Hispanics somewhat overrepresented at the expense of whites.

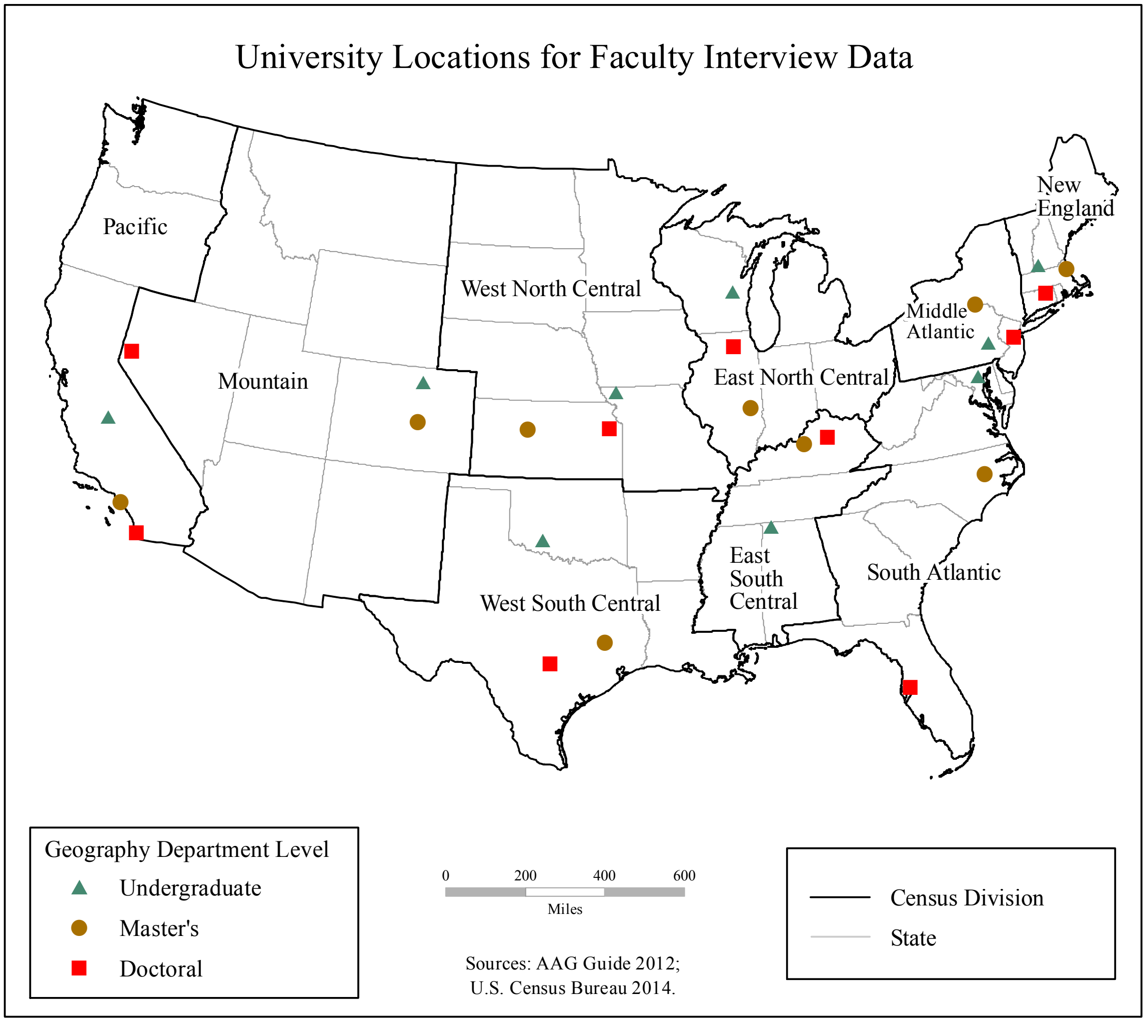


Figure 5.1. Location of sample universities in the U.S. census divisions for faculty interview data (n = 27).

Table 5.1. Background of Faculty Interviewed (percentages to total).

Ethnicity	**Sex**	**Number of Years Taught**				**Subtotal**	**Total**
		0-10	11-20	21-30	>30		
White	Female	2 (7.4)	3 (11.1)	1 (3.7)	2 (7.4)	8 (29.6)	**21 (77.8)**
	Male	4 (14.8)	4 (14.8)	1 (3.7)	4 (14.8)	13 (48.1)	
Hispanic	Female	-	-	-	-	0 (0.0)	**3 (11.1)**
	Male	2 (7.4)	1 (3.7)	-	-	3 (11.1)	
Black	Female	-	-	1 (3.7)	-	1 (3.7)	**1 (3.7)**
	Male	-	-	-	-	0 (0.0)	
Asian	Female	1 (3.7)	-	-	-	1 (3.7)	**2 (7.4)**
	Male	1 (3.7)	-	-	-	1 (3.7)	
Subtotal	Female	3 (11.1)	3 (11.1)	2 (7.4)	2 (7.4)	**10 (37.0)**	
	Male	7 (25.9)	5 (18.5)	1 (3.7)	4 (14.8)	**17 (63.0)**	
Total		**10 (37.0)**	**8 (29.6)**	**3 (11.1)**	**6 (22.3)**		**27 (100)**

Qualitative Analyses

I utilized content analysis to analyze instructors' understanding about geospatial concepts that students find difficult. Content analysis is a qualitative data reduction and sense-making effort that takes a volume of qualitative material and attempts to identify core consistencies and meanings (Patton 2002). I employed conceptual analysis, a form of content analysis, that focuses on looking for the occurrence of selected terms within a text or texts. Conceptual analysis results assisted me in identifying terms/concepts for further examination within the framework of instructors' thoughts and ideas.

Students must integrate three key components—spatial concepts, spatial representations, and reasoning skills—to better understand spatial thinking (NRC 2006; Jo and Bednarz 2009):

Geospatial Concepts

In the interviews, I asked instructors to list difficult geospatial concepts for students to understand and on which students usually score low on tests. In juxtaposition, instructors also listed geospatial concepts about which students generally score high on tests. About 55 percent of instructors responded that understanding of regions, locations, place, area, and site/situation are difficult for students. Students do not easily understand how the concept of place is unique to each individual, and how central location does not necessarily mean the physical center. Conversely, 26 percent instructors reported that comprehending regions, places, and locations is simple for students. About 30 percent of instructors pointed out that understanding maps and doing map exercises is difficult for undergraduate students. On the other hand, 22 percent instructors thought students score high on map activities, including GIS.

About 22 percent of instructors reported students find scale and projections difficult. Some instructors (18.5%) also maintained that students struggle with comprehending geospatial relationships, connections, and interactions, e.g. globalization. Understanding cultural interactions in geospatial terms is also taxing for students, as emphasized by 15 percent instructors. But another 15 percent of instructors reported that students score high on cultural geospatial understanding. Few instructors (11 percent) also commented that students do not easily grasp direction and the concept of time zones.

Tools of Representation

Instructors should use tools of representation (e.g. maps, videos, graphs, photos, and diagrams) to teach geospatial concepts. I asked instructors what strategies they use in their classrooms to teach fundamental geospatial concepts. Surprisingly, only 33 percent of instructors interviewed reported their students undertake map exercises, including GIS and animated map activities. Only 30 percent of instructors responded that they show short videos to emphasize geospatial concepts, while only 15 percent said they use photographs, images, diagrams, or graphs. Many instructors, therefore, do not exploit representational tools in teaching geospatial thinking to students.

Processes of Reasoning

About 30 percent instructors felt that interpretation and application of geospatial concepts to real world, involving higher-order spatial reasoning skills, are challenging for students, and 26 percent instructors believed that lower-order spatial reasoning tasks, such as learning definitions of concepts or understanding facts and geographical characteristics about places, are not demanding for students.

Some instructors employ classroom teaching strategies that stimulate reasoning skills in students. Most instructors (70%) use class discussions and conversational inquiry-based learning to instill geospatial reasoning skills in students. Estaville et al. (2010) recommended inquiry-based learning as one of the salient active learning techniques to engage students in higher-order thinking, metacognition, and real-world problem solving—ingredients of geospatial reasoning skills. Thirty-seven percent of instructors incorporate real-life examples, analogies, ethnographic stories, and case studies to immerse students in geospatial reasoning tasks; another 37 percent require students to engage in group projects with class presentations; and 11 percent of instructors assign students fieldwork, including campus, neighborhood, or city/urban trips.

Other Thoughts

More than half of the instructors strongly believed undergraduate students have vague understandings of geography, lack geospatial thinking skills, and find it hard to comprehend and make maps. These problems are attributed to the lack of imparting geographic and geospatial skills to students, according to Sinton et al. (2013, 42): "Unfortunately, geography, as a stand-alone subject, is largely absent and poorly understood within our educational system in the United States." Faculty firmly felt geography should be properly taught in high schools in the U.S. because a basic grasp of geography is fundamental in improving spatial and geospatial thinking skills of students. About 40 percent of the instructors suggested that teachers must make undergraduate students appreciate the value of geography in students' everyday lives, life decisions, and careers. Teachers must provide real-world examples of the relevance of geography, for instance exploring data analysis or interpreting ethnographies. For effective geospatial learning, students must then be taught with a variety of techniques, such as classroom discussions and examples, projects, fieldwork, map exercises, and GIS activities (both theory and application). Rethinking and redesigning geography curriculum to bolster effectively student geospatial thinking is of cardinal importance.

Mixed-method Analysis

I compared the quantitative and qualitative data analyses to determine if the two correlated in terms of geospatial thinking of undergraduate students. Student performance on the GTS provided the quantitative data through total GTS scores and performance on individual GTS questions (various geospatial thinking domains). Instructor perception in the interviews contributed the qualitative data about student understanding of geospatial concepts. I searched for trends in the two analyses to compare student performance on various geospatial thinking domains with instructor perceptions about student comprehension of different geospatial concepts.

Table 5.2 displays geospatial domains/questions included in the GTS and highlighted in instructor interviews, indicating percentages of students answering correctly and incorrectly as well as the percentage of instructors reporting whether the domain/question was easy or difficult for students. Instructors mentioned four geospatial thinking concepts in their interviews that clearly matched with the domains/ questions in the GTS. Table 5.2 points out instructor perceptions about student understanding of different geospatial concepts do not align with student performance on geospatial thinking domains/questions in the GTS. For example, in the direction and orientation domain, student performance and instructor perspectives sharply trend in the opposite directions. Almost all students answered the direction question correctly.

Table 5.2. Comparison of Quantitative Data (GTS Scores for Domains/Questions) and Qualitative Data (Instructor Perceptions of Student Geospatial Thinking).

Geospatial Thinking Domain	**Percent of Students Answering Correctly**	**Percent of Students Answering Incorrectly**	**Percent of Instructors Reporting Easy/High-Scoring**	**Percent of Instructors Reporting Difficult/Low-Scoring**
Direction and Orientation	90.3	9.7	3.7	11.11
Geospatial Pattern and Transition	88.6	11.4	3.7	7.4
Geospatial Association	78.1	21.9	-	7.4
Geospatial Overlay: Location, Site/ Situation; Distance	63.4	36.6	25.9 (Location, Site/Situation) 7.4 (Distance)	55.55 (Location, Site/Situation) 3.7 (Distance)

What are the reasons for this obvious disconnect between GTS scores and instructor perceptions? Perhaps the brief, semi-structured interviews did not ask enough redundant questions to ferret out the precise meanings of instructor perceptions. Geography faculty do not have a clear understanding about the nature and components of geospatial thinking. Geospatial thinking concepts are not explicitly taught in undergraduate classrooms (Hespanha, Goodchild, and Janelle 2009). Or, maybe the instructors are too critical about their students' understanding of basic geospatial concepts. Perhaps the instructors use assessment and measurement tools different from the GTS instrument and thus the perceptions of geospatial concepts being difficult or easy differ. Certainly this dichotomy between student performance on such geospatial skills tests as the GTS and instructor perceptions of student performance needs to be more carefully and thoroughly examined.

Qualitative Study Limitations and Discussion of Error

I selected 27 instructors for qualitative interviews from universities in nine census divisions to include one instructor each from each census division at each of the three levels of geography departments—undergraduate, master's, and doctoral. This selection procedure is based on both convenient (seeking instructor approval for interview) and stratified (geography department degree-granting level) sampling. With a small sample of 27 instructors, the interviews may not have been a good representation of geography instructor perceptions nationwide and, thus, did not capture enough qualitative data for a sound analysis. However, I was unable to conduct more than 27 interviews because of time constraints.

Error may have occurred in my qualitative analysis method. I extensively examined the content of 27 instructor interviews. Yet I may have misunderstood some important information or point mentioned by instructors about student geospatial thinking. The findings of the qualitative analysis could be strengthened and reinforced by interviewing more instructors and including more questions in the interviews. Also, instead of asking open-ended questions about difficulty of geospatial concepts, I should have asked questions about geospatial concepts directly corresponding with GTS domains.

Summary of Major Qualitative Findings

The analysis of 27 instructor interviews revealed some noteworthy trends and findings. The majority of instructors listed understanding of locations, regions, maps, higher-order spatial reasoning skills, scales, projections, spatial connections, cultural spatial interactions, time zones, and directions as difficult and challenging geospatial thinking domains for undergraduate students. Many other instructors suggested regions, locations, maps, and cultural spatial patterns are geospatial concepts that are easily understood by students. These results are obviously confounding.

Only one-third of instructors reported they rely on maps or videos to emphasize geospatial thinking concepts in classroom exercises. Even fewer instructors employ images or graphs. According to the literature, these pedagogical omissions are serious shortcomings in geography classroom teaching. Maps are essential tools in reinforcing student geospatial thinking (Blaut 1991; Uttal 2000; Liben 2006; Kemp 2008). Intensive utilization of maps, videos, diagrams, photos, and graphs in teaching has the potential to increase geospatial thinking levels of students. A large number of instructors interviewed reported they incorporate classroom activities that strengthen geospatial reasoning skills in students, such as class discussions, inquiry-based learning, project and group activities, case studies, fieldwork, data analysis, and analytical writing.

Most instructors strongly believed high school education in the U.S. is not inculcating good geospatial thinking practices in students, thereby supporting the views of Sinton et al. (2013). Undergraduate students enter college ill prepared to undertake geospatial thinking.

The mixed-method comparison of quantitative and qualitative data shows student performance across various geospatial thinking domains do not match with instructor viewpoints about student geospatial strengths and weaknesses. Instructors' low opinions about student performance in the domains of direction, geospatial pattern and transition, and location do not correspond with student high attainment in these domains on the GTS.

CHAPTER VI

CONCLUSIONS AND FUTURE RESEARCH

Conclusions

One of the important aspects of this study is the mixed-method approach to assess the geospatial thinking of undergraduate students in public universities in the United States. The quantitative analysis of the scores on the Geospatial Thinking Survey (GTS) of 1479 undergraduate students from 61 public universities across nine census divisions of the country explored the relationship of hypothesized demographic, academic, and geographic locational variables with students' geospatial thinking attainment on the GTS. The qualitative analysis of the 27 instructor interviews from universities in nine census divisions employed content analysis to determine instructor perceptions about the comprehension of geospatial concepts by students.

The fundamental research question of my study was: Do undergraduate students in public universities in the United States differ in geospatial thinking? My research was situated within one quantitative and two qualitative research questions, and a dozen quantitative and one qualitative research hypotheses.

Quantitative Research Question

What is the geospatial thinking level of undergraduate students in the United States?

Quantitative Research Hypotheses

Undergraduate students vary in geospatial thinking depending on their: (1) sex, (2) age, (3) ethnicity, (4) socioeconomic status (parents' annual income), (5) socioeconomic status (highest educational attainment of parents), (6) academic major, (7) academic classification, (8) high school geography academic experience (number of high school geography courses), (9) college geography academic experience (number of college geography courses), (10) geography department level, (11) urban/suburban/rural areas (geographic location), and (12) census division (geographic location).

Qualitative Research Questions

1. From instructors' perspective, what geospatial concepts do the students find difficult to understand?
2. From instructors' perspective, what geospatial concepts do the students find easy to understand?

Qualitative Research Hypothesis

The instructors' perspective of students' geospatial thinking strengths and weaknesses matches with students' performance in various geospatial thinking domains as measured by the Geospatial Thinking Survey (GTS).

Discussion of Quantitative Findings

My research answered the fundamental research question by assessing the geospatial thinking of undergraduate students in public universities in the United States. Two-thirds of the students performed at the medium level on the Geospatial Thinking Index, while a 16% of students performed at low and 16% performed at high geospatial thinking levels. This result supports the findings of Huynh and Sharpe (2013) regarding students' geospatial thinking levels. Most students need more explicit training to improve their geospatial thinking.

The findings of my study confirmed the research hypotheses that geospatial thinking of undergraduate students is influenced by sex, age, ethnicity, parents' annual income, highest educational attainment of parents, academic major, academic classification, high school and college geography academic experience, urban/suburban/rural location, and census division. The results of the ANOVA, multiple regression, and Cubist statistical techniques together verified that the most important predictors of students' geospatial thinking may be grouped into two key areas:

1. Academic: number of college geography courses studied, academic classification, academic major, and age.

2. Socioeconomic: ethnicity, parents' annual income, and parents' education.

The multiple regression and Cubist models were able to predict student geospatial thinking based on the significant variables of the academic and socioeconomic components. Both the multiple regression and Cubist models can be applied to real world data to assist in outlining geospatial thinking of students based on their cultural backgrounds. The multiple regression model provided useful equations, and the Cubist models contributed rules that researchers and instructors can use in predicting geospatial thinking of students with different combinations of academic and socioeconomic components and data. In the absence of a wide range of geospatial thinking assessments in the literature (NRC 2006; Huynh and Sharpe 2009, 2013), instructors may rely on these multiple regression and Cubist models to understand better the geospatial thinking levels of their students and then employ appropriate interventions in their teaching.

The chi-square analyses found a strong evidence of association of sex with such geospatial thinking domains as geospatial profile and transition, geospatial overlay, geospatial shapes, and geospatial association; age with geospatial overlay, geospatial profile and transition, geospatial shapes, geospatial association and transition, and geospatial association; ethnicity with geospatial shapes, geospatial association, geospatial profile and transition, geospatial pattern and transition, geospatial overlay, and direction and orientation; academic classification with geospatial shapes, geospatial overlay, geospatial profile and transition, geospatial association, geospatial pattern and transition, and geospatial association and transition; college geography courses with geospatial overlay, geospatial profile and transition, geospatial shapes, geospatial pattern and transition, and geospatial association; and urban/suburban/rural locations with geospatial shapes, geospatial association, geospatial profile and transition, direction and orientation, and geospatial pattern and transition.

The ANOVA and chi-square findings revealed that groups of students displaying higher geospatial thinking performance were whites, students who studied more than five college geography courses, geography majors, seniors, above 24-year old students, rural students, and males. Groups of students with lower geospatial thinking levels included Hispanics, blacks, students who studied two or fewer college geography courses, freshmen, 18-20 year old students, urban students, and females.

Assessment tools, such as the GTS, STAT (AAG 2006; Lee and Bednarz 2012), and geospatial thinking assessment (Huynh and Sharpe 2013) are important as conceptual inventories to diagnose geospatial thinking levels among students prior to instruction and after intervention (Huynh and Sharpe 2013). Such assessments are also critical in identifying difficult, challenging, or misconceived concepts of geospatial thinking (Huynh and Sharpe 2013). In this national study with a sample of 1479 undergraduate students, the majority of the students struggled with geospatial association and transition and geospatial shapes. This finding calls in for alternative teaching methods and training exercises in undergraduate classrooms to improve geospatial thinking of students in these domains.

For the variable sex, the findings of my study support earlier research works postulating that males are better than females at various spatial and geospatial thinking tasks (Allen 1974; Gilmartin and Patton 1984; Cochran and Wheatley 1988; Cherry 1991; Franeck et al. 1993; Voyer, Voyer, and Bryden 1995; Henrie et al. 1997; and Levine et al. 2005). For age and academic classification, my findings corroborate previous research that shows increasing age and education levels imply better spatial and geospatial thinking (Gilmartin and Patton 1984; Henrie et al. 1997; Newcombe and Huttenlocher 2006; Battersby, Golledge, and Marsh 2006; Marsh, Golledge, and Battersby 2007; Golledge, Marsh, and Battersby 2008a; Huynh and Sharpe 2009, 2013; and Lee and Bednarz 2012). My research is the first to analyze extensively the significant influence of ethnicity, geographic locations (urban/suburban/rural patterns and census divisions), and college geography academic experience on the geospatial thinking of students.

The target groups of students with poor geospatial thinking need interventions in undergraduate education to improve their geospatial thinking. Golledge (2002) and Huynh and Sharpe (2013) asserted the importance of formal classroom instruction in geography. Informally or implicitly acquired geographic knowledge is often disorganized and inadequate (Golledge 2002). Expertise is gained through formal learning of fundamental concepts of a discipline (Huynh and Sharpe 2013). Geography is a conceptual and structured body of knowledge based on specific modes of thinking and reasoning that have to be formally taught (Golledge 2002). The misunderstanding of geographic concepts and geospatial thinking by undergraduate students is also confirmed by instructor interviews.

College geography courses are interventions that improve undergraduate student geospatial thinking, and all students should be encouraged to take geography courses. The empirical findings of my research thus support the theoretical assertions of such scholars as Blaut (1991), Downs (1994), Uttal (2000), Golledge (2002), and Liben (2006) that geography education is the most important vehicle in instilling spatial and geospatial thinking skills in students. The findings of my study, grounded in empirical national research, strongly suggest to educational policymakers that, to ensure students are capable of competing globally in employment areas (e.g. logistics, transportation, image analysis, GIS, civil engineering, real estate, site analysis, military operations) that require solid geospatial thinking skills, geography must be integrated into fundamental aspects of K-16 education. Students from other majors, such as nursing, criminal justice, and business, may be confronted with spatial and geospatial thinking in their work, but they will not be equally competent. Even if a student does not want a career in geography, taking college geography courses is important to prepare students for many other careers that require spatial and geospatial thinking skills. Educators should use the data and findings of my study to persuade policymakers to fund geography education in our universities. More funds should be channelized into substantially improving the geospatial thinking of underperforming groups of students, especially Hispanics and blacks.

The GTS is based on STAT (AAG 2206; Lee and Bednarz 2012). There is a need to replicate studies with the same scale to build capacity in the field. Such replication would help in building empirical datasets by producing systematic data about student performance in geospatial thinking (Huynh and Sharpe 2013). Although the GTS overlooked some geospatial concepts, it assessed geospatial thinking of students in six important domains discussed extensively in the literature. Apart from the six explicit geospatial thinking domains of geospatial pattern, direction and orientation, geospatial profile, geospatial association, geospatial shapes, and geospatial overlay, the ten GTS questions encompassed other implicit geospatial skills such as geospatial transition, location, site (conditions) and situation (connections), distance, and analyzing maps and graphs. The GTS, being both reliable and valid, is a useful and practical assessment in gauging existing student geospatial thinking levels.

The outcomes of the principal component analysis (PCA) to group GTS questions into similar domains of geospatial thinking supported theoretical notions that geospatial thinking domains are not correlated yet interconnected. Geospatial thinking is not a unitary construct but a combination of multiple interlinked dimensions, thereby corroborating previous research (Gersmehl and Gersmehl 2006; Lee and Bednarz 2012; Huynh and Sharpe 2013; Ishikawa 2013). This finding was reemphasized by the performance of students on distinct geospatial thinking questions. Irrespective of whether a geospatial concept is simple or complex, as discussed in the literature, undergraduate students performed differently on distinctive questions in the same domain. Students employ different problem solving strategies, often applying nonspatial processing strategies (verbal abilities) to solve spatial tasks (Lee and Bednarz 2012). Instructors should take time to discover their students' geospatial strengths and weaknesses, using such assessments as the GTS, in each class and then target those geospatial concepts explicitly in instruction. For instance, some students may require more intervention in geospatial association, while others may demand extra help with geospatial shapes.

Discussion of Qualitative Findings

The answer to qualitative research questions presented confounding results. In the interviews, the majority of instructors reported understanding of locations, regions, maps, higher-order spatial reasoning skills, scales, projections, spatial connections, cultural spatial interactions, time zones and directions as difficult and challenging geospatial thinking domains for undergraduate students. Many other instructors suggested that regions, locations, maps, and cultural spatial patterns are geospatial concepts that are easily understood by students. From these instructor perceptions, an unambiguous boundary could not be drawn between easy and difficult geospatial concepts for students. The qualitative analysis of the 27 instructor interviews thus rejected the hypothesis by revealing student performance across various geospatial thinking domains do not match well with instructor viewpoints about student geospatial strengths and weaknesses.

Linking Findings to Theory

The purpose of this study was to address the question: Do undergraduate students in public universities in the United States differ in geospatial thinking? Based on the sociocultural theory of psychological process (STPP), my research empirically established the influence of cultural variables such as ethnicity, socioeconomic status, academic achievements, and geographic locations on the geospatial thinking of undergraduate students in the United States. Students displayed stark variations in geospatial thinking as a function of their ethnicity, college geography academic experience, academic classification, urban/suburban/rural locations, age, academic major, census division, parents' annual income and education, and sex.

Certain groups of students, from varying cultural backgrounds, are better than others both in overall geospatial thinking and in different geospatial thinking domains. Groups of students with a higher geospatial thinking performance than others are whites, students who studied more than five college geography courses, geography majors, seniors, above 24-year old students, rural students, and males. Groups of students with lower geospatial thinking levels included Hispanics, blacks, students who studied two or fewer college geography courses, freshmen, 18-20 year old students, urban students, and females.

Although other factors may contribute in shaping student geospatial thinking, my findings support the theoretical context of this research and emphasize that cultural background in the form of ethnicity, home environment (parents' income and education), and formal academic achievement (college geography experience, academic major and classification) is critical in influencing geospatial thinking of undergraduate students in the U.S.

Future Research

In my research, the GTS has been shown to be a reliable and valid assessment of geospatial thinking. However, the GTS overlooked some geospatial concepts such as scale and projections. More geospatial thinking questions need to be designed to address thoroughly the geospatial concepts and reasoning skills discussed in the literature. Questions can, for example, be borrowed from the GTS, STAT (AAG 2006; Lee and

Bednarz 2012), and geospatial thinking assessment (Huynh and Sharpe 2013) to form one comprehensive yet focused and time-effective instrument that could be administered objectively to students countrywide.

This study adequately analyzed variations in student performance on various geospatial thinking domains. However, I could not examine the reasons behind such variations from the students' perspectives. Future studies may closely observe students as they solve different geospatial questions, such as focusing on whether students rely on verbal analysis, employ hand gestures in geospatial problem solving, or solely rely on the geospatial representation (e.g. map or graph) provided in the question. Future research along similar lines may involve interviewing students to better measure their approach in solving geospatial problems.

Comparing the geospatial thinking abilities of undergraduate students in the U.S. with such other countries as India, Mexico, or Nigeria could begin to build a global understanding of student geospatial thinking.

APPENDIX SECTION

APPENDIX A

GEOSPATIAL THINKING SURVEY (GTS)

Acknowledgement: This survey follows closely the Spatial Thinking Ability Test (STAT) of Association of American Geographers (AAG), 2006.

Demographic, Geographic, and Academic Background Questions:

- In which age group are you?
  - 18 - 20
  - 21 - 24
  - >24

- What is your sex?
  - Male
  - Female

- With which ethnic group do you most closely identify yourself?
  - White
  - Hispanic
  - Black
  - Asian

- The annual income of your parents is:
  - <$25,000
  - $25,000 - $50,000
  - $51,000 - $75,000
  - >$75,000

- What is the highest educational attainment of your parents?
  - Less than High School
  - High School
  - Associate’s Degree
  - Bachelor’s Degree
  - Graduate Degree

- In which state did you graduate from high school?
  - (drop-down menu of 50 states)

- In which year did you graduate from high school?

  ____

- Which university do you currently attend?

  ____

- Did you grow up in:
  - a city?
  - a suburb?
  - a rural area?

- The city/suburb/rural area you grew up in is:

  ____

- What was your home zip code when you were growing up (not your university zip code)?
  - Do not know
  - My home zip code when I was growing up was ____________________

- What is your academic major?
  - Geography
  - Other (please specify) ____________________

- What is your academic classification?
  - Freshman (First Year)
  - Sophomore (Second Year)
  - Junior (Third Year)
  - Senior (Fourth Year)
  - Graduate

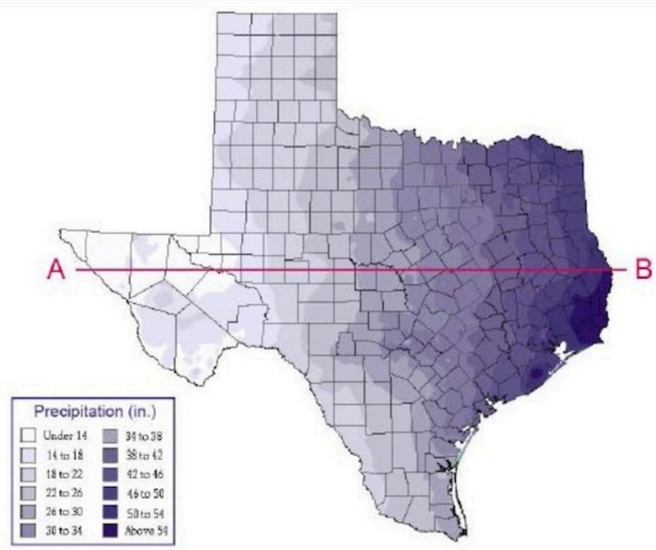
- Number of high school geography courses taken?
  - Never had a geography course
  - 1 geography course
  - 2 geography courses
  - More than 2 geography courses

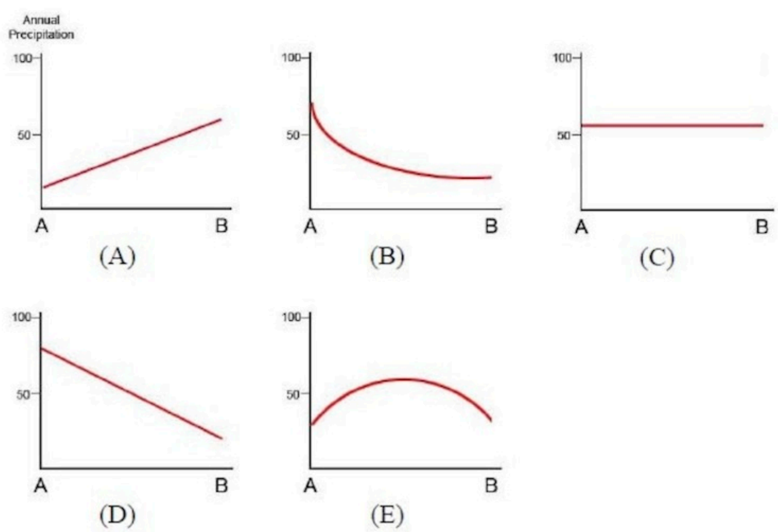
- Number of college level geography courses taken?
  - Never had a geography course
  - 1-2 geography courses
  - 3-5 geography courses
  - More than 5 geography courses

Geospatial Thinking Questions:

1. The map below shows average annual precipitation of Texas. If you draw a graph showing change of Texas annual precipitation between A and B, The graph will best match which curve?

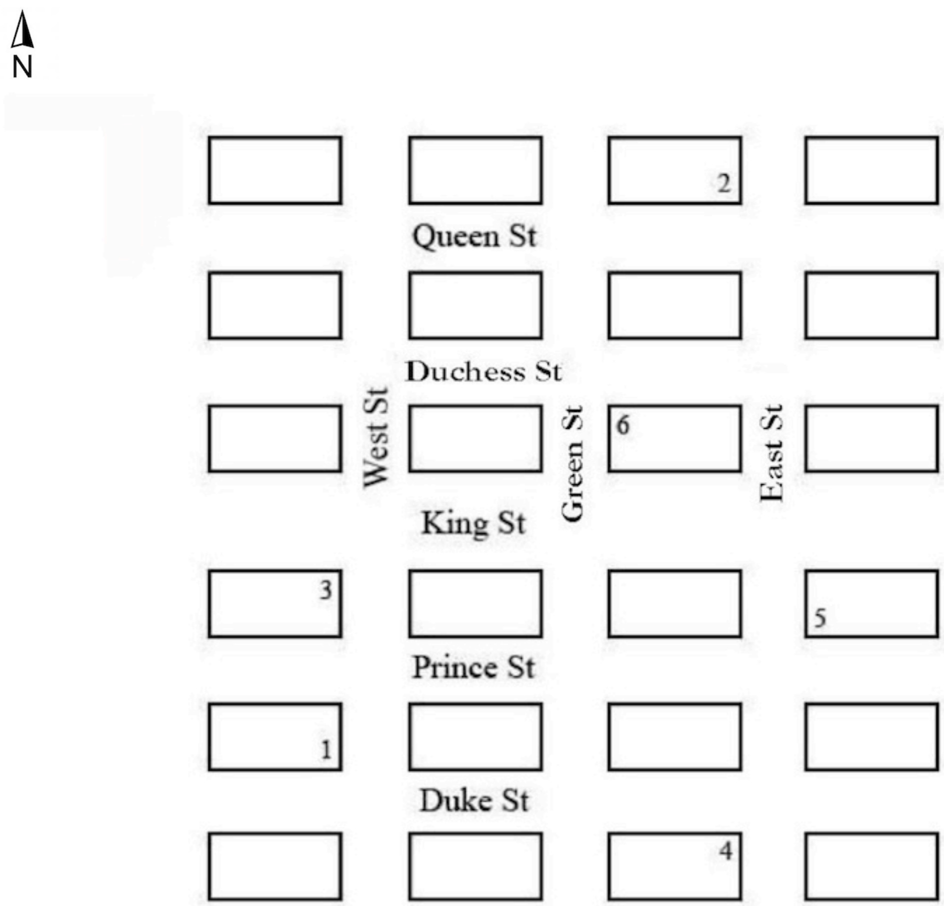
- A
- B
- C
- D
- E





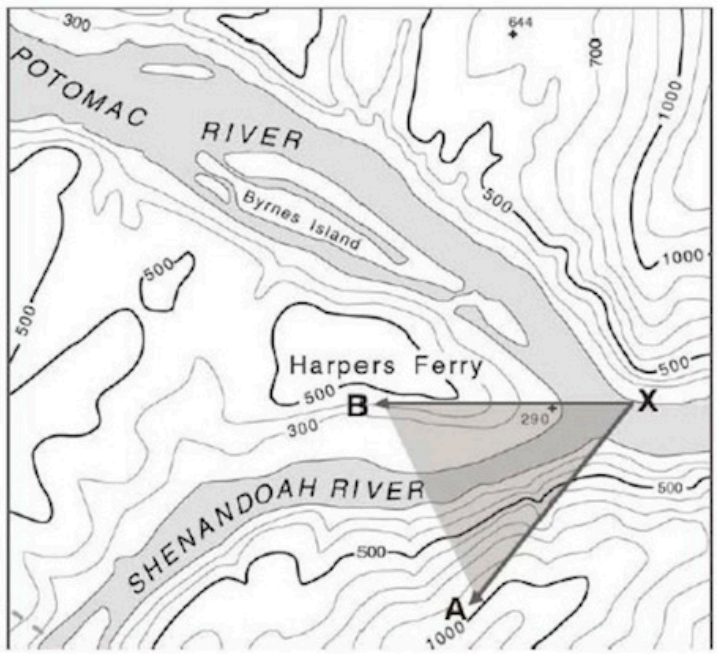
2. Please answer this question on the basis of the street map below. If you are located at point 1 and travel north one block, then turn east and travel three blocks, and then turn south and travel two blocks, you will be closest to which point?

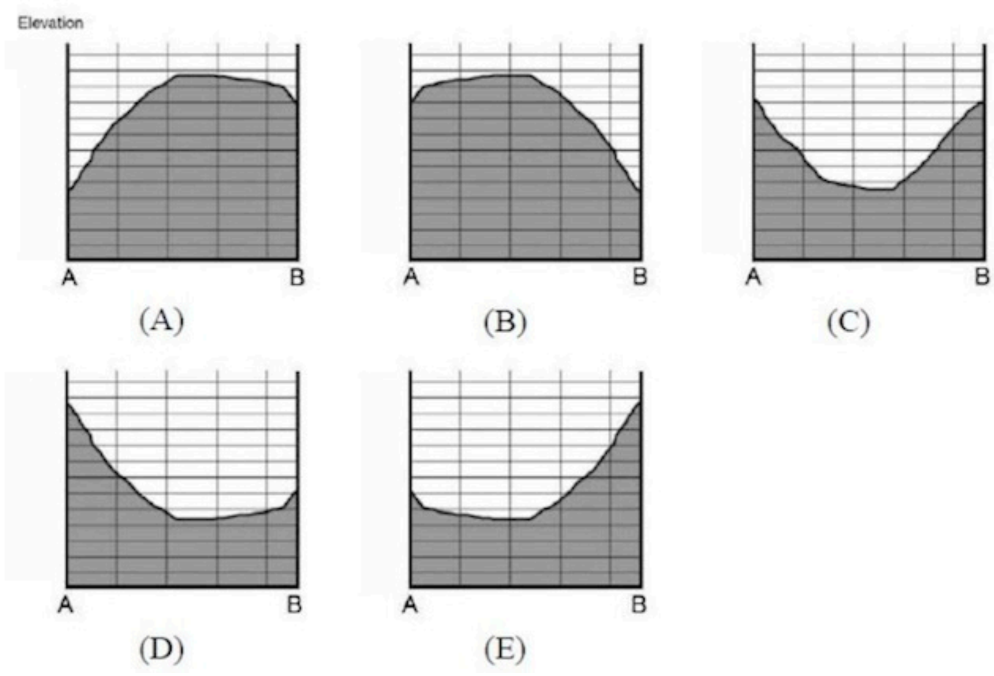
- 2
- 3
- 4
- 5
- 6



3. Imagine you are standing at location X and looking in the direction of A and B. Among five slope profiles (A – E), which profile most closely represents what you would see?

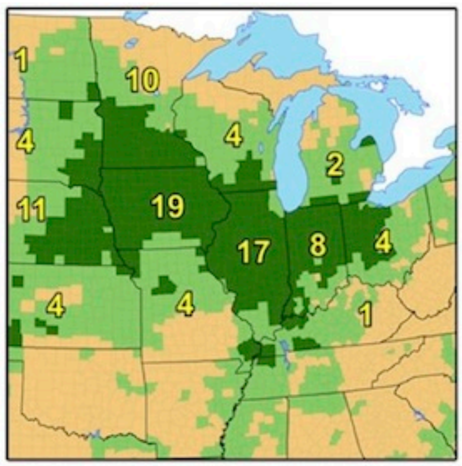
- A
- B
- C
- D
- E



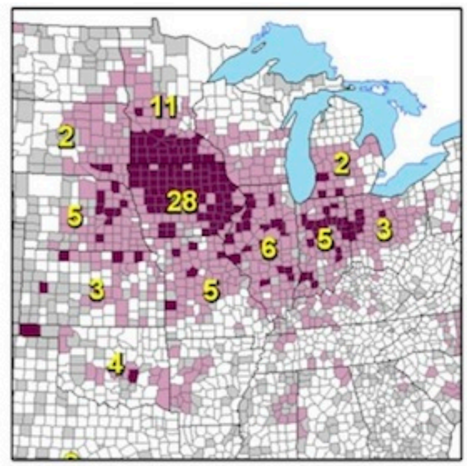


4. The following two maps show production areas for (a) corn and (b) hogs and pigs. If you draw a graph showing the relationship between the general patterns of map (a) and map (b), which of the four graphs is the best?

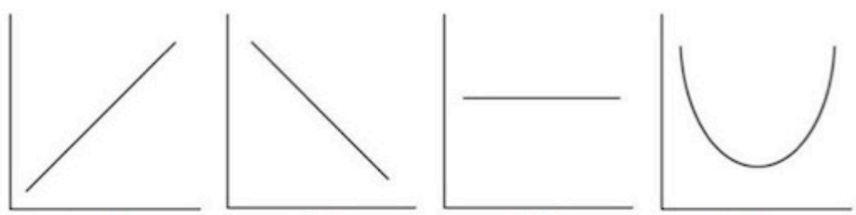
- A
- B
- C
- D



(a)



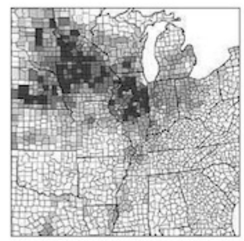
(b)

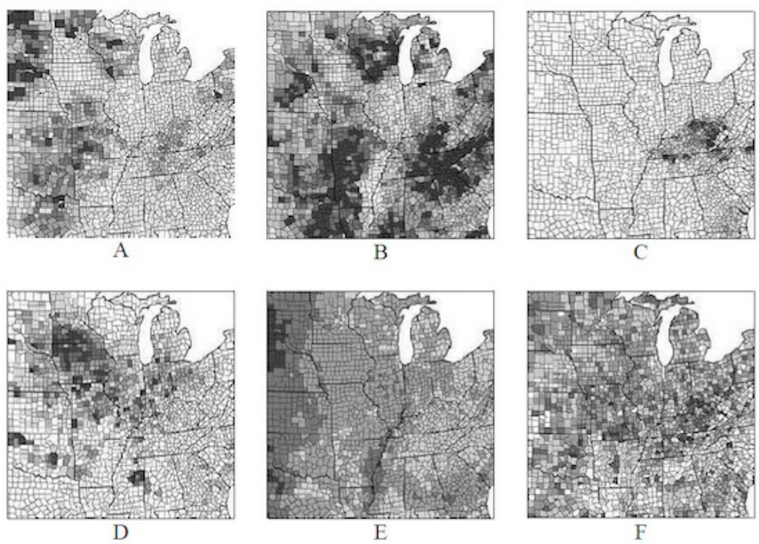


(A) (B) (C) (D)

5. Find a map (A – F) having a strong positive correlation (association or showing similar pattern) with the top map on the right. Choose the closest one.

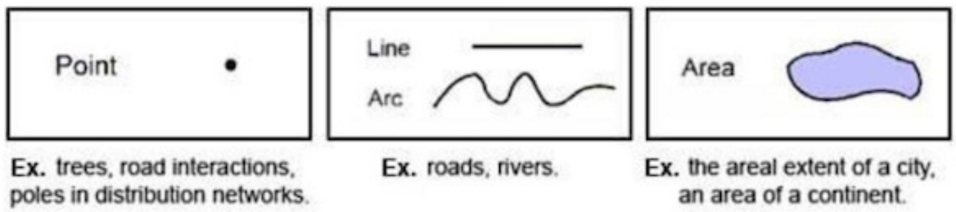
- A
- B
- C
- D
- E
- F





Real-world objects can be represented by points, lines (arcs), and areas. Based on the examples in the figure below, classify the following spatial data in questions 6, 7, 8, and 9.

Example



6. Location of weather stations in Washington County.
   - Lines
   - Area
   - Points and Lines
   - Points

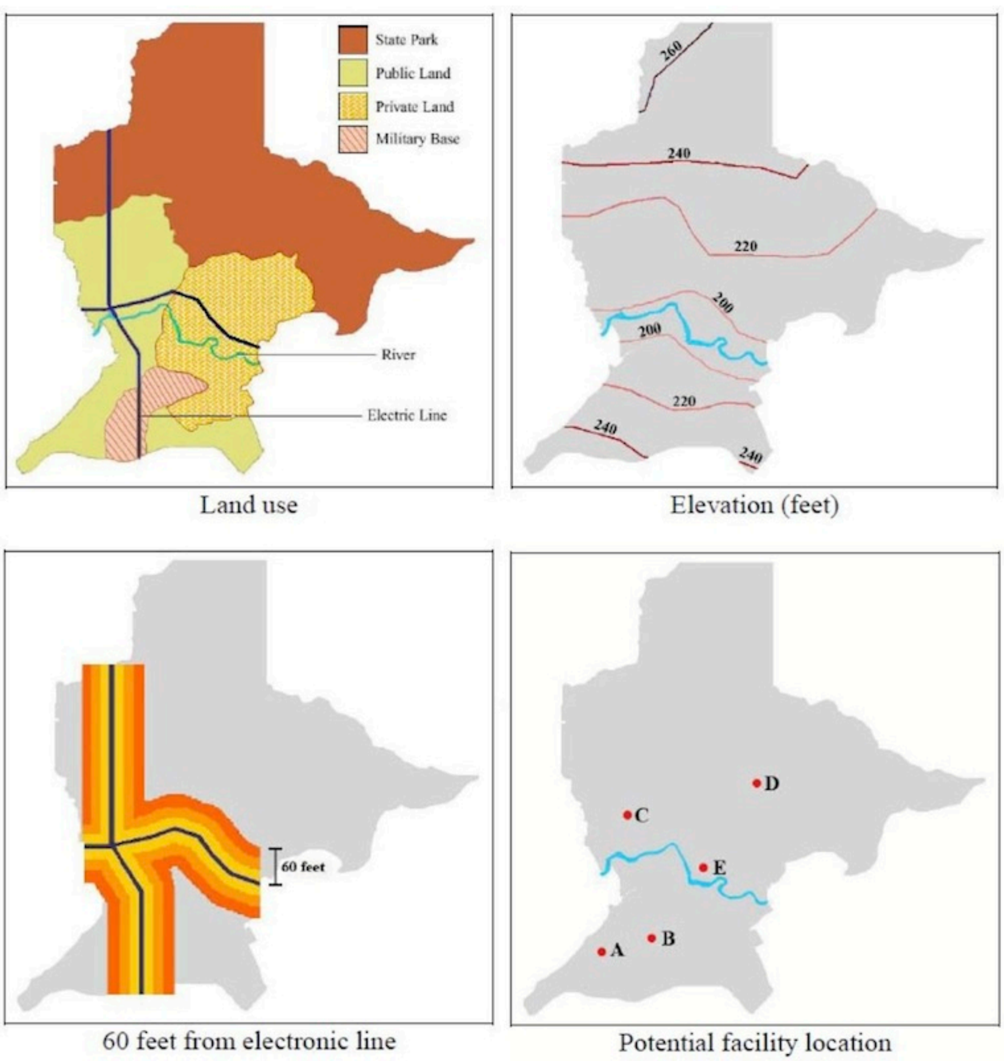
7. Mississippi River channels and their basins.
   - Lines
   - Area
   - Points and Lines
   - Lines and Area

8. Shuttle bus routes and bus stops of the Lincoln Elementary School.
   - Points
   - Area
   - Points and Lines
   - Points and Area

9. Places that can be reached by Franklin County fire engines in 5 minutes or less.
   - Points
   - Lines
   - Area
   - Points and Areas

10. Find the best location for a flood management facility based on the following conditions.
First, a possible site for a flood management facility should be within 60 feet of an existing electric line.
Second, a possible site for a flood management facility should be located less than 220 feet in elevation.
And last, a possible site for a flood management facility should be located in state park or public land.
Choose the best site (A - E) for the flood management facility on the potential facility location map.

- o A
- o B
- o C
- o D
- o E



Land use | Elevation (feet) | 60 feet from electronic line | Potential facility location

APPENDIX B

INSTRUCTOR INTERVIEWS

1. Are you male or female?
2. What ethnic group do you belong to?
3. What is your highest degree in geography?
4. How long have you taught undergraduate geography courses?
5. What geospatial concepts do the students find difficult to understand, or are difficult to explain and exemplify in class? On what geospatial concepts do the students score low?
6. On what geospatial concepts do the students score high?
7. What strategies do you use to teach fundamental geospatial concepts?
8. Do you have any other thoughts regarding undergraduate students' understanding of geospatial concepts?

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