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Role of Geography Courses in Improving Geospatial Thinking of Undergraduates in the United States

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Role of Geography Courses in Improving Geospatial Thinking of Undergraduates in the United States

Abstract

This national study utilizes the Geospatial Thinking Survey (GTS) to assess the geospatial thinking abilities of undergraduates in the United States. A survey of 1479 students from 61 public universities provided the data. The mean score of geography majors was the highest, while that of criminal justice majors was the lowest. The mean score of students who studied at least three college geography courses was significantly higher than those students who took less than three college geography courses. College geography courses apparently bolster student geospatial thinking abilities, thereby corroborating the stronger geospatial thinking skills of geography majors. Moreover, individual questions of the GTS represent different geospatial thinking domains. The results of the internal comparisons of the GTS questions suggest that undergraduate instructors should identify students who need their geospatial thinking ability strengthened in certain domains.

Keywords

geospatial thinking, undergraduate students, academic major, geography courses

1 INTRODUCTION

The groundbreaking National Research Council (NRC) publication, *Learning to Think Spatially* (NRC 2006), stirred national and international interest in spatial thinking research within different disciplines and the application of spatial thinking in everyday problem solving. Spatial thinking—a constructive combination of concepts of space (e.g., location, distance, pattern, and association), tools of representation (e.g., maps, photographs, videos, models, and graphs), and processes of reasoning (e.g., recognizing, evaluating, and predicting)—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). Geospatial thinking is different from general spatial ability and includes the application of geographic contents or properties to general space (Ishikawa 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 2008). Geospatial thinking thus uses "geospace," Earth space or geographic space, at different scales to frame problems, identify answers, and provide solutions employing geospatial concepts, representation tools, and reasoning processes. The geospatial approach is therefore different from such disciplines as architecture, mechanical engineering, astronomy, and nanotechnology that deal with space at various other scales.

Students, knowingly or unintentionally, utilize their cognitive functioning to make informed decisions in their everyday lives using spatial and geospatial conceptual knowledge and reasoning processes. All levels of the educational system should therefore teach systematically spatial thinking to meet the goal of spatial literacy (NRC 2006). Spatial thinking skills are malleable and can be improved with training, practice, and/or direct instruction (Huynh and Sharpe 2013; Newcombe 2010; NRC 2006; Uttal et al. 2013). The ability to use and apply spatial and geospatial concepts, representations, and reasoning intelligently and critically is becoming more crucial when participating in academic, workplace, and everyday settings of the globalized world. Spatial thinking affords overall cognitive development (Gersmehl and Gersmehl 2007), improves educational outcomes (Newcombe 2010), and increases student participation in science, technology, engineering, and mathematics (STEM) careers (Ishikawa 2016; Uttal et al. 2013). Students with spatial and geospatial skill-sets have an edge in the job market, such as in the information technology sector (NRC 2006; Solem, Cheung, and Schlemper 2008). The U.S. Department of Labor encourages people to obtain better geospatial abilities to prepare for career opportunities (Baker 2012).

Geospatial thinking helps people understand chaotic and diversified environments (Golledge 2002), such as remembering a specific map, route planning, following directions to a location, calculating distances, comprehending directions, determining spatial patterns among different natural and cultural features, visualizing 3-D topography from an alternative perspective, comparing conditions in different places, or choosing an optimal location based on given geographical criteria (Verma 2015). "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). Spatial and geospatial thinking are thus essential to global citizenship, workforce preparation, and conceptual comprehension in various disciplines and everyday life (Shin, Milson, and Smith 2016; Verma 2015).

Several scholars have underscored that geography is the most viable academic subject to instill spatial thinking in students (Cutter, Golledge, and Graf 2002; Liben 2006; Sinton et al. 2013; Tate, Jarvis, and Moore 2005). These researchers emphasized that geography relies on spatial concepts as its foundation and thus provides exceptional spatial and geospatial underpinnings to students. Empirical research, and not simply conceptual claims, is needed to show that geography is in fact more effective than other disciplines in imparting spatial and geospatial thinking to students. The purpose of this paper is to utilize a national study to underscore the importance of college geography courses in improving undergraduate students' geospatial thinking abilities.

2 RECENT GEOSPATIAL THINKING RESEARCH

Albert and Golledge (1999) found no statistical difference between geographic information systems (GIS) users and non-users in three map-overlay tests taken by 134 undergraduate students. Lee (2005) observed no significant differences in spatial thinking of 80 undergraduate students from geography majors and science and engineering majors. However, students of both groups increased their scores substantially after completing a GIS course. Lee and Bednarz (2009) revealed that GIS learning helped college students think spatially and observed strong correlations between students' spatial thinking and their success in the GIS course as examined through a spatial-skills test (SST). Kim and Bednarz (2013) concluded that completion of a GIS course strengthened students' spatial habits of mind (SHOM) conducted through self-evaluation of spatial habits—pattern recognition, spatial description, visualization, spatial concept use, and spatial tool use. Perkins et al. (2010) documented a statistically significant increase in student spatial awareness by using global positioning system (GPS) units and *My World* GIS software in a middle school class. Jo, Hong, and Verma (2016) determined that Web-based GIS activities (three *ArcGIS Online* exercises) enhanced students' spatial thinking skills in a sample of 306 undergraduate students enrolled in seven world geography course sections conducted through pre- and post-assessments of the Spatial Thinking Ability Test (STAT) (Lee and Bednarz 2012). Metoyer and Bednarz (2016) discovered that instructional use of geospatial technologies (GST) did not improve spatial thinking skills of 102 high school students from five tenth-grade world geography honor classes in a Texas urban public school; nonetheless, the researchers suggested a positive correlation between thinking spatially and thinking geographically.

From a sample of 532 junior high, high school, and university students, Lee and Bednarz (2012) concluded that students in two universities with more geography majors scored higher on the STAT than students in two other universities with fewer geography majors. In a sample of 77 undergraduate students in five general education geography courses, geography majors and students who studied more college geography courses scored higher on the Geospatial Thinking Survey (GTS) than non-geography majors and students who studied fewer geography courses (Verma 2015). Of 103 students from two universities using the SST and the attitude toward spatial thinking inventory (ATSTI), Shin, Milson, and Smith (2016) found that geography majors had higher mean scores than the elementary education and secondary social studies education majors, and students who studied GIS courses scored higher than those who did not.

Although geographers and other scholars have examined the effects of sex/gender, age, and grade level (progression from novice to expert in school), little research has been undertaken regarding group differences in geospatial thinking based on culture, disability, socioeconomic status, academic major, geography academic experience, ethnicity, language, or urban/rural background. Few studies have addressed the issue from an academic context, even fewer have conducted research at the undergraduate level, and none has conducted a large national sample.

3 PURPOSE

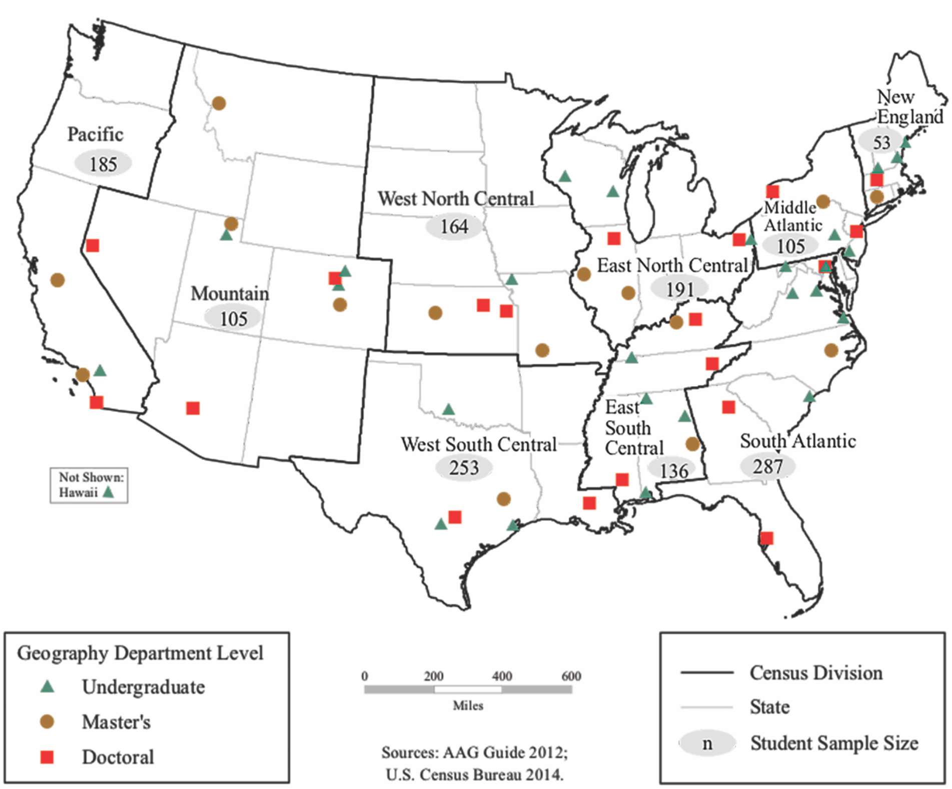
Like different levels of performance in spatial thinking exist as a function of age, sex, and experience (NRC 2006), certain groups of people from various ethnic, socioeconomic, academic, and geographic backgrounds should demonstrate differences in how people approach and incorporate spatial and geospatial thinking. Albert and Golledge (1999, 8) pondered about "… how individuals are able to mentally encode, process, store, and retrieve geographic information and why certain individuals are better or worse in these activities." To design better educational lessons and materials, develop targeted instruction and deliver more meaningful classes, and assess student mastery more effectively, the geographic community must pay more attention to such differences in spatial and geospatial thinking abilities in students belonging to different groups (Anthamatten 2010; Gersmehl 2012; Gersmehl and Gersmehl 2006; Huynh and Sharpe 2009; Ishikawa 2013; Liben 2006; Newcombe 2010; Sinton et al. 2013; Uttal et al. 2013). Investigating the nature of group differences based on academic major and college geography courses can lead to an enhanced understanding of the comprehension and use of geospatial thinking in educating more discerning geospatial thinkers. The purpose of this national study in the U.S. was to test statistically the notion in the literature that undergraduate geography majors or other students who have taken multiple geography courses have higher levels of geospatial thinking abilities than students in other disciplines or students who have taken no geography courses. This research, in contrast to the foregoing investigations, focuses on the influence of academic major and academic background in geography on geospatial thinking abilities of undergraduate students with data drawn from across the nation, rather than from two or three local classrooms. This study's findings will be useful to educational policymakers, in curricula construction, and in classroom pedagogical strategies.

4 METHOD

4.1 Data Collection

Our method incorporates many aspects of earlier studies. Following other geography research (Huynh and Sharpe 2013, 2009; Lee and Bednarz 2012, 2009), our sampling process employed a stratified convenience sample. We contacted instructors via telephone calls and e-mail messages in geography departments in 64 public universities in the United States. Instructors in 61 geography departments at three levels—undergraduate, master's, and doctoral degree granting (Figure 1)—agreed to encourage their students to participate in the online GTS by providing their students with the Uniform Resource Locator (URL) via Survey Monkey at https://sites.google.com/site/geospatial2013gts/home/geospatial-thinking-survey. Care was taken to select and contact universities for a balanced national representation and comparative analysis for each category of geography department degree-granting level—undergraduate, master's, and doctoral (Table 1). We contacted instructors teaching both undergraduate lower-level general education courses and upper-level geography courses in the geography departments to gain input from their students pursuing both geography and non-geography majors. Students were informed that the participation in the online, IRB-approved GTS was voluntary and anonymous.

From across the country, 1573 students in 32 states completed the GTS online. The sample included a few graduate, international, private university, or community college students, and some invalid responses. These cases were not included in the analyses as the focus of this study was undergraduate students in public universities. Moreover, students from public universities provided a better reflection of the general population than private universities that tend to have more monolithic student bodies. After discarding the 94 unusable cases, the total sample size became 1479 (Table 1).



Sources: AAG Guide 2012; U.S. Census Bureau 2014.

Figure 1. Location of sample universities in the U.S. census divisions for student data (n = 61).

Table 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)**

4.2 Characteristics of the Test Instrument

Few standardized tests of geospatial thinking exist in the literature (Huynh and Sharpe 2013, 2009; Lee and Bednarz 2009; NRC 2006). As the basis of the GTS, we therefore used geospatial questions from the STAT developed and used by Lee (2005), endorsed by the Association of American Geographers (AAG 2006), and employed by Lee and Bednarz (2012, 2009), Ishikawa (2013) and Tomaszewski et al. (2015). Geospatial thinking consists of several different components/domains, outlined in Table 2 as encompassed by the GTS. The Appendix lists the ten GTS questions. The GTS also included demographic, geographic, and academic background questions.

4.3 Reliability and Validity

A pilot study (Verma 2015) confirmed the reliability of the GTS. The internal consistency of the GTS was calculated using 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 0.708, a value indicating an acceptable level of internal consistency among the survey questions. Also, spatial thinking consists of multiple components/domains that are not correlated to each other (Gersmehl 2012; Gersmehl and Gersmehl 2006; Huynh and Sharpe 2013; Ishikawa 2013; Lee and Bednarz 2012; Sinton et al. 2013; Smith 2007; Voyer, Voyer, and Bryden 1995), thus leading to lower internal consistency among the test items.

Table 2. Geospatial thinking domains in the Geospatial Thinking Survey (GTS). (*Note*: 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, 5
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; reasoning 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 geospatial/ geographical conditions, connections, distance; inferring a geospatial aura (influence)	Cell 23: Complex-spatial concept; using tool of representation; reasoning at processing level	10

Validity shows how well a 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 and content validity because it covers a representative sample of the geospatial thinking skills discussed in the literature. The GTS is thus a reliable and valid test of geospatial thinking skills, and, as mentioned, the GTS drew its ten geospatial questions from the STAT (AAG 2006; Lee and Bednarz 2012).

5 ANALYSES AND DISCUSSION

5.1 Variables of Interest and Undergraduate Student Sample

The dependent variable was geospatial thinking ability measured by student scores on the GTS. A student's score varied between 0 and 10 based on the ten GTS questions. The independent variables were academic major and number of college geography courses (a measure of formal academic experience in undergraduate geography). The category—students who take multiple geography courses—does not necessarily mean the students are geography majors. Students with other academic majors who minor in geography or simply have a keen academic or personal interest in geography can also enroll in multiple geography courses, e.g., future K-12 teachers. Nevertheless, we intuitively expected a strong correlation between the variables geography majors and the number of geography courses taken.

Students with non-geography academic majors were the control group, and geography majors were the experimental group. Drawing from the geography education literature, taking geography courses was expected to act as an intervention to improve geospatial thinking. The research therefore examined whether a relationship existed between geography courses and geospatial thinking abilities of undergraduate students in the U.S.

5.2 Academic Major Scores on the GTS

We employed a one-way analysis of variance (ANOVA) to compare means on a quantitative Y dependent variable, the GTS score, across two groups of X independent variables, academic major and college geography. We ran ANOVAs (alpha = 0.05) in Statistical Package for the Social Sciences (SPSS) software for each of the two independent variables. We 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).

The ANOVA is a parametric test that assumes the data being analyzed are normally distributed (Monday, Klein, and Lee 2005). The GTS scores are approximately normally distributed (Figure 2). This normal distribution 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. The GTS as an assessment instrument therefore 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 their geospatial thinking assessment (GTA).

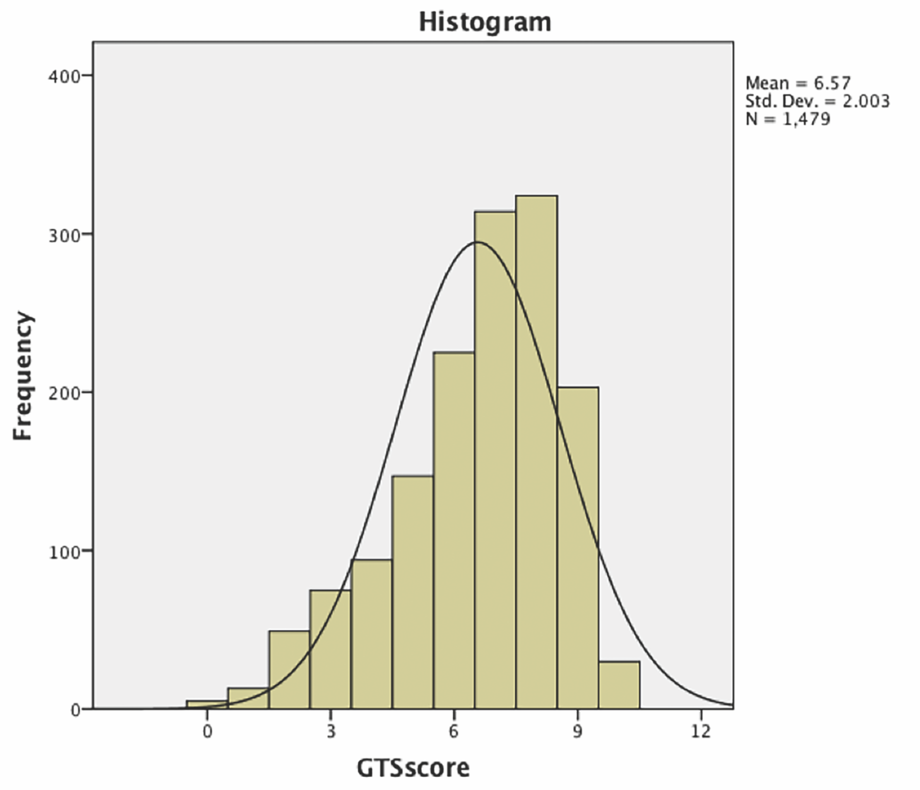


Figure 2. Histogram of student performance on the GTS.

For the GTS academic major question, respondents reported a large variety of academic majors. An academic major category with 30 or more respondents kept its distinct category. We grouped academic majors with less than 30 respondents into larger categories based on academic college affiliation. For example, 37 students reported history as their academic major; history was then 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 assigned to 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 were some of the academic majors grouped into the Humanities Majors category.

Table 3 exhibits the distribution of students in 18 academic major groups, arranged according to decreasing mean scores. There were Geography student(s) who scored the lowest of 2, while students from several disciplines scored either 9 or 10 on the GTS. There are always outliers and exception students in various disciplines. Hence, it is important to analyze the mean scores for different academic majors. The ANOVA found a statistically significant difference among the mean scores of different academic majors ($p < 0.001$). An association between academic major and student geospatial thinking ability thus exists. The mean score of geography majors (7.57) is the highest, while that of criminal justice majors (5.29) is the lowest. This finding confirms, at the national level, the empirical inferences drawn by Lee and Bednarz (2012) and Verma (2015) at local level about geography exerting a positive influence on undergraduates' geospatial thinking abilities. According to the GTS, geography students have better geospatial thinking abilities than non-geography majors. This outcome apparently is because geographic thinking and reasoning revolves around such spatial concepts as scale transformation, spatial association, distance and direction changes, and location identification (Cutter, Golledge, and Graf 2002; Golledge 2002).

Table 3. 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	15.1	<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**		

Such academic majors as psychology, business, health, nursing, education, communication, criminal justice, and other social science majors evidently do not place explicit and concerted emphasis on geospatial thinking concepts. This finding is discernable in Table 4 that displays the significant post-hoc comparisons for the academic major groups. Both geography and geology students scored significantly higher than nursing, health, psychology, criminal justice, education, communication, business, Other Social Science Majors, and No Major students.

Table 4. Significant post-hoc comparisons (Games-Howell) of GTS score by academic majors (p value in parentheses).

Academic Majors	Geog.	Geol.	Envt. Sci.	Other Scien.	Bio.	Engin-eering	Health	Nurs-ing
Other Science							-1.33 (0.04)	-1.45 (0.04)
Psychology	1.42 (0.001)	1.33 (0.03)						
Other Social Science	1.50 (<0.01)	1.42 (0.001)	1.14 (0.03)	1.09 (0.01)				
No Major	1.55 (0.001)	1.46 (0.02)						
Business	1.57 (<0.01)	1.48 (<0.01)	1.20 (0.01)	1.15 (0.001)	1.02 (0.01)			
Health	1.75 (<0.01)	1.66 (0.005)		1.33 (0.04)				
Nursing	1.87 (<0.01)	1.78 (0.005)		1.45 (0.04)				
Education	1.95 (<0.01)	1.87 (<0.01)	1.59 (<0.01)	1.53 (<0.01)	1.40 (<0.01)	1.34 (0.004)		
Communication	2.03 (<0.01)	1.95 (<0.01)	1.67 (0.001)	1.61 (<0.01)	1.48 (0.002)	1.42 (0.02)		
Criminal Justice	2.28 (<0.01)	2.19 (0.001)	1.91 (0.01)	1.86 (0.004)	1.73 (0.01)	1.67 (0.04)		

5.3 Effect of the Number of Geography Courses Taken

Table 5 shows the distribution of students with different academic experience in college geography measured by the number of undergraduate geography courses taken. Although the students who completed the survey were enrolled in geography classes, they were asked not to count the course they were currently enrolled in because it was not yet completed. The lowest score for student(s) who have taken more than 5 geography courses is 4, while there were student(s) who scored 10 from "None" geography course category. This is because there are always outliers and exceptions in various categories. Hence, it is important to analyze the mean scores for each category. The ANOVA found a statistical 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 (7.72) was the highest, while those students who had taken no college geography scored the lowest (6.10) on an average. Therefore, an association exists between the number of college geography courses taken and geospatial thinking ability. Post-hoc comparisons (Table 6) 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, most likely geography majors, scored significantly higher than students who had taken no, 1-2, or 3-5 college geography courses. These findings, in sum, corroborate that taking three or more geography courses seems to improve substantially student geospatial thinking skills, thereby suggesting that non-geography majors may wish to take multiple geography courses to improve their geospatial thinking skills.

Table 5. 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**
>5	253 (17.1)	10	10	4	7.72	44.93	<0.001
3-5	161 (10.9)	10	10	2	7.00		
1-2	812 (54.9)	10	10	0	6.27		
None	253 (17.1)	10	10	0	6.10		
Total	**1479 (100)**	**10**	**10**	**0**	**6.57**		

Table 6. Post-hoc comparisons (Games-Howell) of GTS score by number of college geography courses (p value in parentheses); significant contributors to the difference are in italics.

Number of College Geography Courses	**3-5**	**1-2**	**None**
>5	*-0.72 (<0.001)*	*-1.45 (<0.001)*	*-1.62 (<0.001)*
3-5		*-0.73 (<0.001)*	*-0.90 (<0.001)*
1-2			-0.17 (0.67)

College geography courses, then, are interventions that help to improve undergraduate student geospatial thinking, and undergraduate students should be encouraged to take geography courses. The empirical findings of this research thus support the conceptual assertions of such scholars as Battersby, Golledge, and Marsh (2006), Blaut (1991), Downs (1994), Golledge (2002), Liben (2006), and Uttal (2000) that geography education is an important academic vehicle in instilling spatial and geospatial thinking skills in students. The findings of this study, grounded in empirical national research, strongly suggest to educational policymakers and university educators that to ensure students are capable of competing globally in various employment areas (e.g., logistics, transportation, image analysis, urban planning, civil engineering, real estate, site analysis, military operations, location-based apps) that require solid geospatial thinking skills, geography should be integrated into fundamental aspects of university education. Students from other majors, such as nursing, criminal justice, education, or business, may be confronted with spatial and geospatial tasks in their work, but they probably will not be as equally competent. Future teachers who have poorer geospatial thinking abilities may struggle instructing their students in these skills (Shin, Milson, and Smith 2016). Non-geography students should therefore be encouraged to take foundational geography courses so they will be competent in school, workplace, and everyday life with higher geospatial thinking skills.

5.4 Student Performance on Individual Questions of the GTS

Digging deeper into the findings, we investigated the outcomes of specific GTS questions. Prior research has demonstrated that different spatial/geospatial thinking domains are not correlated, so people proficient at one type of spatial/geospatial thinking task may not be as capable at other spatial/geospatial thinking activities (Gersmehl 2012; Gersmehl and Gersmehl 2006; Huynh and Sharpe 2013; Ishikawa 2013; Lee and Bednarz 2012; Sinton et al. 2013; Smith 2007; Voyer, Voyer, and Bryden 1995). Spatial/geospatial skills, moreover, vary in their malleability (Metoyer and Bednarz 2016). Both spatial and geospatial thinking are therefore combinations of distinct and overlapping skills that may be affected differently by demographic, ethnic, or academic variances of people.

Individual questions of the GTS represent different geospatial thinking domains (Table 2). Students may perform well at one component of geospatial thinking and not on others, thereby requiring the examination of each GTS question to assess student performance in separate geospatial thinking domains. We used the chi-square test of independence to interpret group differences for distinct geospatial thinking domains of students with varying college geography experience. We ran chi-square (alpha = 0.05) to analyze whether differences in college geography experience were associated with an understanding of each geospatial thinking domain. The student responses on individual questions were categorical, as they were coded dichotomously, i.e. correct or incorrect. To analyze whether college geography experience and a particular GTS question were associated, we used the chi-square test for each of the ten questions. This analysis was important for identifying specific pedagogical and curricular intervention areas (Tomaszewski et al. 2015).

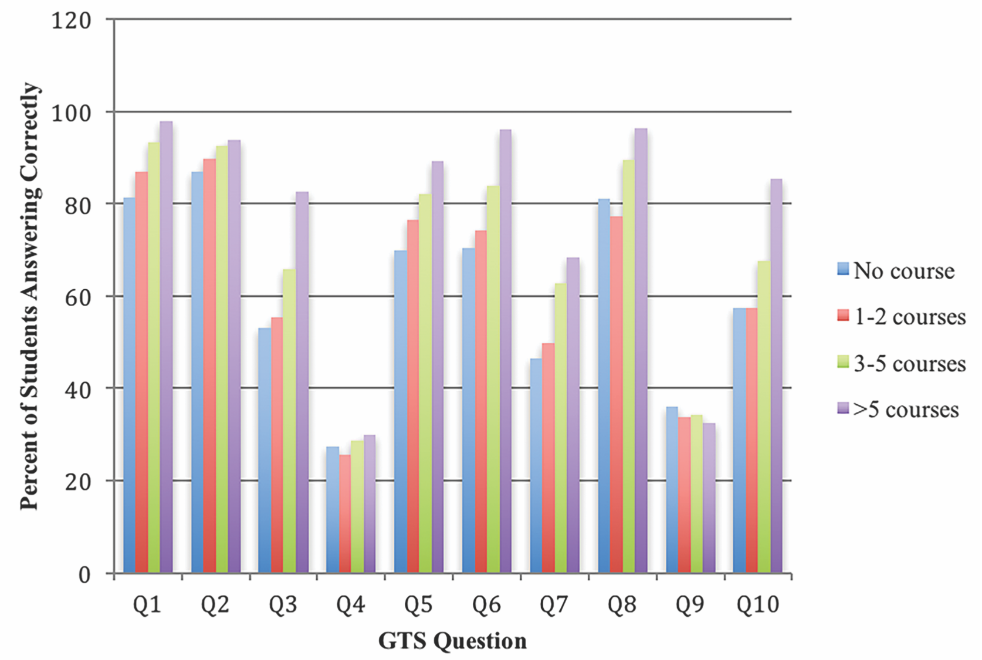


Figure 3. Student performance on GTS questions based on number of college geography courses taken.

Figure 3 and Table 7 show the relationship between college geography courses and understanding of various geospatial thinking domains. Such geospatial thinking abilities as geospatial pattern and transition (Q1), geospatial profile and transition (Q3), geospatial association (Q5), geospatial shapes (Q6, 7, 8), and geospatial overlay (Q10) were statistically associated with differences in college geography experience (Table 7). This outcome means that studying geography courses in college influences the understanding of these fundamental geospatial concepts. For example, 98 percent of the undergraduate students who took more than five geography courses and 93 percent of students who took 3-5 geography courses answered Q1 (geospatial pattern and transition) correctly, while only 81 percent of students who took no college geography courses answered the question correctly. Table 7 and Figure 3 present similar results for other significant associations for questions 3, 5, 6, 7, 8, and 10. The comprehension of direction and orientation (Q2), geospatial association and transition (Q4), and one of four questions about geospatial shapes (Q9) is independent of college geography experience (Table 7). Although 94 percent of the undergraduate students who took more than five geography courses and 93 percent of those who took 3-5 geography courses answered Q2 (direction and orientation) correctly as opposed to 87 percent of students who took no college geography courses, no significant difference exists regarding the association between understanding of direction and orientation and college geography experience (Table 7). Direction and orientation (Q2) was the easiest question on the GTS for most of the students, as 90 percent of the students answered the question correctly. In a study undertaken by Tomaszweski et al. (2015), students also scored highest on direction and orientation question on a modified version of the STAT. Q2 represents a simple-spatial concept (Table 2), and undergraduate students seem to be good at map navigation, wayfinding, and route planning, irrespective of how many college geography courses they have taken. Q4 compels students to first discern geospatial association between two maps, and then transfer the information to a graph, thereby involving more complex geospatial reasoning. Only 27 percent of the students answered Q4 correctly (Table 7), as it is a complex-spatial concept (Table 2). Although Q9 from the Geospatial Shapes domain represents a simple-spatial concept (Table 2), it entailed analyzing points and areas in terms of geographical data. Only 34 percent of the students answered Q9 correctly (Table 7). Tomaszewski et al. (2015) also observed that students scored low on the questions on comprehending geographic features as point, line, or polygon. Both Q4 and Q9 were too difficult for the students regardless of their academic exposure to college geography. These outcomes indicate the need for either further refinement of the GTS and STAT question design or the adoption of appropriate pedagogical approaches in geography classes (Tomaszewski et al. 2015) to address these weaknesses in geospatial thinking ability.

Table 8 shows internal comparisons of significant associations between college geography experience and different geospatial thinking domains. The results suggest that undergraduate curricula should identify specifically students who have not taken any college geography courses so their geospatial thinking ability in certain domains can be strengthened. Students who have studied more than five college geography courses have better understanding of geospatial pattern and transition, geospatial profile and transition, geospatial association, geospatial shapes, and geospatial overlay; whereas students with less than three college geography courses have poor comprehension of these domains. Taking multiple college geography courses, then, seems to be a basic way of improving student comprehension of these geospatial concepts.

Table 7. Association of college geography experience with different geospatial thinking domains.

Geospatial Thinking Domain	Number of College Geography Courses Taken	Number of Student Responses (%)		Chi-Sq.	p value	Result
		Correct	Incorrect			
Q1 Geospatial Pattern and Transition	>5	248 (98.0)	5 (2.0)	40.59	<0.01	Differences exist
	3-5	150 (93.2)	11 (6.8)			
	1-2	706 (86.9)	106 (13.1)			
	None	206 (81.4)	47 (18.6)			
Q2 Direction and Orientation	>5	237 (93.7)	16 (6.3)	7.67	0.053	No differences exist
	3-5	149 (92.5)	12 (7.5)			
	1-2	729 (89.8)	83 (10.2)			
	None	220 (87.0)	33 (13.0)			
Q3 Geospatial Profile and Transition	>5	209 (82.6)	44 (17.4)	68.58	<0.01	Differences exist
	3-5	106 (65.8)	55 (34.2)			
	1-2	450 (55.4)	362 (44.6)			
	None	134 (53.0)	119 (47.0)			
Q4 Geospatial Association and Transition	>5	76 (30.0)	177 (70.0)	2.05	0.562	No differences exist
	3-5	46 (28.6)	115 (71.4)			
	1-2	209 (25.7)	603 (74.3)			
	None	69 (27.3)	184 (72.7)			
Q5 Geospatial Association	>5	226 (89.3)	27 (10.7)	31.31	<0.01	Differences exist
	3-5	132 (82.0)	29 (18.0)			
	1-2	620 (76.4)	192 (23.6)			
	None	177 (70.0)	76 (30.0)			
Q6 Geospatial Shapes	>5	243 (96.0)	10 (4.0)	67.15	<0.01	Differences exist
	3-5	135 (83.9)	26 (16.1)			
	1-2	603 (74.3)	209 (25.7)			
	None	178 (70.4)	75 (29.6)			
Q7 Geospatial Shapes	>5	173 (68.4)	80 (31.6)	37.37	<0.01	Differences exist
	3-5	101 (62.7)	60 (37.3)			
	1-2	404 (49.8)	408 (50.2)			
	None	118 (46.6)	135 (53.4)			
Q8 Geospatial Shapes	>5	244 (96.4)	9 (3.6)	54.93	<0.01	Differences exist
	3-5	144 (89.4)	17 (10.6)			
	1-2	628 (77.3)	184 (22.7)			
	None	205 (81.0)	48 (19.0)			
Q9 Geospatial Shapes	>5	82 (32.4)	171 (67.6)	0.74	0.862	No differences exist
	3-5	55 (34.2)	106 (65.8)			
	1-2	274 (33.7)	538 (66.3)			
	None	91 (36.0)	162 (64.0)			

Q10 Geospatial Overlay	>5	216 (85.4)	37 (14.6)	70.07	<0.01	Differences exist
	3-5	109 (67.7)	52 (32.3)			
	1-2	467 (57.5)	345 (42.5)			
	None	145 (57.3)	108 (42.7)			

Table 8. Internal comparisons of college geography experience with significant differences in various geospatial thinking domains (significant contributors to the association are in italics).

Variable	**Number of College Geog. Courses Taken**	**Standardized Residuals**		**Significant Contributors to the Association and Internal Comparisons**
		Correct	**Incorrect**	
Q1 Geospatial Pattern and Transition	>5	1.6	***-4.4***	Fewer students with >5 college geography courses than expected answered Q1 incorrectly, thus outperforming the other groups. More students with no college geography than expected answered Q1 incorrectly, thus under-performing the other groups.
	3-5	0.6	-1.7	
	1-2	-0.5	1.4	
	None	-1.2	***3.4***	
Q3 Geospatial Profile and Transition	>5	***4.5***	***-5.5***	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. Fewer students with 1-2 college geography courses than expected answered Q3 correctly, and more students with 1-2 and no college geography courses than expected answered Q3 incorrectly, thus underperforming the other groups.
	3-5	0.8	-1.0	
	1-2	***-2.0***	***2.4***	
	None	-1.6	***2.0***	
Q5 Geospatial Association	>5	***2.0***	***-3.8***	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. More students with no college geography than expected answered Q5 incorrectly, thus underperforming the other groups.
	3-5	0.6	-1.1	
	1-2	-0.6	1.1	
	None	-1.5	***2.8***	
Q6 Geospatial Shapes	>5	***3.2***	***-6.0***	More students with >5 college geography courses than expected answered Q6 correctly, and fewer students with >5 college courses than expected answered Q6 incorrectly, thus outperforming the other groups. More students with 1-2 and no college
	3-5	0.8	-1.5	
	1-2	-1.3	***2.5***	

	None	-1.4	***2.7***	geography courses than expected answered Q6 incorrectly, thus underperforming the other groups.
Q7 Geospatial Shapes	>5	***3.2***	***-3.4***	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.
	3-5	1.5	-1.7	
	1-2	-1.6	1.7	
	None	-1.6	1.7	
Q8 Geospatial Shapes	>5	***2.4***	***-5.3***	More students with >5 college geography courses than expected answered Q8 correctly, and fewer students with >5 and 3-5 college geography courses than expected answered Q8 incorrectly, thus outperforming the other groups. More students with 1-2 college geography courses than expected answered Q8 incorrectly, thus underperforming the other groups.
	3-5	1.0	***-2.1***	
	1-2	-1.6	***3.6***	
	None	-0.3	0.6	
Q10 Geospatial Overlay	>5	***4.4***	***-5.8***	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. Fewer students with 1-2 college geography courses than expected answered Q10 correctly, and more students with 1-2 college geography courses than expected answered Q10 incorrectly, thus underperforming the other groups.
	3-5	0.7	-0.9	
	1-2	***-2.1***	***2.7***	
	None	-1.2	1.6	

6 CONCLUSIONS AND RECOMMENDATIONS

Research suggests that spatial thinking is important for academic success in geography and other disciplines (Metoyer and Bednarz 2016; Newcombe 2010; Uttal et al. 2013), yet no consensus exists in the literature about constructive methods and interventions for explicitly teaching spatial thinking to the students (Metoyer and Bednarz 2016). From the results of our study, geography seems to be an academic subject that can help undergraduate students in effectively acquiring geospatial thinking skills, a specific type of spatial thinking skills. This national study empirically informs the literature about the differences in geospatial thinking skills among students with varying academic majors and academic experience in college level geography. Such variables as academic major and academic experience in college geography courses seem to influence positively student geospatial thinking skills. The findings of the ANOVA analysis confirmed that geography majors and students who had taken at least three geography courses performed better on the GTS geospatial questions.

Although this research did not expand on the specific geographic tools or methods contributing to improved geospatial thinking abilities, it corroborated through a national investigation local studies regarding the conceptual reasoning and findings of Albert and Golledge (1999), Battersby, Golledge, and Marsh (2006), Bodzin (2011), Kemp (2008), Lee (2005), Lee and Bednarz (2009), Marsh, Golledge, and Battersby (2007), Perkins et al. (2010), and Shin, Milson, and Smith (2016) that such geography activities as map, GIS, and GPS exercises inculcate geospatial thinking skills in students. Both geographic tools (e.g., maps, GIS, and GST) and geographic inquiry (provided by practicing geospatial thinking) in combination are important in learning spatial/geospatial thinking skills (Metoyer and Bednarz 2016). Students may know how to use maps, spatial data, or GIS, but, in the absence of geographic inquiry, they may not be able to apply appropriate geospatial thinking necessary to solve real-world problems.

This investigation should be useful in higher education policymaking and disciplinary funding by encouraging undergraduates to enroll in geography classes to help obtain foundational understandings of geospatial concepts. The preparation of future geography teachers should certainly include explicit attention to geospatial thinking. Educators should thus use the data and findings to persuade educational policymakers to fund geography education across university curricula.

Geospatial thinking is not a unitary construct but a combination of multiple interlinked dimensions. This study, corroborating previous research (Gersmehl and Gersmehl 2006; Huynh and Sharpe 2013; Ishikawa 2013; Lee and Bednarz 2012; Tomaszewski et al. 2015), underscores how undergraduate students from different academic backgrounds employ geospatial thinking differently in dissimilar, noncorrelated geospatial thinking domains, and thus identified specific geospatial thinking skill weaknesses of undergraduate students. The chi-square analysis found a strong evidence of association of college geography courses with geospatial pattern and transition, geospatial profile and transition, geospatial association, geospatial shapes, and geospatial overlay. Students who studied at least three college geography courses performed better than those who studied two or fewer college geography courses on the foregoing geospatial thinking domains.

Assessment tools, such as the GTS, STAT, and GTA are important conceptual inventories to diagnose geospatial thinking competencies among students prior to instruction and after intervention. Such assessments are also critical in identifying difficult, challenging, or misconceived concepts of geospatial thinking. Instructors should therefore take time to discover their students' geospatial strengths and weaknesses, using such assessments as the GTS, in each course and then target those geospatial concepts that explicitly need attention. For instance, some students may require more involvement with geospatial association, while others may demand extra help with geospatial shapes. Based on the differences highlighted in students' geospatial thinking skills, educators should then refine and restructure geography undergraduate teaching, including curriculum, textbooks, classroom modules, and assessments.

The findings of this research adds to the body of scarce geospatial thinking research in higher education and thus answers the call from the National Research Council and several scholars to gather empirical data based on reliable and valid assessments and consider issues of representativeness and replicability. Data collection in the field of geography education is also vital in aiding the development of coherent learning theories and predictions about student geospatial knowledge and thinking abilities. Scholars may use the findings of such research to conduct further inquiries, particularly qualitative investigations, about geospatial thinking abilities and to strengthen student standardized testing regarding geospatial thinking skills.

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