GIS Integration in Secondary School Classrooms: Effects on Student and Teacher Spatial Thinking Ability

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Introduction

The National Research Council report (NRC, 2006) defines spatial thinking as "the knowledge, skills, and habits of mind to use concepts of space and representations, and processes of reasoning to structure problems, find answers, and express solutions to these problems". Authors in NRC 2006 and 2013 reports argue that spatial thinking is universal and useful in a wide variety of academic disciplines and everyday problem-solving situations, and should be taught at all levels in the educational systems, especially in science education (Lee & Bednarz, 2009; NRC, 2006; Uttal & Cohen, 2012). They call to foster spatial literacy in students who have the habit of mind of thinking spatially, practice spatial thinking in an informed way, and adopt a critical stance to spatial thinking (NRC, 2006).

In order to cultivate students' spatial thinking ability, there are growing interests on teachers' spatial thinking skills and spatial thinking classroom integration (Jo & Bednarz, 2014; Jo, 2011; Shin, Milson & Smith, 2016). Spatial thinking skills become an emerging topic in teachers' professional development and training, in order to prepare teachers to infuse spatial thinking into their instruction (Bednarz & Audet 1999; Jo & Bednarz, 2014; Shin, Milson & Smith, 2016).

In addition, for the purpose of spatial thinking development in teaching and learning, NRC (2006) emphasizes the significance of using geographic information system (GIS). GIS is an integrated system of hardware, software, and procedures designed to support the collection, management, manipulation, analysis, modeling, and display of spatially referenced data about Earth's surface in order to solve complex planning and management problems (NRC, 2006). NRC (2006) states "GIS has a clearly demonstrated potential as a support system for spatial thinking" and "must be brought to bear in fostering an understanding for and appreciation of spatial thinking".

However, despite of the importance of spatial thinking on students and teachers, there are several research gaps that have not been addressed. For example, only a few empirical studies have tested the idea of NRC (2006) that learning using GIS can positively impact students' spatial thinking ability (e.g., Bodzin, 2010; Lee &Bednarz, 2009; Madsen & Rump, 2012; Jo, Hong & Verma, 2016). Further, even fewer studies have focused on exploring secondary school students' and teachers' spatial thinking ability, and the possible factors influencing students' spatial thinking ability (Shin, Milson & Smith, 2016); prior studies only tested the impact of taking GIS courses rather than integrating GIS into regular science classes (Bodzin and Cirucci, 2009; Milson and Earle, 2008; Madsen & Rump, 2012). Insights on how to improve students' spatial thinking ability are needed (Lee & Bednarz, 2009, 2012; Tomaszewski et al. 2015). The current study intended to fill research gaps described above.

The study is taking place within the context of the geo-technology experiences for students and teachers (GTEST), a National Science Foundation (NSF) funded project. The aim of GTEST is to provide middle and high school students and teachers with geo-technology experiences in order to improve students' spatial thinking and train future geo-spatially competent workers. Specifically, the three research questions for the current study are:

(1) What is the status of middle and high school students' and teachers' spatial thinking ability?

(2) Does integrating GIS in secondary school science, social studies, and technology curriculum facilitate students' spatial thinking ability?

(3) What are the factors influencing students' spatial thinking ability?

Theoretical Framework

The term "spatial thinking" has been used in both nonacademic and academic settings extensively. A variety of spatial thinking definitions exist, such as Gersmehl (2005), Golledge et al. (2008) and Janelle and Goodchild (2009). Besides, in geography education, the concept of spatial thinking has a nebulous meaning as various terms, such as thinking spatially, geospatial thinking, spatial intelligence, and spatial ability, are used synonymously (Huynh & Sharpe 2013).

A growing interest in understanding the role of spatial thinking skills in education is evidenced in the National Research Council report on Learning to Think Spatially (NRC, 2006). Through multi-year collaboration among experts in different fields, including education, geography, earth science, planetary science, psychology and cognitive science, the report clarifies definitions, concepts, and categories of spatial thinking and provides a framework of spatial thinking for today's education (NRC, 2006). In addition, it examines how spatial thinking might be incorporated into existing standards-based curriculums, and emphasizes that spatial thinking must be recognized as a fundamental part of k-12 education and as an integrator and a facilitator for problem solving across curriculums (NRC, 2006).

NRC (2006) introduces three spatial thinking contexts: life space (cognition in space), physical space (cognition about space), and intellectual space (cognition with space). Spatial thinking in life space means to build on the four-dimensional world of space-time to grip the spatial relations between self and objects in the physical environment. Spatial thinking in physical space means to build on the four-dimensional world of space-time with a focus on understanding the nature, structure, and function of phenomena. Spatial thinking in intellectual space means to understand relationships among concepts and objects that are not in and of themselves necessarily spatial, but the nature of the space that is defined by the particular problem (NRC, 2006).

The report also introduces several ways in which spatial thinking may be characterized (NRC, 2006). For example, spatial thinking can be broken down into three different components: spatial knowledge, spatial ways of thinking and acting, and spatial capabilities:

- Spatial knowledge includes concepts such as symmetry, orientation, rotation scale, relative vs. absolute distance, and distance decay;
- Spatial ways of thinking and acting are recognizing and using the similarity distance metaphor, using diagramming or graphing in problem-solving, recognizing clusters and patterns in data, separating change over space from change over time, knowing how, where, and when to use the various spatial-thinking strategies, and being critically aware of the strengths and limitations of each of these strategies;
- Spatial capabilities include the ability to use supporting tools and technologies such as spreadsheet, graphical, statistical and GIS software to help in problem-solving.

Another way of characterizing spatial thinking is based on the following three components: concepts of space, i.e., relationships among units of measurement, different ways of calculating distance; tools of representation, such as understanding of relationships among views, and effects of geographic projections; and processes of reasoning, such as the ability to think about shortest distances in different ways, and make decisions based on spatial information (NRC, 2006). The third way of characterizing spatial thinking is by differentiating spatial component tasks, such as extracting spatial structures, performing spatial transformations, and drawing functional inferences. Within the framework of spatial thinking provided by NRC (2006), there is not only one way to characterize spatial thinking, and the above various characterizations of spatial thinking are all acceptable.

Within the contexts and characteristics of spatial thinking introduced by NRC (2006), several theories of spatial thinking components are developed (e.g., Germehl, 2005; Golledge et al., 2008; Janelle & Goodchild, 2009). By reviewing the theories, Lee and Bednarz (2012) developed eight spatial thinking components. In the current study, we tested three of the eight spatial thinking ability components, which are (1) visually navigate road maps using verbal information including a participant's current location, direction to destination, street information; (2) visually verify a map overlay process and select the appropriate maps layers involved in the overlay; and (3) visually extract types of spatial data from verbally expressed spatial information (Lee & Bednarz, 2012).

Literature Review

Spatial Thinking and Learning

The researchers (geographers, astronomers, psychologists and educators) in the reports of National Research Council 2006 and 2013 argue that spatial thinking is universal and useful in a wide variety of academic disciplines and everyday problem-solving situations. The researchers claim that spatial thinking can and should be taught at all levels in the educational system (NRC, 2006).

For example, prior studies provided sufficient evidences on the idea that spatial thinking is fundamental to the theoretical and practical underpinnings of geography (e.g., Huynh & Sharp, 2013; Kim & Bednarz, 2013; Favier & Joop, 2014; Xiang & Liu, 2017). The nature of geography study is to explore patterns and processes of phenomenon on the Earth's surface at a variety of scales (Huynh & Sharp, 2013). Due to the nature of geography, which is to explore the concept of space, spatial thinking is the core ability during the process (Huynh & Sharp, 2013).

Research indicates that proficiency in spatial thinking is associated with success in engineering, architecture, medicine, mathematics, and sciences learning (e.g., Hegarty, 2010; Uttal, Miller & Newcombe, 2013; Uttal & Cohen, 2012; Wu & Shah, 2014). For example, Uttal, Miller & Newcombe (2013) reviewed the relationship between achievement in science, technology, engineering, mathematics (STEM), and spatial thinking, and the results indicate that spatial training could improve STEM learning. Specifically, in chemistry, the behavior of isomers has a close relationship with spatial configurations (Uttal & Cohen, 2012), and in biology, understanding of cell structure can be enhanced through spatial visualization (Wu & Shah, 2014).

Despite of the importance of spatial thinking ability in teaching and learning, most studies of spatial thinking ability are within the subject of geography (Jo & Bednarz, 2014; Jo, 2011; Shin, Milson & Smith, 2016; Lee & Bednarz, 2009); very little research explored spatial thinking in other disciplines, such as science and technology (Bodzin, 2010; Sorby, 2009). Thus, more research needs to be done in broader disciplines.

Geospatial Technology and Learning

Geospatial technologies are technologies for collecting or processing data related to space and location, such as Google Earth, remotely sensing satellites and aerial images, geographic information systems (GIS), and ArcExplorer. Those geospatial technologies allow individuals to examine the world through multiple layering of data within a spatial environment (Doering & Veletsianos, 2008). Geospatial technologies have become readily accessible, widely available, and more apparent in our daily lives than ever before (Bodzin & Cirucci, 2009), and they start to be used for teaching and learning in classrooms.

A number of studies have found that geospatial related technology could improve student learning in a variety of ways (e.g., Bodzin & Cirucci, 2009; Doering & Veletsianos, 2008; Milson & Earle, 2008). For example, Milson and Earle (2008) developed an internet-based geographic information system (IGIS) for ninth graders to improve their geography learning outcomes. Students used IGIS in teams to examine the geography features of Africa (Milson and Earle, 2008). By enhancing students' freedom in classroom and letting them construct knowledge about key concepts in geography, the results indicate that IGIS can be a successful tool for geography education in an inductive learning environment (Milson & Earle, 2008). The results suggest expanded freedom from student perspective as a positive aspect of IGIS project and IGIS projects can lead to gains in students' cultural awareness and empathy for distant others (Milson & Earle, 2008).

Bodzin and Cirucci (2009) conducted a study focusing on the use of Google Earth, remotely sensed satellite, and aerial imagery on geography study in middle school. They focused on investigating students' study on ground cover and land use (Bodzin & Cirucci, 2009). By analyzing students' assessment after practicing geospatial-technology, they found that integrating geospatial technologies with focus on development of spatial thinking skills could provide a platform for effectively achieving education goals (Bodzin & Cirucci, 2009).

Thus, prior studies suggest that geospatial technologies could be integrated into geography class since it could improve students learning in a variety of ways, such as developing spatial thinking skills, and inducting educational environment. However, above studies only focus on students' study in geography. Previous research suggests that geospatial technologies not only can be integrated into geography, but also can be used in several other subjects, such as STEM courses and social studies (Alibrandi, 2003; Alibrandi & Sarnoff, 2006; Donaldson, 2011). In addition, geospatial-technologies also positively impact students' attitude and motivation (Baker and White 2003; West 2003). In this case, geospatial technologies can and should be brought into classroom, but the actual practice in classroom still lags far behind what academics and organizations had hoped for a decade ago (Doering & Veletsianos, 2008; NRC, 2006).

Geography Information System and Spatial Thinking Ability

Although it is tempting to believe that cognitive abilities are fixed, there are enough evidences support that spatial thinking ability can be improved through various learning activities (e.g., Terlicki, Newcombe, & Little, 2008; Wright et al., 2008; Uttal, Miller & Newcombe, 2013; Gold et al., 2018), such as direct spatial thinking ability training (Wright et al., 2008), and integrating spatial thinking techniques in disciplinary classes (Bodzin, 2010; Gold et al., 2018). Newcombe & Stieff (2012) found that the differences among people's spatial thinking ability may be due to the length and frequency of doing spatial thinking related activities, or the use of training techniques that are more efficacious, or both. In other words, it is important to have appropriate techniques and intervention design to improve spatial thinking ability.

National Research Council (2006) illustrates that GIS is an integrated system of hardware, software, and procedures designed to support the collection, management, manipulation, analysis, modeling, and display of spatially referenced data about Earth's surface in order to solve complex planning and management problems. National Research Council (2006) also shows that GIS have clearly demonstrated potential as a support system for spatial thinking and must be brought to foster an understanding for and appreciation of spatial thinking. All students deserve and need the opportunity to be challenged, to be supported and to become critical spatial thinkers.

A few empirical studies test the idea of NRC (2006) that learning to use GIS can positively impact students’ spatial thinking ability (e.g., Lee &Bednarz,2009; Madsen & Rump, 2012). For example, Lee and Bednarz (2009) studied GIS's effect on university students' spatial thinking ability. They conducted pre- and post-test to 80 university students before and after taking GIS related courses, such as GIS Introduction and Computer Cartography. Non-GIS users served as control group in the study. They found hands-on, lab- or project-based experience could improve students' spatial thinking, and greater improvement occurred in skills closely connected to or supported by students' experience with spatial representations through their completion of geo-technology course work (Lee & Bednarz, 2009).

Madsen and Rump (2012) also studied the use of GIS as an instrument for developing spatial thinking. The participants of the study were first-year geography major students who took GIS and Cartography course, and the study focused on students' learning processes in using GIS (Madsen & Rump, 2012). The results of the study indicate that in the process of using GIS, students have different strategies for creating their personal instrument for spatial thinking; it is important to support students in the process of using GIS, to make GIS a personal instrument in developing their spatial thinking (Madsen & Rump, 2012).

Kim and Bednarz (2012) focused on developing students' critical spatial thinking through using GIS. Similarly, they hypothesized that GIS would have a positive effect on students' spatial thinking (Kim & Bednarz, 2012). The participants of their study were upper-level undergraduate students, who enrolled in introductory GIS course and geography course. The results indicate that GIS learning is beneficial in enhancing students' critical spatial thinking, identified as the ability to assess data reliability, use sound spatial reasoning, and evaluate problem-solving validity.

However, research that supports the positive impact of GIS on spatial thinking is still lacking or inconsistent (Lee & Bednarz, 2009). Several studies suggest that more works need to be done to explore the connections between GIS and students' learning, particularly through students' spatial thinking ability (Gatrell, 2005; Keiper,1999; Wiegand 2003; Lee and Bednarz, 2009).

Also, NRC (2006) identifies a great challenge to develop students' spatial thinking: How might current versions of GIS be incorporated into existing standards-based instruction in all knowledge domains across the school curriculum? The challenge has not been fully addressed. Prior studies only tested the impact of taking GIS courses rather than integrating GIS into disciplinary based curriculums (Bodzin and Cirucci, 2009; Milson and Earle, 2008; Madsen & Rump, 2012). Insights on how to improve students' spatial thinking ability by GIS curriculum integration are needed (Lee & Bednarz, 2009, 2012; Tomaszewski et al. 2015).

Factors Influencing Spatial Thinking Ability

We have very limited understanding on the factors influencing one's current spatial thinking ability. Prior studies indicate gender could be one of the factor. For example, men outperform women (Voyer, Voyer, & Bryden, 1995; Ceci &Williams, 2010; Sorby, 2009), women might lack spatial skills to succeed in science (Summers, 2005; Newcombe & Stieff, 2011). Specific for secondary school students, Tomaszewski et al. (2015) conducted a study to measure high school and middle school students' spatial thinking ability. They found that male students outperformed females in spatial thinking ability.

Grade level could be another factor that influences spatial thinking ability. For example, university students' spatial thinking ability is higher than that of secondary school students (Lee & Bednarz, 2012). Also, recent studies have reached a consensus that GIS has an important role in developing students' spatial thinking ability (Qiu 2006; Huynh 2009; Lee and Bednarz 2009; Kim 2011); In other words, it is reasonable to hypothesize that some GIS related factors could impact students' spatial thinking ability, such as students' ability of using GIS. However, how the above factors may influence students' spatial thinking ability has not been explored, especially for secondary school students.

Method

GTEST Research Project

This study is based upon a project supported by the National Science Foundation, Geo-Technology Experience for Students and Teachers (GTEST). GTEST is a three-year ongoing project starting in Spring 2017. The purpose of GTEST is to prepare teachers to engage middle and high school students in high-needs and high-potential school districts with cutting-edge web GIS technologies in order to improve their spatial thinking skills and motivate them to pursue geo-technology related educational experiences. These experiences prepare them to become part of a diverse next-generation IT workforce.

Sites

The sites of GTEST project are two high-needs and high-potential urban school districts. District A serves an economically and culturally diverse population of approximately 32,000 students, many of whom are struggling to meet the state standards. Among the district student population, 22.3% are white (non-Hispanic), 52.8% black, 16.1% Hispanic, 5.6% Asian or pacific islanders, and 1.3% American Indian or native of Alaska. District B has about 7,000 students in 11 schools. The percentage of students who qualify for free and reduced lunch is 75.14%. Among the student population, 56% are White (non-Hispanic), 37% black, 2% Hispanic, 4% native American, and 1% Asian.

Participants

The current study used the first two years GTEST project data (2017-19). For teacher participants, the current study involved total of 17 teachers in the two years. Table 1 shows the teacher demographic information. Year 1 teachers teach Biology, Earth Science, Geology, Environmental Science, Criminal Justice, and Technology. Teacher 8, 9, 10 from year 1 were also recruited to participate in year two; the rest seven teachers in year two were new to GTEST project. Year 2 teachers teach Science, Biology, Earth Science, Geology, Environment Science, Social Studies, and Technology.

For student participants, in year one, the study involved 430 students from grade 8 to 12. In year two, the study involved 544 students from grade 7 to 12. During the two years, a total of 974 students experience GIS integrated instruction in class. Table 2 shows the student demographic information.

Design

Figure 1 presents the research timeline. In each summer, 10 teachers were invited to join a summer camp to learn different GIS tools; in the meantime, each teacher developed GIS integration lessons to be taught during the upcoming academic year. The summer camp was

Table 1. Demographics of Participating Teachers (N = 17)

Teacher ID	Participating Year	District	Gender	Race	Subject Teaching	Grade Level
1	2017-18	A	M	Multi-Race	Biology	9th
2	2017-18	A	F	White	Biology	8th
3	2017-18	A	F	White	Earth Science	10th
4	2017-18	A	F	Black	Criminal Justice	10th
5	2017-18	A	M	White	Biology	9th
6	2017-18	A	F	White	Living Environment	9th
7	2017-18	B	F	White	AP Environmental Science	12th
8	2017-19	A	F	White	Earth Science AP Environmental Science	9th - 12th 11th
9	2017-19	B	M	White	Technology	8th
10	2017-19	B	M	White	Geology	9th and 10th
11	2018-19	A	M	White	Science	7th
12	2018-19	A	F	White	AP Environmental Science	12th
13	2018-19	A	F	White	Living Environment	9th
14	2018-19	B	M	Multi-Race	Social Studies	7th
15	2018-19	B	M	White	Science	7th
16	2018-19	B	M	White	Technology	8th
17	2018-19	A	M	White	Biology	8th

Table 2. Demographics of Participating Students (N = 974)

	Number of Students	Percentage
Gender		
Male	466	47.8%
Female	496	52.2%
Race		
Black	175	33.5%
White	222	42.5%
Hispanic	75	14.4%
Asian	20	3.8%
Multi-race	29	5.2%
Grade		
7th	179	18.4%
8th	473	48.6%
9th	216	22.2%
10th	52	5.3%
11th	31	3.2%
12th	16	1.6%

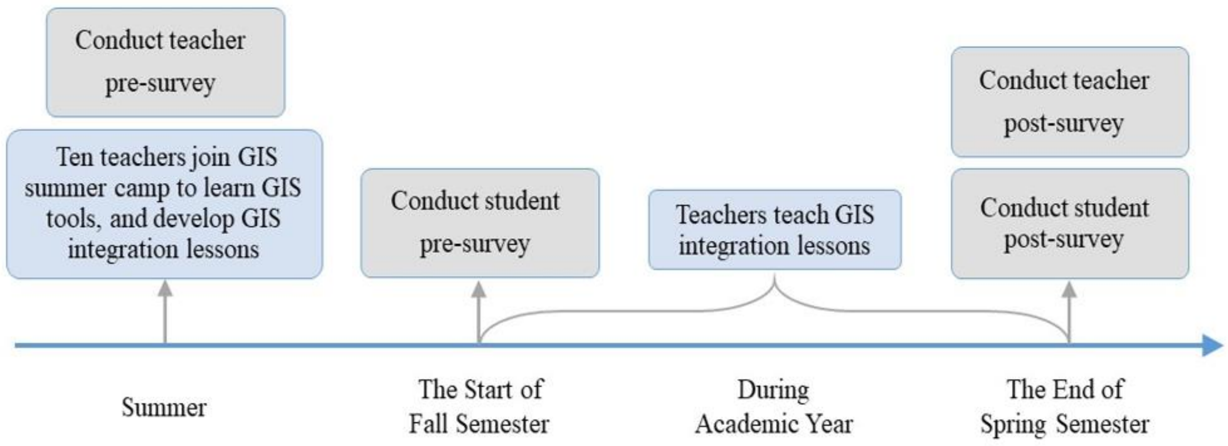


Figure 1. **Research Timeline**

Table 3. GIS Tools and Related Spatial Thinking Components

The Five GIS Tools in Camp	Spatial Thinking Components (Lee & Bednarz, 2012)
Google Earth	• Comprehending orientation and direction • Discerning spatial patterns and graphing a spatial transition • Overlaying and dissolving maps • Representations and images from one dimension to another and the reverse • Comprehending integration of geographic features represented as points, networks, and regions; comprehending spatial shapes and patterns • Discerning spatial patterns and graphing a spatial transition
ArcGIS Online and Collector	• Discerning spatial patterns and graphing a spatial transition • Overlaying and dissolving maps • Comprehending integration of geographic features represented as points, networks, and regions; comprehending spatial shapes and patterns
Esri Story Maps	• Comprehending orientation and direction • Comprehending integration of geographic features represented as points, networks, and regions; comprehending spatial shapes and patterns
Sketch Up	• Being able to transform perceptions, representations and images from one dimension to another and the reverse
Drones	• Recognizing spatial form • Comprehending orientation and direction • Representations and images from one dimension to another and the reverse

facilitated by experts in geo-technology, curriculum and instruction, counseling psychology, and industrial and government GIS partners. The camp curriculum systematically introduced five advanced and well-liked geo-technology tools: Google Earth, ArcGIS Online and Collector, Esri Story Maps, Sketch Up, and drones, and the related GIS concepts and skills. The use of the five GIS tools is closely related to several spatial thinking abilities as shown in Table 3.

Duration of the summer camp was three weeks, 15 days. In each day, the camp instructor introduced the use of certain GIS tools and associated spatial thinking concepts and skills. Teachers were also asked to spend one-hour each day in the camp to design GIS integrated lessons. During the one-hour lesson design period, several GIS curriculum integration resources were shared and introduced to teachers to support their GIS integration instructional design. At the end of the camp, each teacher developed 5 GIS integration lessons ready to be taught during the upcoming academic year, Teachers' sample GIS integration lesson plans are shown in Appendix A.

After learning the use of GIS tools, teachers taught the developed GIS integration science, social studies, and technology lessons during the academic year so that their students were able to experience GIS. Other than the five lessons designed in the summer camp, teachers continually designed and taught GIS integration lessons according to their curriculum needs. One doctoral student in GIS and one doctoral student in science education visited the teachers regularly to provide technological, content, and pedagogical supports.

Table 4 shows Spring 2018 teacher reported GIS frequency and integration content. Both science teachers such as Biology and Earth Science teachers, and social study teachers such as Geography teachers integrated multiple GIS tools in different class content. The integration frequency ranges from 8 to 15 for the school year. Figure 2 to 4 are student and teacher sample integration projects using Google Earth and Storymap.

Table 4. GIS Integration Content and Frequency

	Frequency and GIS Integration Content				
GIS Tool	Teacher 1 (8th Biology)	Teacher 2 (8th Geography)	Teacher 3 (9th Earth Science)	Teacher 4 (11th Environmental Science)	Teacher 5 (8th Biology)
Google Earth	10 Biomes, day & night, seasons, solar system exploration, ecology-- watersheds, human impact on ecosystem using the time lapse feature	5 Plot latitude/longitude and plot locations of various places in the world	6 Intro lesson, mapping locations, bus routes for emergencies, story maps	3Looking at the locations of biodiversity hot spots worldwide	3Locate specific places and explore tools
Storymap	2 Scientist across the world, evolution of primates	1 Plot the advancement of early civilizations	3 Making 2 story maps of places they would like to visit and emergency evacuation story map	5 Project exploring invasive species across the US and where they came from	3 Favorite places, multicultural scientists
ArcGIS Collector	1 Map making trip	1 Plotted various places around the School	2		1 Tree identification
Sketch Up		1 Observe 3D renderings of certain areas			Volume and architectural design
Drone	1 Fly drones at school	1 Fly drones with the students	3		
Total Frequency	**15**	**8**	**14**	**8**	**9**

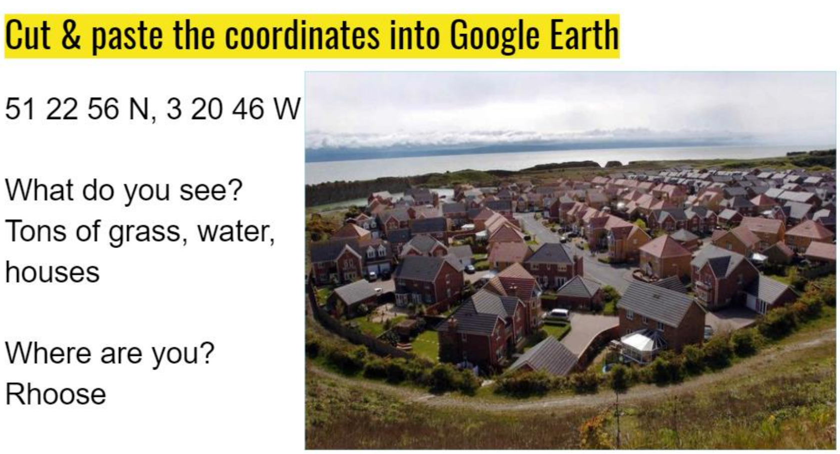


***Figure 2*. Student Google Earth Project Example**

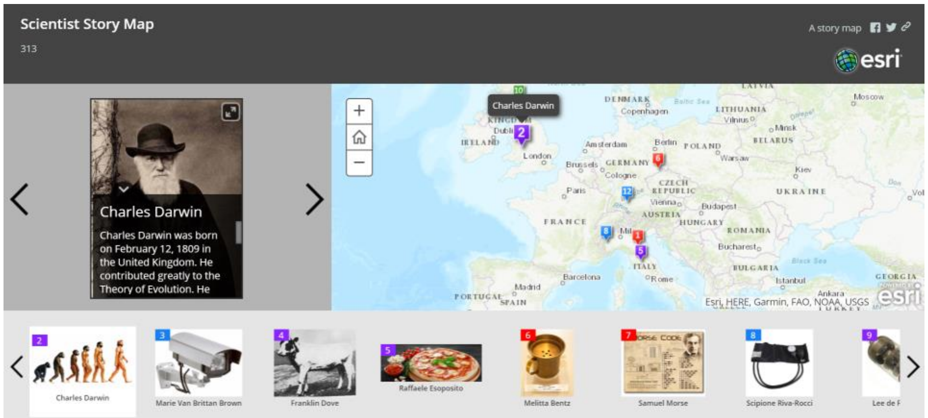


Figure 3. **Student Storymap Project Example**

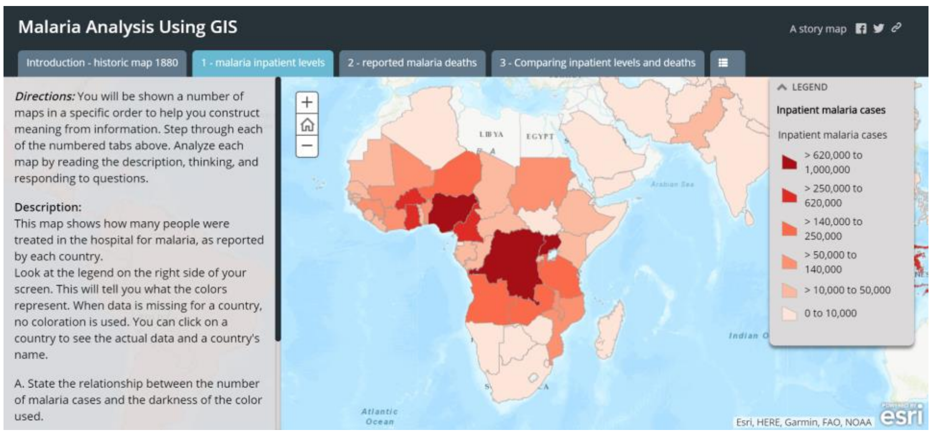


Figure 4. **Teacher Storymap Example**

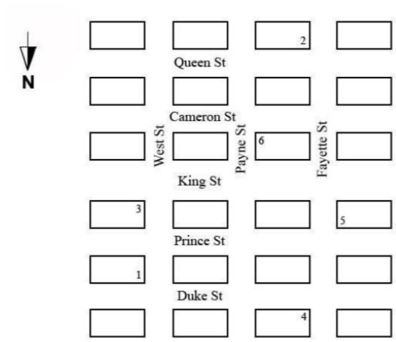
Data Collection

The top part of Figure 1 presents the data collection timeline. For teacher data, pre-survey and post survey were conducted at the start of the summer camp and the end of the school year, to assess teachers' demographic information, spatial thinking ability, GIS curriculum integration content and frequency, and etc. For student data, pre-survey and post surveys were conducted at the start and the end of an academic year, to obtain students' demographic information, spatial thinking, GIS ability, and etc.

To obtain teacher and student spatial thinking ability, this study administered a subset of the Spatial Thinking Ability Test (STAT) developed by Lee and Bednarz (2012). The STAT contains 16 questions that measure eight different spatial thinking ability components (Lee & Bednarz, 2012). However, considering the length of the test and the applicability for secondary level students, not all the 16 questions in the STAT were asked. Instead, 8 questions were selected that were more appropriate for middle school and high school students' understanding level. The selected eight questions correspond to three spatial thinking components as shown in figures 5a, 5b and 5c. The validity and reliability was established for the subset 8 questions using Rasch measurement (Li & Liu, 2018).

Table 5 shows the data sources for each research questions. To answer research question 1, about student and teacher current spatial thinking ability, the study applied two-year student STAT pre-test results (N = 974) from Fall 2017 and 2018, and two-year teacher STAT pre-test results (N = 17) from summer 2017 and 2018. STAT pre-test results indicate students and teachers' current status of spatial thinking ability before GIS intervention.

DIRECTIONS: Answer question on the basis of the street map below.

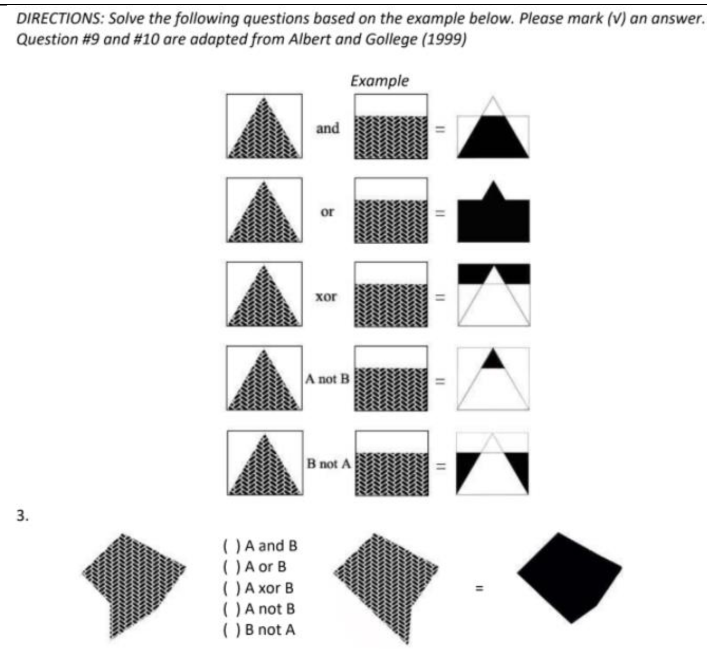


1. If you are located at point 1 and travel north one block, then turn west and travel three blocks, and then turn south and travel two blocks, you will be closest to point.

   (A) 2
   (B) 3
   (C) 4
   (D) 5
   (E) 6

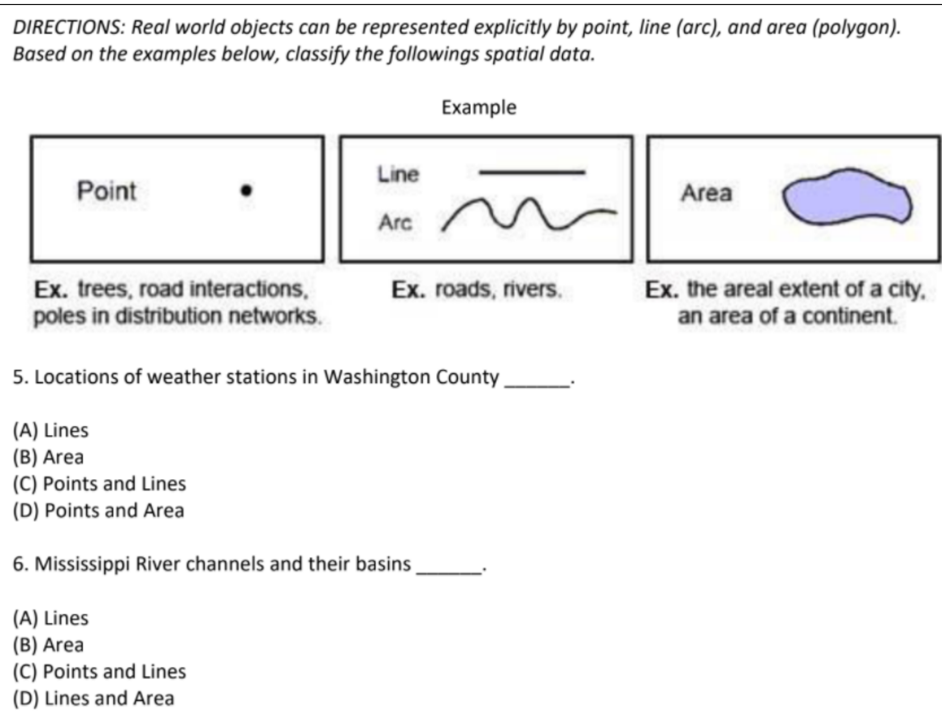
Spatial Thinking Ability: visually navigate road maps using verbal information including a participant's current location, direction to destination, street information (Lee & Bednarz, 2012)

***Figure 5a.* Example of STAT Questions and Spatial Thinking Ability**



Spatial Thinking Ability: visually verify a map overlay process and select the appropriate maps layers involved in the overlay (Lee & Bednarz, 2012)

Figure 5b. **Example of STAT Questions and Spatial Thinking Ability**



Spatial Thinking Ability: visually extract types of spatial data from verbally expressed spatial information (Lee & Bednarz, 2012)

Figure 5c. **Example of STAT Questions and Spatial Thinking Ability**

Table 5. Data Sources for Each Research Questions

	Survey Question Category	Data Collection Period	Research Questions		
			Q1	Q2	Q3
Teacher Survey	STAT pre-test (8 Items)	Spring 17 & 18	√		
	GIS Integration Frequency	Fall 2018		√	
Student Survey	STAT pre-test (8 Items)	Spring 2017		√	
	STAT pre-test (8 Items)	Spring 17 &18	√		√
	STAT post-test (8 Items)	Fall 2018		√	
	Demographic Information	Spring 17 & 18			√
	Self-Report GIS Use Ability	Spring 17 & 18			√
	Science Courses Number	Spring 17 & 18			√

To answer research question 2, about the effectiveness of GIS integration class on students' spatial thinking ability, student year 1 STAT pre- and post-test results were collected. In addition, 4 comparison classes are identified, with a total number of 225 students. Comparison classes were at the same grade level having same science or non-science courses but taught by different teachers. Student pre- and post-survey were also conducted in comparison classes at the same time as the GIS integration classes, to compare the results between the intervention and comparison classes. In this way, whether GIS intervention can improve students' spatial thinking ability were testable.

To answer research question 3, survey questions on students' gender, grade level, GIS ability, and science courses number were asked along with the STAT items in Fall 2017 and 2018 pre-survey. The GIS ability was measured by 14 Likert scale items, which asked students' agreement on the ability of using GIS tools, such as the ability of using 3D maps or using Google Earth to locate place. The instrument was highly reliable with α = .90.

Data Analysis

Rasch measurement scores were generated for the 8-item subscale STAT. The scores were applied in all the following analyses in this study. For research question 1, to explore students and teachers' current spatial thinking ability, descriptive statistics were conducted for each of the spatial thinking items.

For research question 2, Hierarchical linear modeling was used to explore whether taking GIS integrated class facilitated students' spatial thinking ability. Following shows the random-intercept model with level-1 covariate:

Level-1 Model

$$\text{Post-STAT}_{ij} = \beta_{0j} + \beta_{1j}{*}(\text{Pre-STAT}_{ij}) + r_{ij}$$

Level-2 Model

$$\beta_{0j} = \gamma_{00} + \gamma_{01}{*}(\text{GIS Intervention}_j) + \gamma_{02}{*}(\text{GIS Frequency}_j) + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + u_{1j}$$

In level-1, to control student background, student STAT pre-test serves as the covariate. Intervention/comparison group and teacher GIS integration frequency are the two factors at level-2.

For research question 3, the study conducted Multiple Linear Regression to explore the factors influencing students' spatial thinking ability, factors include student gender, grade, GIS ability, and the number of science courses the student have taken.

Findings

Student and Teacher Spatial Thinking Ability

Table 6 shows the 8-item subscale STAT percentage mean of correct answers per question and overall percentage mean for students and teachers. Student over all percentage mean of the subscale STAT was 31.54%, which means on average students answered 2 to 3 questions right out of the 8 questions. For the 8 questions, the highest mean was question 1 (M = 51.33%), and the lowest mean was question 3 (M = 19.30%), which indicate 51.33% students answered question 1 right, but only 19.3% students answered question 3 right.

Teacher overall percentage mean of the subscale STAT was 64.92%, which means on average teachers answered 5 questions right out of the 8 questions. Similar to students' results, for the 8 questions, the highest mean was question 1 (M = 88.24%), and the lowest mean was question 3 (M = 41.18%), which indicate 88.24% teachers answered question 1 right, but 41.18% teachers answered question 3 right.

Question 1 and 2 measure spatial thinking ability of "comprehending orientation and direction"; question 3 and 4 measure "overlaying and dissolving maps"; question 5 to 8 measure "visually extract types of spatial data from verbally expressed spatial information" (Lee & Bednarz, 2011). According to Figure 2, students and teacher spatial thinking ability show similar pattern, which means average scores for question 1 and 2 were relatively high, average scores for question 3 and 4 were relatively low, average scores for questions 5 to 8 varied. In other words, question about "comprehending orientation and direction" was relatively easy for students and teacher to answer, but questions about "overlaying and dissolving maps" was harder.

Table 6. A percentage mean of correct answers per question and percentage mean

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Mean	SD
Teachers (N = 17)	88.24	70.58	41.18	42.06	59.56	70.59	88.24	58.82	64.92	16.97
Students (N = 974)	51.33	43.10	19.30	24.29	33.33	23.04	38.83	21.13	31.54	11.17

Note: Q1 through Q8 are spatial thinking ability test questions 1 through 8.

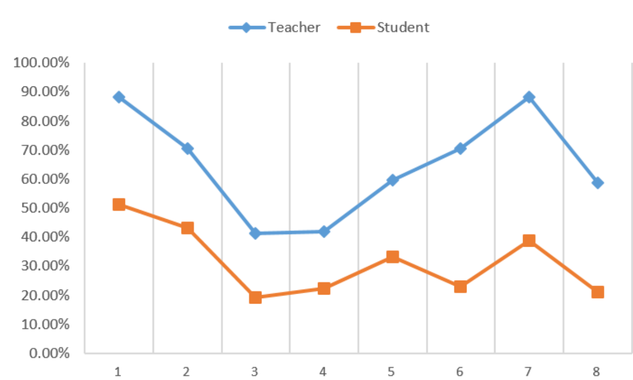


Figure 6. **Percentage of Correct Answers per Question of Students and Teachers**

GIS Integration Class and Spatial Thinking Ability

The pre- and post-test data were merged and sorted to include only those students who had completed both the pre- and post-test. Due to drop off and truancy during the school year, 229 students remained as participants for both pre- and post-test.

Hierarchical linear modeling was used to explore whether taking GIS integrated class facilitate students' spatial thinking ability. The fully unconditional model results indicate about 12% of the variance in students spatial thinking ability was between classes (ICC = 0.12, τ = 0.231, χ^2 = 39.226, $p < .01$).

Table 7. Means and Standard deviations for pre- and post- STAT test

Total N = 229	Pre-test Mean (SD)	Post-test Mean (SD)
GIS Intervention (N = 122)	-0.86 (1.36)	-0.81 (1.47)
Control (N = 107)	-0.63 (1.10)	-0.70 (1.25)

Table 8. Fixed Effect Results for Random-Intercept Model with Level-1 Covariate

Fixed Effect	Coefficient	Standard Error	t-ratio	d.f.	p-value
For STA, β_0					
Intercept, γ_{00}	-0.925	0.191	-4.82	5	0.005
GIS Intervention, γ_{01}	-0.225	0.461	-0.48	5	0.646
GIS Frequency, γ_{02}	0.028	0.047	0.60	5	0.575
For Pre-STAT slope, β_1					
Intercept, γ_{10}	0.504	0.083	6.02	7	<0.001

Table 7 shows the means and standard deviations for pre- and post-STAT test. Table 8 shows the fixed effect results for Random-Intercept Model with level-1 covariate. The results indicate there was no statistical significantly difference on student average spatial thinking ability between GIS intervention group and control group students (γ = -0.225, $p > .05$). Also, students' frequency of taking GIS integration class have no statistically significantly relationship with student average spatial thinking ability.

Factors Influencing Spatial Thinking Ability

Table 9 shows the means, standard deviations, and correlation results on students' grade GIS ability, GIS career interest, and spatial thinking ability. The results indicate students' GIS ability, number of science courses that the student have taken, and spatial thinking ability were significantly correlated with each other.

Table 9. Correlations between Grade, GIS Factors and Spatial Thinking Ability

			Correlations (r)			
Variable	Mean	SD	Grade	GIS Ability	GIS Career Interest	STAT
Grade	8.40	1.08	1.00			
GIS Ability	3.45	0.77	0.09*	1.00		
Science Courses	1.90	1.64	0.08*	0.8**	1.00	
STAT	-0.50	1.24	0.40**	0.12**	0.12**	1.00

*p<.05 **p<.01 N = 748

Table 10. Relationships between Demographic, GIS Factors and Spatial Thinking Ability

Factor(s)	Unstandardized β	Standardized β	S.E.	t-value
Gender	-0.26**	-0.10**	0.02	-3.11
Grade	0.46**	0.40**	0.00	11.80
GIS Ability	0.14*	0.08*	0.01	2.50
Science Courses	0.05*	0.07*	0.01	2.01
Total R^2 0.18				
d.f. 743				

*p<.05 **p<.01

Multiple Liner Regression was conducted to explore the relationships between the factors and students' spatial thinking ability. According to table 10, the overall model including gender, grade, GIS ability, and number of science courses accounted for 18% variance in predicting students' spatial thinking ability (R^2 = 0.18).

The results indicate students' gender had significantly negative relationship with student spatial thinking ability ($\beta = -.10$, $t = -3.11$, $p < .01$), which indicates male students spatial thinking ability was 0.26 score higher than female students. Grade had significantly positive relationship with student spatial thinking ability ($\beta = .40$, $t = 11.80$, $p < .01$), which indicates students in higher grade level had better spatial thinking ability. With 1 grade level increased, there was 0.46 score increased in student spatial thinking ability.

Students' ability of GIS using had significantly positive relationship with students' spatial thinking ability ($\beta = .08$, $t = 2.50$, $p < .05$), which indicates secondary school students who had higher ability on using GIS tools tended to have higher spatial thinking ability compare to students had lower GIS using ability. With one standard deviation increased on students' ability of GIS using, 0.08 standard deviation was increased on students' spatial thinking ability.

Also, students' number of science courses had significantly positive relationship with students' spatial thinking ability ($\beta = .08$, $t = 2.01$, $p < .05$), which indicates secondary school students who had taken more science courses tended to have higher spatial thinking ability compare to students had less science courses. With one standard deviation increased on students' science courses number, 0.08 standard deviation was increased on students' spatial thinking ability.

Discussions

The NRC (2006) suggested that researchers seek answers to the question "How can one learn to become a better spatial thinker?" The present research addressed the question in three-folds: explored students' current spatial thinking ability, figured out how the use of GIS might facilitate students' spatial thinking ability, and identified factors influencing spatial thinking ability.

First, by exploring students' current spatial thinking in different spatial component, their low ability spatial thinking component was identified. Educators and future researchers now have a guideline on which specific component should be paid closer attention, and also take into account the different spatial thinking abilities in terms of grade level.

To be specifically, the study results indicated students' overall spatial thinking ability needs to be improved, which is consistent with the prior studies (NRC, 2006; Newcombe, 2010). It revealed that secondary school students were in general still lacking skills in overlaying and dissolving maps (Golledge, 2002), but they had better ability on comprehending orientation and direction (Golledge, 2002). The ability of overlaying and dissolving maps is required in several content in science. For example, one student mentioned topographic map in the interview, which is an important content in high school Earth Science. If students do not have the ability of overlaying and dissolving maps, they may not be able to understand overlays in topographic map, which means they cannot identify the geographical features represented in the map. Thus, science teachers were suggested to take into account student strength and weakness in spatial thinking when designing and planning relevant science class.

Consistent with prior studies (Lee & Bednarz, 2012; Tomaszewski et al., 2015), the above findings suggested the importance of studying students' spatial thinking in terms of different components independently in order to provide more precise and effective advices on improving student's spatial thinking ability. For example, "transform perceptions, representations and images from one dimension to another and the reverse" (Golledge, 2012) is one of the important spatial thinking ability that frequently used science learning. To understand a certain concept or features of a subject, students are often required to transfer a 2D graph to 3D, so it is meaningful to study their ability only on this single component.

Second, how GIS can be integrated in different science disciplines and whether it can help improving students' spatial thinking in science class was explored by integrating GIS into science curriculum. The results not only responded NRC (2006) and other researchers' call on incorporating GIS into students' learning (Bodzin and Cirucci, 2009; Milson and Earle, 2008; Bodzin, 2010), but also added evidences on the relationship between science learning and spatial thinking.

Although the results showed after taking one-year GIS integration class, students' spatial thinking abilities have not been improved significantly, it does not mean the study findings was inconsistent with prior studies supporting the use of GIS in class (NRC, 2006; Bodzin and Cirucci, 2009; Milson and Earle, 2008; Madsen & Rump, 2012). The insignificant gain might be due to several reasons, such as the content, length, and frequency of the GIS integration classes, and the spatial thinking components that were taken in to account. Suggestion can be made to future researchers to take a long-term intervention, integrate GIS more frequently, also analyze the gain of spatial thinking ability in terms of different components in different science disciplines.

Third, by identifying possible factors that may influence students' spatial thinking, some detailed evidences and suggestions have been added to this field. Consistent with prior studies which indicated gender gap exists in spatial thinking ability for university students (Sorby, 2009) and teachers (Shin, Milson & Smith, 2016), the current study indicated gender differences on spatial thinking ability also exist in secondary school student level. Since spatial thinking ability is relevant to a wide variety of academic disciplines and everyday problem-solving situations

(NRC, 2006), it is important for both female and male students to have better spatial thinking skills. Future researcher can study on how to narrow down the gender gap on secondary school students' spatial thinking ability, such as how gender influences students' spatial thinking in terms of different spatial component, to provide more detailed suggestions.

The findings also added evidences on GIS's important role in developing students' spatial thinking ability, and the close relationship between science learning and spatial thinking. Future research can study on how to improve students' ability on using GIS tools, how to bring GIS in students' science learning, in order to respond NRC's (2006) call on improving students' spatial thinking ability and training future geo-spatial workers.

Although this study filled some gaps in this research area, it had some limitations. Firstly, limited by the actual data collection situation, we were not able to collect random sample and identify control groups for each teacher; also, the sample size in each grade level were vary. This might cause bias when making inference to the whole population. In addition, we studied three spatial thinking components to represent middle and high school students' spatial thinking ability, more components need to be added on to explore the question comprehensively.

In conclusion, this study provided some solid suggestions to build future long-term spatial thinking ability research program in science education. As researchers, we should attach importance to high school and middle school students' spatial thinking ability in their science learning. Also, we should keep in mind that GIS could be promising technology tool to improve students' spatial thinking ability, and more works need to be done to further explore this topic.

References

Alibrandi, M. 2003. GIS in the Classroom: Using Geographic Information Systems in Social Studies and Environmental Science. Portsmouth, New Hampshire: Heinemann.

Alibrandi, M., and H. Sarnoff. 2006. Using GIS to answer the ‘whys’ of ‘where’ in social studies. *Social Education* 70(3): 138–143.

Bednarz, R. S., & Lee, J. (2011). The components of spatial thinking: Empirical evidence. Procedia - *Social and Behavioral Sciences*, 21, 103-107.

Bednarz, S. W., & Audet, R. H. (1999). The status of GIS technology in teacher preparation programs. *Journal of Geography*, 98(2), 60-67. doi:10.1080/00221349908978861

Bodzin, A. M., & Cirucci, L. (2009). Integrating geospatial technologies to examine urban land use change: A design partnership. *Journal of Geography*, 108(4-5)

Bodzin, A. M. (2011). The implementation of a geospatial information technology (GIT) supported land use change curriculum with urban middle school learners to promote spatial thinking. *Journal of Research in Science Teaching*, 48(3), 281-300.

Bond, T. G., & Fox, C. M. (2015). *Applying the Rasch model: Fundamental measurement in the human sciences* (3rd ed.). Mahwah, New Jersey: Lawrence Erlbaum.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, Calif: Sage Publications.

Doering, A., & Veletsianos, G. (2008). An investigation of the use of real-time, authentic geospatial data in the K-12 classroom. *Journal of Geography*, 106(6), 217-225.

Donaldson, D. P. 2001. With a little help from our friends: Implementing geographic information systems. *Social Education* 65(3): 147–150.

Gersmehl, P. J., & Gersmehl, C. A. (2007). Spatial thinking by young children: Neurologic evidence for early development and "educability". *Journal of Geography*, 106(5), 181-191.

Glesne, C. (2011). *Becoming qualitative researchers* (4th ed.). New York: Pearson.

Golledge, R. G. (2002). The nature of geographic knowledge. *Annals of the Association of American Geographers*, 92(1), 1-14.

Golledge, R. G. (2008). Behavioral geography and the Theoretical/Quantitative revolution. *Geographical Analysis*, 40(3), 23.

Janelle, D. G., Rebich Hespanha, S., Goodchild, F., & Goodchild, M. F. (2009). Workshops and national dissemination of geographic analysis in the social sciences: The CSISS experience in the USA. *Journal of Geography in Higher Education*, 33(sup1), S88-S103.

Jo, I., & Bednarz, S. W. (2014). Dispositions toward teaching spatial thinking through geography: Conceptualization and an exemplar assessment. *Journal of Geography*, 113(5), 198-207.

Jo, I., Hong, J. E., & Verma, K. (2016). Facilitating spatial thinking in world geography using web-based GIS. *Journal of Geography in Higher Education*, 40(3), 442-459.

Learning to think spatially (2006). Washington, D.C: *National Academies Press*.

Lee, J., & Bednarz, R. (2009). Effect of GIS learning on spatial thinking. *Journal of Geography in Higher Education*, 33(2), 183-198.

Lee, J., & Bednarz, R. (2012). Components of spatial thinking: Evidence from a spatial thinking ability test. *Journal of Geography* 111(1), 15-26.

Li, S., & Liu, X. (March, 2018). Integrating GIS into secondary school science curriculums: A mixed method study on student spatial thinking abilities. Paper presented at the NARST annual International conference, Atlanta, GA, March 10-13, 2018.

Liu, X. (2010). *Using and developing measurement instruments in science education: A Rasch modeling approach.* Charlotte, NC: Information Age Publishing.

Milson, A. J., & Earle, B. D. (2008). Internet-based GIS in an inductive learning environment: A case study of ninth-grade geography students. *Journal of Geography*, 106(6), 227-237.

Madsen, Lene Møller, and Camilla Rump. "Considerations of How to Study Learning Processes When Students Use GIS as an Instrument for Developing Spatial Thinking Skills." *Journal of Geography in Higher Education* 36.1 (2012): 97-116.

Newcombe, N. S. (2010). Picture this: Increasing math and science learning by improving spatial thinking. *American Educator*, 34(2), 29.

National Research Council of the National Academies (2013). *Future U.S. Workforce for Geospatial Intelligence*. The National Academies Press.

National Research Council (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. Washington, DC: The National Academies Press.Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist*, 40 (1), 1 – 12.

Qiu, X. 2006. Geographic information technologies: An influence on the spatial ability of university students? Ph.D. diss., Texas State University–San Marcos.

Saldaña, J. (2013). *The coding manual for qualitative researchers* (2nd ed.). Los Angeles: SAGE.

Shin, E. E., Milson, A. J., & Smith, T. J. (2016). Future teachers' spatial thinking skills and attitudes. *Journal of Geography*, 115(4), 139-146.

Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education*, 31(3), 459-480.

Spradley, J. P. (1980). *Participant observation*. Fort Worth: Harcourt Brace Jovanovich.

Tomaszewski, B., Vodacek, A., Parody, R., & Holt, N. (2015). Spatial thinking ability assessment in rwandan secondary schools: Baseline results. *Journal of Geography*, 114(2), 39-48.

Uttal, D. H., & Cohen, C. A. (2012). 4 Spatial Thinking and STEM Education: When, Why, and How? *Psychology of Learning and Motivation-Advances in Research and Theory*, 57, 147.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology & Psychiatry & Allied Disciplines*, 17(2), 89–100.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, 117(2), 250-270.

Appendix A

Teacher Example Lesson Plan

Topic: Environmental impact of the Chernobyl Nuclear Meltdown

Content Areas: Living Environment-Human Impact Unit

Grade Level: 9th

Duration: 2 class periods

GIS Tool: Google Earth

Objectives:

- Students will be able to analyze the environmental impact of the Chernobyl Nuclear Meltdown by reading excerpts from a case study written by the United Nations Scientific Committee on the Effects of Radiation (UNSCEAR).

- Using Google Earth and information from the case study, students will be able to map ten locations (cities, landmarks, geographic features) to illustrate the spread of radiation across Europe.

Instructional Sequence:

1. Think-Pair-Share

Students watch a video reporting on the Chernobyl Nuclear Accident and hypothesize 3-4 environmental impacts caused by the disaster. They will write hypothesizes in their notebooks.

2. Students read excerpts from a case study written by UNSCEAR and create a list of four environmental impacts of the Chernobyl Nuclear Accident on air, land, water, and animals/humans.

3. Students will write their four impacts on 4 post its and post on the whiteboard.

4. Students will re-read the excerpts and choose ten locations cited by UNSCEAR. These locations could be cities, rivers, or landmarks affected by radiation.

5. Students will then use Google Earth and their 10 locations and put Placemarks on Google Earth to show the spread of radiation across Europe.

6. Students will then use Google Earth's Sightseeing Tour feature to illustrate the contaminated area.

Assessment: Students will present their maps.

Other Resources: (Such as PowerPoint, Video, Supplemental Readings, etc.)

Excerpts from http://www.unscear.org/unscear/en/chernobyl.html

Supporting References: Google Earth

http://www.unscear.org/docs/reports/2000/Volume%20II_Effects/AnnexJ_pages%20451-566.pdf