

**Integrating GIS into Secondary School Science Curriculums:  
A Mixed-Method Study on Students' Spatial Thinking Ability**

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**PRELIMINARY FINDINGS – DON'T CITE. CONTACT the AUTHOR FOR FINAL  
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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”. It calls to “foster a new generation of American students who are equipped to think spatially”. Spatial thinking is universal and relevant to a wide variety of academic disciplines and everyday problem-solving situations (NRC, 2006). Prior studies suggest that spatial thinking can and should be taught at all levels in the educational system, especially in science education (Lee & Bednarz, 2009; NRC, 2006; Uttal & Cohen, 2012).

In order to develop student spatial thinking ability, NRC (2006) emphasizes the significance of using geographic information system (GIS) in students’ learning. However, so far, 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., Lee & Bednarz, 2009; Madsen & Rump, 2012). Further, even fewer studies have focused on exploring secondary school students’ spatial thinking ability; 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' Spatial Thinking Ability? How are they different from grade to grade?
- (2) How do middle and high school students experience instruction of integration of GIS in science classes?
- (3) Does integrating GIS in science classes facilitate students' development of spatial thinking ability?

### **Theoretical Framework**

For spatial thinking ability, this study applies the definition provided by NRC (2006) as described earlier. NRC (2006) also introduces three spatial 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; 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; intellectual space refers to the relationship between concepts and objects that are not in and of themselves necessarily spatial, instead the nature of space is defined by a particular problem (NRC, 2006).

Within the contexts of spatial thinking, several theories have been developed (Gersmehl 2005, Golledge et al. 2008, and Janelle and Goodchild 2009). 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).

This study also applies the scaffolding theory. Wood, Bruner, and Ross (1976) define scaffolding as “adult controlling elements of the task that are essentially beyond the learners’ capacity, thus permitting learners to concentrate upon and complete those elements that are within their range of competence”. The theory of scaffolding is originated from Vygotsky’s concept of zone of proximal development (ZPD). The ZPD is between learners’ current ability level and the level after efficiently scaffolding. In the case of this study, the field between students’ current STA level and the desired STA level after efficiently scaffolding is students’ ZPD. To effectively develop students in this zone, science teachers can act as resources (Wood et al., 1976); they can also use GIS as a scaffolding tool to improve students’ STA. Prior studies suggest that technologies can be effective tools for scaffolding students’ learning (Puntambekar & Hubscher, 2005).

## **Literature Review**

### **Spatial Thinking and Learning**

The term "spatial thinking" has been used in both nonacademic and academic settings extensively. A variety of definitions exist before the National Research Council report (2006), such as Gersmehl (2005), Golledge et al. (2008) and Janelle and Goodchild (2009) (Lee & Bednarz, 2011). Besides, in geography education, the concept of spatial thinking has a nebulous

identity literature as various terms, such as thinking spatially, geospatial thinking, spatial intelligence, and spatial ability, are used synonymously (Huynh & Sharpe 2013).

The authors (geographers, astronomers, psychologists and educators) in National Research Council 2006 and 2013 reports argue that spatial thinking is universal and useful in a wide variety of academic disciplines and everyday problem-solving situations (Lee & Bednarz, 2012). The authors claim that spatial thinking can and should be taught at all levels in the educational system.

Although spatial thinking is important in geography, it is equally important in other science subjects (Uttal & Cohen, 2012). Uttal and Cohen provided an example in chemistry that requires spatial thinking: “a great deal of attention is devoted in chemistry to the study the behavior of isomers, which are compounds with identical molecular compositions, but different spatial configurations.”

### Measurement of Spatial Thinking

Lee and Bednarz (2011) developed the Spatial Thinking Ability Test (STAT). In the study, they firstly reviewed the prior studies about the concepts of spatial thinking (Gersmehl, 2005; Golledge et al., 2008; Janelle & Goodchild, 2009). By reorganizing the components of spatial thinking suggested by prior studies, they created eight types of spatial thinking measures corresponding to eight spatial thinking components. For example, questions 1 and 2 measure students' spatial thinking ability to visually navigate road maps using verbal information including participants' current location, directions to destination, street information, etc. (Lee & Bednarz, 2012), which pertains to the component of "comprehending orientation and direction" (Golledge, 2002). Thus, the STAT covers spatial thinking components of a wide range (Lee & Bednarz, 2012).

Besides the STAT, Cohen and Hegarty (2012) designed a spatial thinking test called Santa Barbara Solids Test (SBST). Rather than focusing on all spatial thinking concepts, the SBST only explores students' spatial skill of cross-section (Cohen & Hegarty, 2012). The study consists of 30 multiple choice questions distributed evenly over three levels of geometric structure and two types of cutting planes; one-third of the figures are simple solids, one-third are joined solids, and one-third are embedded solids (Cohen & Hegarty, 2012).

There are a few questionnaires on spatial thinking, such as Hegarty et al. (2002), but the questionnaires are for classifying types of spatial behavior rather than determining levels of spatial ability (Lee & Bednarz, 2012).

#### Spatial Thinking and Geo-Spatial Technology

Geo-technologies are technologies that collect or process data related to space and location, such as remotely sensed satellite and aerial images, geographic information systems (GIS) and ArcExplorer. Those geo-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 it is starting to be used in teaching and learning in class.

A number of studies found that geospatial related technology could improve students learning in a variety of ways (e.g. Bodzin & Cirucci, 2009; Doering & Veletsianos, 2008; Milson & Earle, 2008). Prior studies also indicated that geospatial technologies can be integrated not only into geography but also several other subjects, such as science and social studies (Alibrandi, 2003; Alibrandi & Sarnoff, 2006; Donaldson, 2011).

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 had 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”. All students deserve and need the opportunity to be challenged, to be supported and to become critical spatial thinkers”.

However, only a few empirical studies support the idea of NRC (2006) that learning GIS improves students' spatial thinking ability. Lee and Bednarz (2009) studied GIS's effect on university students' spatial thinking ability. They conducted a “spatial-skill test” of 80 university students' spatial thinking ability before and after taking GIS related courses, and non-GIS users were acting as the control group. Their results indicate that hands-on, lab- or project-based GIS experience improves students' spatial thinking ability. Similarly, Madsen and Rump (2012) studied the use of GIS for developing spatial thinking. Compared with Lee and Bednarz (2009), Madsen and Rump (2012) measured students' spatial thinking in both qualitative and quantitative ways. The participants of the study were first-year geography major students from a university, who were taking the GIS and Cartography courses. The results indicate that GIS positively influences the way students perceive and understand geographical issues, and by using GIS, students were able to create their personal instrument to improve their spatial thinking (Madsen & Rump, 2012).

In summary, prior studies have emphasized the importance of spatial thinking in students' learning (Lee & Bednarz, 2009; NRC, 2006; Uttal & Cohen, 2012), and that spatial thinking is a very broad and complex concept and can be addressed in many different science subjects

(Alibrandi, 2003; Alibrandi & Sarnoff, 2006). However, prior studies only focused on student's spatial thinking ability on a single subject, such as on geography study; or focused on student's overall spatial thinking ability, rather than looking at each spatial thinking components independently (Lee & Bednarz, 2012). In addition, prior studies have provided very limited suggestions on how to improve students' spatial thinking ability. Thus, the purpose of this present study is to find out the current state of high school students' spatial thinking abilities, to study students' learning experiences of science using GIS, and to find out if students' learning experiences of science using GIS may improve their spatial thinking abilities.

## **Method**

### **GTEST Research Project**

The GTEST project is a three-year ongoing project starting from Spring 2017. The project involves middle and high school (grades 7-12) students and teachers from two urban public school districts. Each summer, 10 science teachers are selected to join a summer camp to learn to use GIS and to develop their own GIS integrated lessons. During the academic year, supported by the GTEST research group, teachers teach the developed GIS integrated science lessons in their science classes so that their students will be able to experience GIS integrated instruction in class.

The current study used the data from the first academic year (2017-2018) of the GTEST project. In summer 2017, 10 teachers joined the GIS summer camp and created various numbers of GIS integrated science lessons. Eight out of the ten teachers are science teachers, they are teaching science subjects of Biology and Earth Science. Two teachers are not teaching science; but data from their students are still applicable since the study is focused on students' spatial



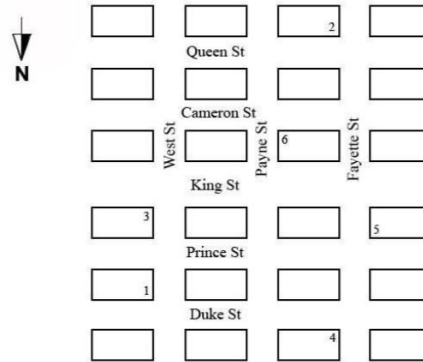
thinking ability rather than science achievement. GTEST teachers' classes are designated as experimental classes, and a comparison class is also identified for each experimental class. Comparison classes are at the same grade level having the same science or non-science course but taught by different teachers.

### Data Collection

To answer research question one, this study administered a subset of the Spatial Thinking Ability Test (STAT) developed by Lee and Bednarz (2012) at the beginning of the fall 2017 semester to measure students' current spatial thinking ability in both experimental and comparison classes. 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, we did not use all the 16 questions in the STAT. Instead, we selected 8 questions that are more appropriate for middle school and high school students' understanding level, because the related components are more relevant to science learning. The selected eight questions correspond to three spatial thinking components as shown in figures 1a, 1b and 1c. In September 2017, 552 students completed the pre-test of the eight questions related to their spatial thinking ability. Table 1 presents the participant students' demographics.

In order to better understand students' spatial thinking ability, and to answer the research question two about students' GIS integration class experience, we also collected qualitative data by conducting interviews and observations of GIS integration instruction. For the class observations, we conducted participatory observations focusing on how teachers integrated GIS into certain science classes, and how students responded to and experienced GIS integrated instructions. Informal interviews have also been conducted during the observations with both

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

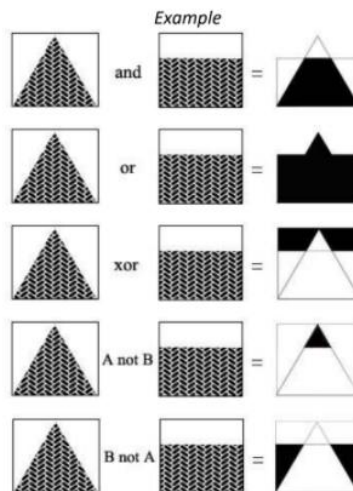


1. If you are located at point 1 and travel north one block, then turn west and travel three blocks, and then turn south and travel two blocks, you will be closest to point.
- (A) 2  
(B) 3  
(C) 4  
(D) 5  
(E) 6

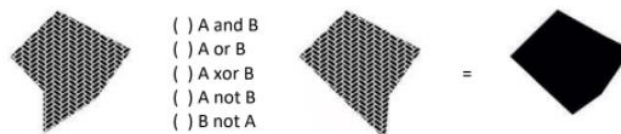
Spatial Thinking Ability: visually navigate road maps using verbal information including a participant's current location, direction to destination, street information (Lee & Bednarz, 2012)

**Figure 1a. Example of STAT Questions and Spatial Thinking Ability**

DIRECTIONS: Solve the following questions based on the example below. Please mark (v) an answer. Question #9 and #10 are adapted from Albert and Gollege (1999)



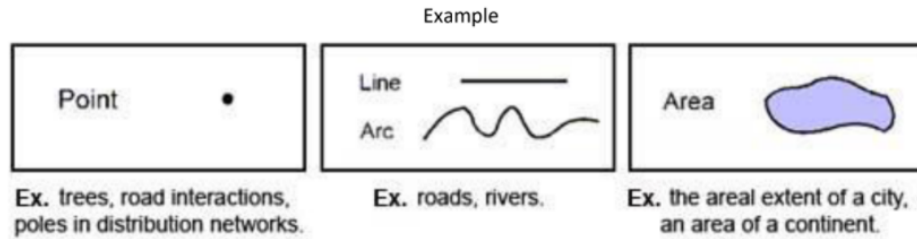
3.



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

**Figure 1b. Example of STAT Questions and Spatial Thinking Ability**

*DIRECTIONS: Real world objects can be represented explicitly by point, line (arc), and area (polygon). Based on the examples below, classify the followings spatial data.*



5. Locations of weather stations in Washington County \_\_\_\_\_.

- (A) Lines
- (B) Area
- (C) Points and Lines
- (D) Points and Area

6. Mississippi River channels and their basins \_\_\_\_\_.

- (A) Lines
- (B) Area
- (C) Points and Lines
- (D) Lines and Area

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

**Figure 1c. Example of STAT Questions and Spatial Thinking Ability**

	Number of Students	Percentage
Gender		
Male	277	53.1%
Female	272	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		
8 <sup>th</sup>	310	56.2%
9 <sup>th</sup>	162	29.3%
10 <sup>th</sup>	42	7.6%
11 <sup>th</sup>	23	4.2%
12 <sup>th</sup>	15	2.7%

**Table 1. Demographics of Participated Students**

students and teachers to build triangulation (Spradley, 1980). Questions about students' experiences in GIS and spatial thinking ability have been asked in the informal interviews. Field notes, visual data and research journals were created during the observations.

So far, we have observed five GIS integration science classes in which teachers applied Google Earth and Storymap in those classes. For example, some Earth Science teachers applied Google Earth when they reviewed the content of latitude and longitude, and some Biology teachers applied Storymap when they introduced famous Biological scientists and science history to the students.

In addition, we also conducted one to one interviews to the students in order to add evidences on their current spatial thinking ability, and to figure out their experiences in using GIS tools in science class. To avoid overloading data (Glesne, 2011), we selected 7 students as interview participants according to teachers' recommendation and class observations. Three of them were 8<sup>th</sup> graders, three were 11<sup>th</sup> graders, one was 12<sup>th</sup> grader; and three of them were from Biology classes, and four of them were from Earth Science classes. Also, the seven interviewed participants all had experiences in taking GIS integrated classes and making their own class project by using GIS tools.

For the interview questions, we divided them into two parts. On one hand, we asked about the eight spatial thinking ability questions in the pre-test. For example, we asked student to pick the easiest and hardest questions for them and explained the reason. Also, students were asked to describe the thinking process of how they did certain questions. In this way, we will have more evidences on students' current spatial thinking ability and be able to figure out the ability difference on different spatial components. On the other hand, we asked questions about their experience on using GIS tools and taking GIS integrated science class. Students had an

opportunity to describe their project by using GIS tools and how they felt about taking GIS integration class. Interview questions are presented in Appendix.

To answer research question three, we will conduct a post-test to the same group of students and compare the results to the pre-test and between the experimental and comparison classes. In this way we will be able to measure whether GIS intervention can improve students' spatial thinking ability. Since post-test will be conducted in May this year, question three is not answerable at this time.

### Data Analysis

To validate the eight spatial thinking questions as a scale, we applied Rasch modeling to establish evidence for the scale reliability and validity (Bond & Fox, 2015; Liu, 2010). To study students' current spatial thinking ability, descriptive statistics has been generated for the eight spatial thinking questions among different grade levels. To explore the differences on students' spatial thinking ability among different grades, one-way analysis of variance (ANOVA) has been conducted.

For all the qualitative data including interview transcripts, field notes, visual data and research journals, phenomenology data analysis and representation approach introduced by Creswell (1998) has been applied. After transcribing the interviews and reorganizing field notes, visual data and research journals, data organization (Creswell, 1998) has been conducted as the first step. We read throughout all the data and classified the data into files according to the themes of the two research questions. After data organization, reading and memoing was the next step according to Creswell (1998). In this step, we read the text by categories and made margin notes and forming initial codes. Open coding and initial coding introduced by Saldaña (2013)

was applied as the first cycle coding method. Next, based on the theoretical framework in this research study, we described and classified the data into codes and themes to interpret the data (Creswell, 1998). During this step, “second theme” was generated. Table 2 shows the two themes used for the two cycle coding. The last step was representing and visualizing data. Examples and visual data was reorganized and generated in this step.

First Cycle Themes	Second Cycle Themes
Spatial thinking ability	Comprehending orientation and direction
	Overlaying and dissolving maps
	Comprehending integration of geographic features represented as points, networks, and regions
GIS experiences	General experiences
	Google Earth
	Special features
	Science learning
	General experiences
	Storymap
	Special features
	Science learning

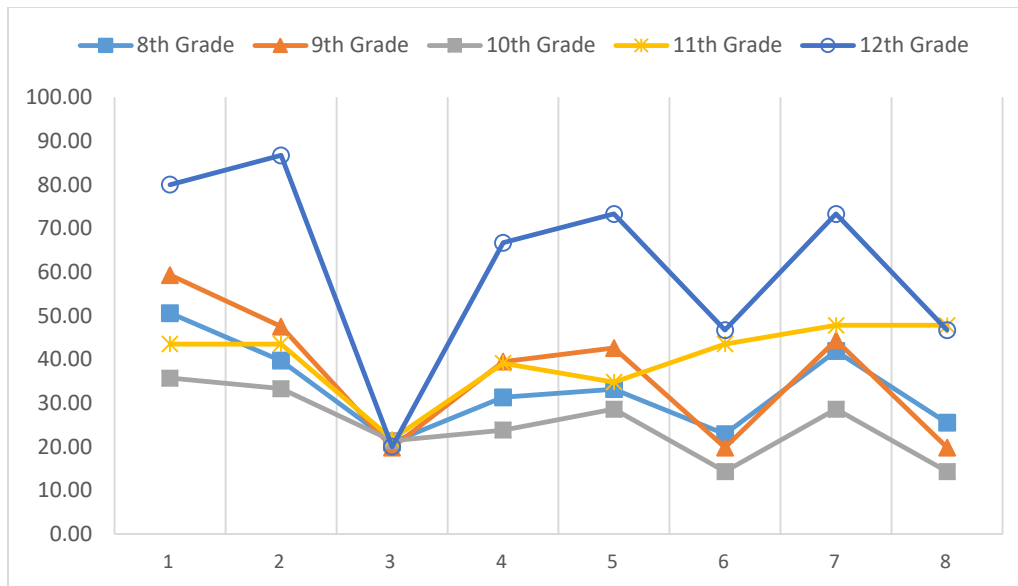
**Table 2. Themes for Coding Qualitative Data**

**Table 3. A percentage mean of correct answers per question and percentage mean by grades**

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Mean	SD
8th Grade (N= 310)	50.6	39.7	21.0	31.3	33.2	22.9	41.9	25.5	33.3	21.3
9th Grade (N= 162)	59.3	47.5	19.8	39.5	42.6	19.8	44.4	19.8	36.6	21.3
10th Grade (N= 42)	35.7	33.3	21.4	23.8	28.6	14.3	28.6	14.3	25.0	17.9
11th Grade (N= 23)	43.5	43.5	21.7	39.1	34.8	43.5	47.8	47.8	40.2	32.2
12th Grade (N= 15)	80.0	86.7	20.0	66.7	73.3	46.7	73.3	46.7	61.7	23.4
Mean	52.3	42.8	20.6	34.3	36.6	22.7	42.8	24.5		
SD	50.0	49.5	40.5	47.5	48.2	42.0	49.5	43.1		

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

2. The total percentage mean of the eight spatial thinking questions among all the students is 34.6, with 22.3 standard deviation.



**Figure 2. Percentage of correct answers per question comparison by grades**

## Findings

### Spatial Thinking Ability

Descriptive statistics of student raw scores on STAT are presented in Table 3 and Figure 2. Overall, students' average scores among different grade levels were different. For example, 12<sup>th</sup> grade students' average score ( $M = 61.7$ ,  $SD = 23.4$ ) was higher than other lower grade students' scores. However, 10<sup>th</sup> grade students' average score ( $M = 25.0$ ,  $SD = 17.9$ ) was lower than that of other grade students.

In order to validate the SATA questions as a scale, we used Rasch modeling to establish preliminary evidence of its construct validity and reliability (Bond & Fox, 2015; Liu, 2010). Rasch analysis estimated both person and item reliability, and the results can be found in Table 4. The item reliability was 0.97 with a separation of 5.74; the person reliability was 0.38 with a separation of 0.78.

Person	Reliability	0.38
	Separation	0.78
Item	Reliability	0.97
	Separation	5.74

**Table 4. Reliability and Separation for Person and Items**

Item	Measure	S.E.	MNSQ		ZSTD	
			INFIT	OUTFIT	INFIT	OUTFIT
Q1	-1.02	0.10	0.96	0.92	-1.1	-1.5
Q2	-0.50	0.10	0.97	0.94	-0.8	-1.1
Q3	0.88	0.12	1.18	1.41	<b>2.6</b>	<b>3.5</b>
Q4	-0.02	0.10	0.93	0.92	-1.7	-1.3
Q5	-0.16	0.10	0.96	0.97	-1.0	-0.6
Q6	0.72	0.11	1.07	1.07	1.2	0.7
Q7	-0.49	0.10	0.89	0.84	<b>-3.1</b>	<b>-3.3</b>
Q8	0.60	0.11	1.09	1.14	1.6	1.6

**Table 5. Fit Statistics of Spatial Thinking Items**

Table 5 shows the fit statistics by presenting INFIT and OUTFIT values of all the eight spatial thinking ability items. Both the INFIT values and OUTFIT values of the Mean Squares of Residual in Chi-square (MSNQ) were within the range of 0.8 to 1.2. However, both of the INFIT and OUTFIT ZSTD of question 3 and question 7 were out of the range (-2.0 to 2.0). Thus, question 3 and question 7 are possibly misfitting.

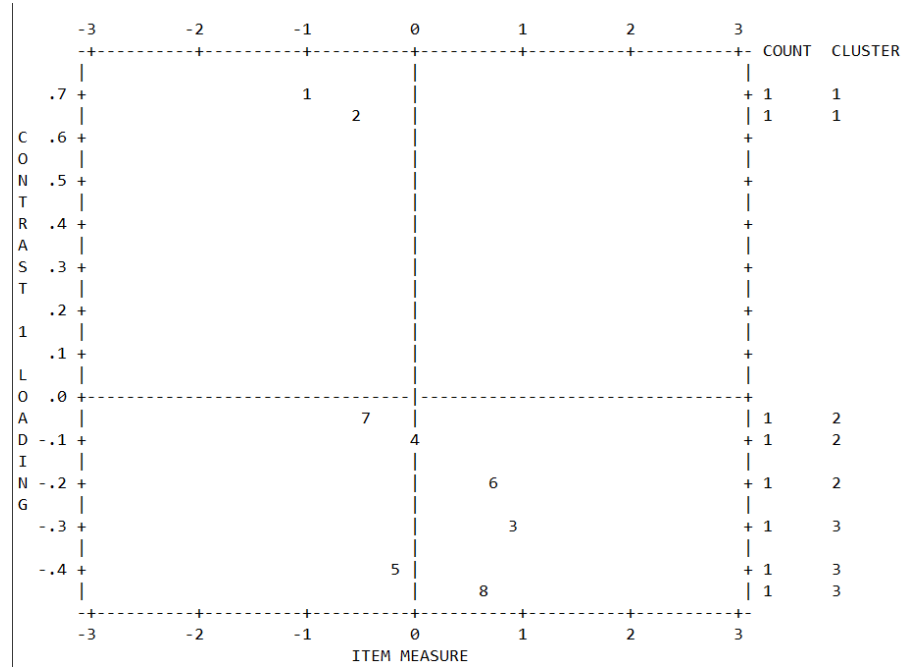
Table 6 shows the result of principal component analysis of residuals. The total variance explained by measures was 22.7%, which was low. The eigenvalue of the 1<sup>st</sup> contrast was 1.45, with 13.7% of unexplained variance. According to the dimensionality map in figure 3, the factor loading of items 3 to 7 were within the range of -0.4 to +0.4, which means those items might measure the same intended dimension (Liu, 2010). Item 1, 2 and 8 were not within the range, which required closer examination.

Table 7 shows the results of Differential Item Functioning (DIF) values between genders of each item. The DIF values suggest possible item bias between genders. According to the result,



Raw variance explained by measures	22.7%
Raw unexplained variance	77.3%
Unexplained variance in 1 <sup>st</sup> contrast	13.7% (1.45)
Items out of range	1, 2, 8

**Table 6. The Result of PCA (with eigenvalue in brackets for 1<sup>st</sup> contrast)**



**Figure 3. The Dimensionality Map of the Spatial Thinking Ability Items**

Item Number	Gender	DIF Measure	DIF S.E.	t-value
Q1	F	-1.14	0.14	-1.13
	M	-0.91	0.14	
Q2	F	-0.34	0.14	1.76
	M	-0.69	0.14	
Q3	F	0.67	0.16	-1.93
	M	1.13	0.18	
Q4	F	0.06	0.14	0.78
	M	-0.10	0.15	
Q5	F	-0.20	0.14	-0.38
	M	-0.12	0.15	
Q6	F	0.72	0.16	-0.10
	M	0.74	0.17	
Q7	F	-0.45	0.14	0.36
	M	-0.52	0.14	
Q8	F	0.64	0.16	0.39
	M	0.55	0.16	

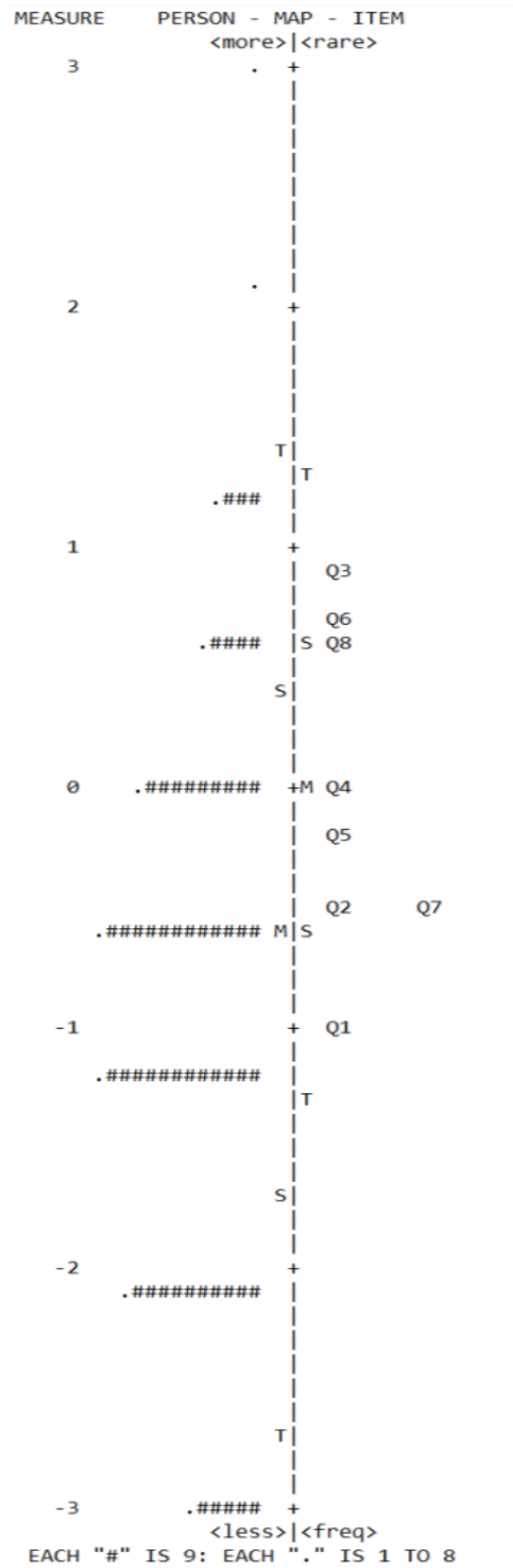
**Table 7. Differential Item Functioning (DIF) Between Gender**

there was no significant difference on item difficulty between genders, which indicated all the eight spatial thinking items had equal difficulty on male and female students.

Refer to the Wright map (Figure 4), the right side shows the item difficulty of the eight spatial thinking questions. Among all the questions, question 3 was the hardest question for students to answer, with a difficulty of 0.88; while question 1 was the easiest question for students to answer with a difficulty of -1.02. No items were between Q4 and Q8, and no items were below Q1, suggesting major gaps in items to target students at those ability levels.

The left side of Figure 4 shows the distribution of students' abilities. It indicated that student abilities ranged from 2 to -3, while item difficulties ranged from about 1 through -1, indicating a mismatch. Overall, the average difficulty of items was much higher than the average student ability.

Interview data from 7 students also suggest similar findings about the STAT test items. For example, when asked about the easiest question among the 8 questions, five out of the seven students indicated question 1 or question 2 to be the easiest question for them to answer; the rest two students thought all the questions were not easy for them. One student described his thinking process on doing question 1 (Figure 1a): "I look at North is here", he said this when he was using his finger pointing at the North direction on the question. Then he said "I am able to know the direction of West, East and South. So if I'm at point 1, travel one block to North, I actually go down 1 block. Then I travel three blocks to West, I actually go right three blocks. Then I go up 1 block, I'm at point 5". In this case, although the four directions of this question were reversed, the student were still able to recognize the new directions and describe the process of doing the question very clearly. Also, although sometimes students chose the wrong answer since they did not realize that the direction were reversed, after providing them a hint about the reversed



**Figure 4. Wright Map of the STAT Results**

direction, they were able to find the right answer. For example, one student was asked that “if North is go down, which direction would be the new West?” The student responded very quickly: “to the right. I see, now after you go down, you can turn right three blocks”.

Another student said this when he was talking about his spatial thinking ability: “If I need to go somewhere, if I have a map, I can look at it and I can figure out the direction and road to get there”. This statement indicated that students not only were able to solve questions about direction, but also were able to apply this spatial thinking ability in real life. Thus, we can conclude that most of the students have the ability on comprehending orientation and direction.

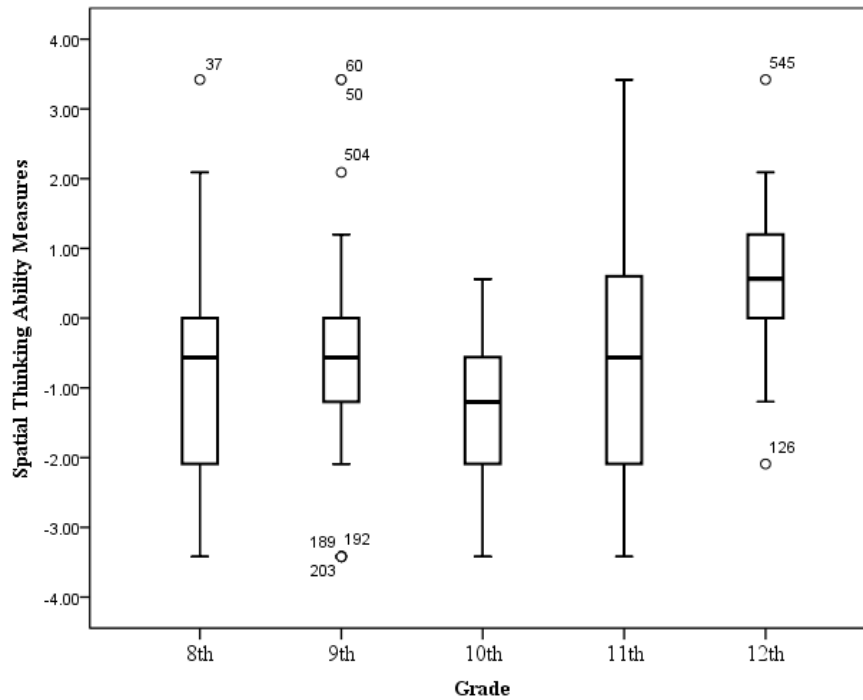
However, students’ ability on overlaying and dissolving maps was relatively low. Most of the students indicated question 3 and 4 (Figure 1b) to be very hard for them to understand and find the right answer. For example, one student said this when she was referring to the examples of question 3 and 4: “I tried my best to look at it to see what is the relationship and how these are similar, but I did not get it. I just guess the answer is A”. According to her description, the student was not able to overlay the map and recognize the different types of overlay.

Another student said something similar: “question 4 is very hard. I can’t really understand it. I don’t know what does the example means, and I can’t see the difference between those examples.” After explaining the relationships to her, she said “oh, so it asked me to put it together”. However, after understanding the question, the student still picked answer A, which was a wrong answer of question 4. In this case, even after the students understanding she should put the two graph together to find the answer, she still picked the wrong answer. Thus, we can conclude that students were having difficulty in overlaying and dissolving maps.

Since question 3 and 4 supposed to test the same ability component of spatial thinking, the item difficulty should be similar to the students. However, refer to item difficulty of STAT test result, question 3 was the hardest question, but the item difficulty of question 4 was among average. The inconsistent result can be explained by students' interviews. For example, one student described how she did question 4: "if you combine A and B, the left part of graph A will still stay the same position, and also the left part of graph B. It just the right side of the two graphs will combine, and you are able to see two points left". She chose the right answer after her explanation. However, when asked why she combined the two graphs together, she said "I don't know, I guess it asked me to put it together". In this case, the student did the question based on guessing rather than understanding the overlaying relationships in the examples, which means their ability of overlaying and dissolving maps could still low.

For spatial thinking ability among different grade levels, figure 5 shows the ability measurement scores. Through the boxplot (figure 5) we can see that on average, 12<sup>th</sup> grade has the highest spatial thinking ability ( $M = 0.64$ ,  $SD = 1.35$ ); while 10<sup>th</sup> grade has the lowest spatial thinking ability ( $M = -1.43$ ,  $SD = 1.17$ ). According to the figure, the average ability measurement score for grade 8 ( $M = -0.95$ ,  $SD = 1.28$ ), 9 ( $M = -0.73$ ,  $SD = 1.23$ ) and 11 ( $M = -0.57$ ,  $SD = 2.02$ ) are similar, but the 11<sup>th</sup> grade has greater spread in the data.

To test whether the above differences between different grades are statistic significant, one-way analysis of variance (ANOVA) has been applied. Table 8 shows the ANOVA result, the result indicated that there was a significant difference on students' spatial thinking ability among different grade levels [ $F(4, 547) = 8.122$ ,  $p < 0.01$ ]. Post-hoc comparisons using the Tukey HSD test (Table 9) indicated that the mean of spatial thinking ability measurement score for 12<sup>th</sup> grade ( $M = 0.64$ ,  $SD = 1.35$ ) was significantly different than all other grade levels. Also, the mean of



**Figure 5. Boxplot of Student Spatial Thinking Ability Measurement Score by Grades**

#### ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	54.42	4	13.61	8.12	.000
Within Groups	916.23	547	1.68		
Total	970.65	551			

**Table 8. ANOVA Results for the Spatial Thinking Ability Measurement Score by Grades**

	8 <sup>th</sup> Grade	9 <sup>th</sup> Grade	10 <sup>th</sup> Grade	11 <sup>th</sup> Grade
9 <sup>th</sup> Grade	-0.22			
10 <sup>th</sup> Grade	0.48	0.70*		
11 <sup>th</sup> Grade	-0.37	-0.15	0.85	
12 <sup>th</sup> Grade	-1.59**	-1.37**	-2.07**	-1.22*

\*p < .05 \*\*p < .01

**Table 9. Post-hoc Comparison of Spatial Thinking Ability Measurement Score by Grades**

spatial thinking ability measurement score for 9<sup>th</sup> grade ( $M = -0.73$ ,  $SD = 1.23$ ) was significantly different than 10<sup>th</sup> grade ( $M = -1.43$ ,  $SD = 1.17$ ). No significant difference was found between 8<sup>th</sup> grade, 9<sup>th</sup> grade and 11<sup>th</sup> grade. Taken together, the above results suggest that students' grade levels were associated with students' spatial thinking ability, but the relationship was not linear. Specifically, the results suggest that 12<sup>th</sup> grade students had the highest spatial thinking ability among all other grade students. However, students in 10<sup>th</sup> grade had lower spatial thinking ability than 9<sup>th</sup> grade students, which means students' spatial thinking ability may not grow linearly by each grade levels.

Interview data also shows consistent results on students' spatial thinking between different grade levels. For example, a 12<sup>th</sup> grade student said the eight STAT questions were medium hard for him. He was pretty confident on his answers. However, students from other grade levels indicated the questions were hard or very hard for them. Also, when talking about students' overall spatial thinking ability, the 12<sup>th</sup> grade student said: "I think my ability to use the spatial thinking is good. When I did our project one time, compare to other students, I'm able to recognize perspectives of objectives or features on map." The student was talking about his project of making a topographic model. Building the model requires students to recognize the objectives and figures on a 2D map and convert it into a 3D model, which refers to several components of spatial thinking. However, after understanding the concept of spatial thinking and hearing some examples, lower grade level students indicated their spatial thinking ability to be not good. For example, one 8<sup>th</sup> grade student said: "I think my spatial thinking ability is not high, I'm not confident with it. For the eight questions, I'm not confident about whether it was right or wrong when I chose the answers". In this case, 12<sup>th</sup> grade students not only have higher spatial

thinking ability than other grade students, but they also are more confident with their spatial thinking ability.

To sum up, for secondary school students, both test results and interview data indicated students' overall spatial thinking ability was still relatively low, although the ability level can be differentiated by different spatial thinking components and grade levels. To be specifically, solving spatial problems about overlaying and dissolving maps were difficult for students, but they had better skills on solving problems about comprehending orientation and direction. Also, 12<sup>th</sup> grade students had relatively higher spatial thinking ability than all other grades, but the relationship between spatial thinking ability and grade level was not linear. There was a reverse order in ability between 9<sup>th</sup> and 10<sup>th</sup> grade.

#### GIS Experiences in Science Class

Google Earth and Storymap were two GIS tools that had been applied in this study. To understand students' experiences on using the above tools in science class, formal one on one student interviews and GIS integration class observations were conducted. Also, several informal interviews with teachers after each class observations were conducted to build triangulation. In general, all the interviewed participant students provided positive feedbacks on using the GIS tools in class. For example, a student said this when talking about the overall experiences of using the GIS tools: "It is fun to use the Google Earth and Storymap. It's easy to access, it's quick to do and it's not difficult." Also, a teacher talked about students' experience in using the tools: "They enjoyed using the map online and made great projects by the tools."

When talking about general experience of using GIS tools, one student said: "for me, I notice a lot of people like for this one (GIS tools). They like to do it and they learn from it. They



can make their own story and they can search different places about the story. But like when we are in class, we are just taking notes and using paper maps, they don't like to pay attention. They distracted". What the student said indicated students prefer to use the GIS tools than paper maps because they were more engaged through the using of the tools. Some other student indicated the GIS tools allowed them more chances to work with their classmates. For example, one student said: "it's a hands on activity, everyone can do it. So like one student and other students can relate to it, and say 'oh this person is really good and I can try something like that'. I have more chance to share my work with my classmate and work with them to learn from each other".

Some teachers indicated the same opinion as the students. They stated their students were more concentrate in the class when they did the activity, and they had more chance to communicate and learn from each other. Thus, in general, the GIS tools are easy to use and accessible for secondary school students, and students are willing to use the tools and more engaged in the class.

### Student Experiences with Google Earth

To be specific, for Google Earth, several students pointed out a common characteristic of Google Earth: it shows more features of a map, such as different views, different scales, and information of different locations. They indicated the features of Google Earth was very useful for their learning and it was flexible to use. For example, one student said this when she comparing the use of 2D paper map and Google Earth: "the 2D map doesn't really like the 3D map. 3D map shows us more features, like I can see the street view, I'm able to see what things really like." Another student said similar thing: "I enjoyed in using the Google Earth. I did zoom in and out to see different angles of a location, it's good to see the different views of mountains and volcanos." What the students said indicated Google Earth allowed them to see the visually

information about certain location. Also, another student said: “the Google Earth has a lot of things about locations and stuff. If we need to know where to go and how to go there, I am able to know some places I can’t drive there, I have to fly to there. So it’s kind of useful to me”. In this way, Google Earth contains plentiful and various information about locations for students to use, and students feel it was very helpful both for their study and for their personal life.

### Student Experiences with Storymap

For the using of Storymap, students indicated that although it does not have as much features as Google Earth, some special features of Storymap were very useful for their learning. Some students pointed out Storymap allowed them to see the relationship between different locations. One student said this when he was describing his Storymap project: “I did the storymap for many sport arenas, because I like basketball. I just typed in the coordinates, and it takes me to there, on the street view of the arena. I just snipped the picture and added it in. I never been to some of the places in my Storymap, but it allows me to see the details of the places and also the relationships between the places.” For the Storymap activity, some teachers asked students to do the places they want to go, others asked students to do important places about scientist. However, no matter for what content, students all indicated that it is good to see the places in one map and view the relationship between locations.

In addition, some students said that Storymap allowed them to collect different types of information and put them together, and this special feature of Storymap was also helpful. For example, figure 7 shows a Storymap project that created by one of the students. The topic of the Storymap is about famous scientists. Here is how the student talked about her project: “basically we pick scientists, we pick which ones we are interested in, and then we say where they were born and where they did the research. The Storymap allows you to see the map of the whole

world, and you got several pinpoint to put on specific places. And you can write about the place and say an important person that live in that place, and put into detail about his or her research. You can also put a picture about the place and you can zoom in, out. You basically learn in multiple ways". Through the use of Storymap, students were able to learn through various ways, such as introduction of a place, location of place, picture of the place or certain person related to the place. Thus, Storymap not only allowed students to see the relationships between locations, but also allowed them to learn a topic or a concept through different ways, which helped their learning.

### Impact of GIS on Student Science Learning

The interview results indicated that Google Earth also can be a scaffolding tool on certain science content learning. For example, several students indicated they had a better understanding of coordinates through doing the Google Earth Scavenger Hunt activity. Figure 6 show one of the student's class project by using Google Earth. According to the screenshot of the project, we can see that by searching the coordinates Google Earth, students were able to see the certain locations. Then through zooming in and out, and changing the angles and views, students were able to see the object closely in Google Earth. The student who did the project said: "The Google Earth activity helped me learned the coordinates, it's associate with the coordinates. I wasn't really familiar with the coordinates, but I know how I can use it now. Like when I say about coordinates, it is another way to say the street name, the address or other stuff like that. So that's why when you have the coordinates, the stuff (Google Earth) just show me where is that." In this case, before using Google Earth, the student was confused with the concept of coordinates, which was his initial level of understanding. However, after using the tool, the student was able to know how to use the coordinates and had a better understanding of the concept, which was a

## Cut & paste the coordinates into Google Earth

51 22 56 N, 3 20 46 W

What do you see?  
Tons of grass, water,  
houses

Where are you?  
Rhoose



Figure 6. Student Google Earth Project Example

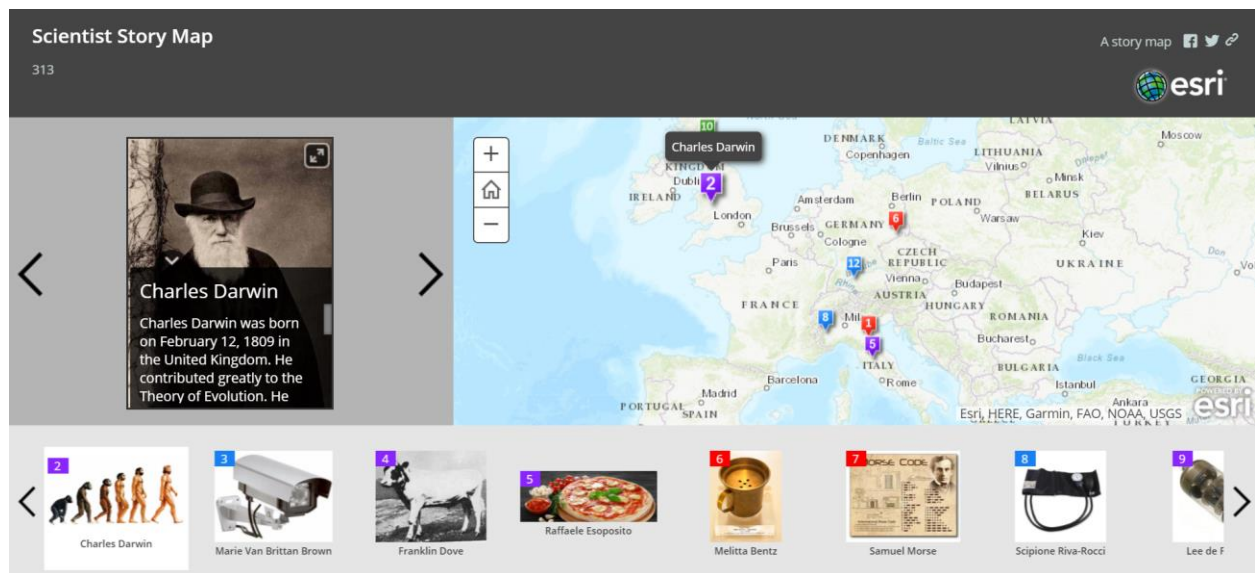
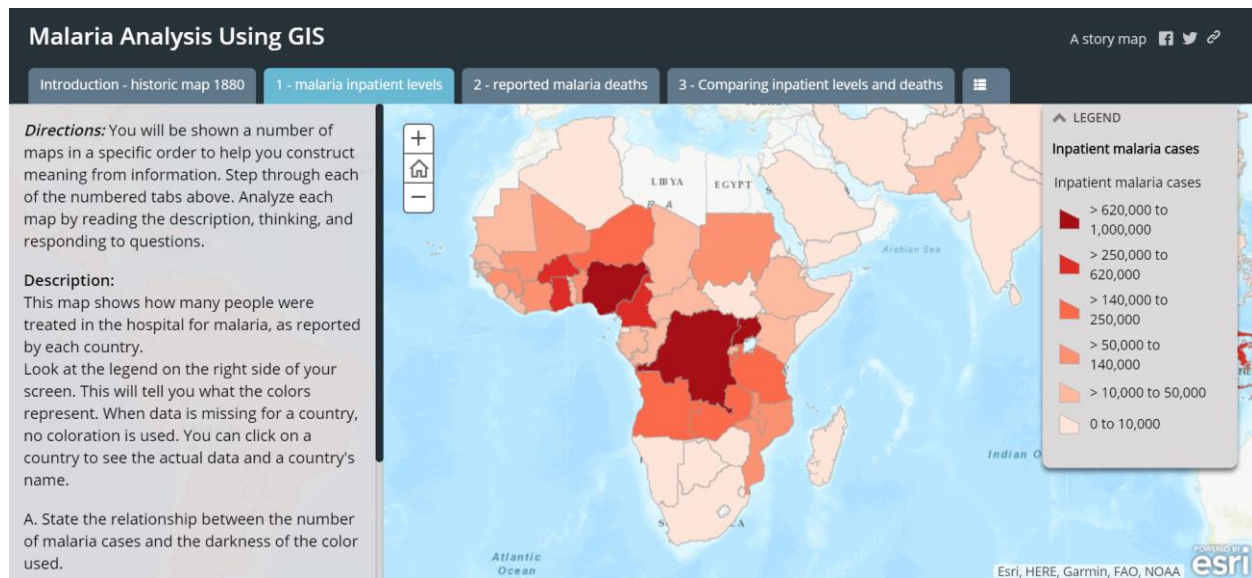


Figure 7. Student Storymap Project Example



**Figure 8. Teacher Storymap Example**

higher level of understanding. In this way, Google Earth is a scaffolding tool for the student to learn coordinates. Following are two similar examples can be evidences to support the claim. One student said this when he was referring to the coordinates: “it was very useful to know where these places were, like I would never understand those number, but I learned it through the activity”. Also, another student said: “instead of actually searching where something was on a 2D map, you can actually look at the Google Earth. For example, like 55 North and 52 West, you will know where is was on a map. It did help with my learning on latitude and longitude”. Thus, after using the Google Earth, students were able to give examples of latitude and longitude based on their understanding of the concepts, also they were able to make connection between the concept with the real map, which means they improved their understanding of the coordinates through the activity.

As for Storymap, one student said this about the use of Storymap: “it helped with my science study. When you zoom in through the Storymap, you are able to see more information about the places, and you are able to know more about the scientist. It kind of helped me to

remember the scientist. Such as where they were born and what they did. It's really fun to use". This example indicated the use of Storymap helped the student's learning about scientists' experience and stories, which is an important part of science learning. Also, some teachers pointed out the Storymap can also be integrated to other science content. For example, a biology teacher said: "my student engaged in the Storymap activity and we will not stop from here; I'm going to use it also in my human Biology class". Also, another teacher showed his pre-made Storymap (figure 8) on Malaria analysis in 9<sup>th</sup> grade Biology class, students will have chance to use the Storymap to learn the disease spread and prevention. Thus, both of the students and teachers agreed that Storymap can be a useful tool on science learning.

To sum up, the GIS tools in the current study were useful tools for students' learning. Specifically, Google Earth allowed students to use various features related to map, and it also can be scaffolding tool on learning certain science content knowledge, such as the content of latitude and longitude. Storymap allowed students to visualize the relationship between several locations, and to introduce the locations and relative content in multiple ways. Depending on the topic, Storymap also helped students learning on science, such as knowing the history of science and scientists. Students enjoyed and engaged in using GIS tools, and the use of the tools benefited their science learning.

## **Discussion and Conclusions**

Based on the findings presented above, we can see that secondary school students are in general still lacking skills in overlaying and dissolving maps (Golledge, 2002), but they have 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 may not understand the geographical features represented in the map. Thus, science teachers need 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 suggest the importance of studying students' spatial thinking in terms of different components independently in order to provide more precise and effective advice 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. However, we only studied three components in the current study. In the post-test, we will add more questions related to other components to better answer the research questions.

The findings indicated 12<sup>th</sup> grade students' spatial thinking ability was better than others, and there was a reverse between 9<sup>th</sup> and 10<sup>th</sup> grade students. After looking at the sample of 10<sup>th</sup> grade, we found the total of 42 10<sup>th</sup> grade students in our sample; they are all from one community high school, and they are all from criminal justice class rather than science class. Also, most of the 10<sup>th</sup> grade students are not taking any science class in the research year. Thus, the 10<sup>th</sup> grade students may not be representative.

The study results on spatial thinking ability among different grade levels deserve educators' further consideration and exploration. Firstly, since 12<sup>th</sup> grade students have better

overall spatial thinking ability, we should pay more attention on lower grade students' spatial thinking ability and figure out how to improve it. In addition, we also should consider the reason behind the ability differences. In the current study, the sample of 12<sup>th</sup> grade students are all from AP Biology class. It maybe because those 12<sup>th</sup> grade students are better behavior students or higher achievement students, but the reason requires further examination. Moreover, according to the results, secondary students' ability did not grow along with their age or grade level. However, as stated above, spatial thinking ability is an important and essential ability, not only for students' in secondary school, but also in college level study. Thus, we should ask whether high school students are well-prepared on spatial thinking ability for their college study? Also, research indicated the U.S. is facing a shortage of geospatially-trained workers (NRC, 2013). We also should ask how to improve their ability in order to qualified them in relevant future work? Those are all the questions that emerged in this field and deserve policymakers and researchers to consider and explore.

In general, the study result indicated students' overall spatial thinking ability needs to be improved, which is consistent with the prior studies (NRC, 2006; Newcombe, 2010). However, how to improve the ability is an emerge topic in recently research. A number of studies suggested geospatial technologies should be integrated into class since it can improve students learning in a variety of ways (e.g. Bodzin & Cirucci, 2009; Doering & Veletsianos, 2008; Milson & Earle, 2008). Thus, the current study hypothesized GIS could be an effective tool on improving students' spatial thinking ability. Although we have not conduct the post-test after GIS integration which means we cannot test the hypothesis through statistic method, the current research results allowed us to know students' experiences on GIS. Those experiences can also provide some insights to future study on improving spatial thinking ability.



For example, the results indicated through the use of Google Earth, students were able to see different geographic views, such as 2D map, 3D map and satellite map. This feature of Google Earth is associated with the spatial thinking ability component of “being able to transform perceptions, representations and images from one dimension to another and the reverse” (Golledge, 2002). The study results also indicated Google Earth allowed students to see more features of map, such as different scales, and various information of different locations, which associated with spatial component of “comprehending integration of geographic features” (Golledge, 2002). For the Storymap, students were allowed to see the relationship between different locations, which is associated with several spatial components such as map overlay (Golledge, 2002). In addition, there are also some other GIS tools that we will applied in the future study, such as Sketch Up and ArcGIS Collector, which are also closely related to some spatial thinking components. For example, Sketch Up allowed students to see and build 3D model by using 2D graphs.

The current study also indicated middle and high school students enjoyed in using GIS tools, and the use of GIS tools helped their science content learning. Those results all pointed out that GIS tools can and should be integrated in science class. The GIS tools not only engaged students in their science content learning, but also may have positive impact on their spatial thinking ability. We will continue to do the current study to test whether GIS is an effective tool on improving students’ spatial thinking ability.

Although this study filled some gaps in this research area, this study remains preliminary. Firstly, limited by the actual data collection situation, we were not able to collect random sample, and also the sample size in each grade level were vary. This might cause bias when making inference to the whole population. In addition, the reliability and validity of the spatial thinking

ability test were not high enough, and we were not able to test all the ability components. The test needs improvement by adding more items to cover the whole ability range of students, which is what we plan to do for the post-test. Moreover, we have not answered the last research question about the influence of GIS on spatial ability. But again, this is an exploratory study, we will be able to answer the last question once we have the data from post-test.

In conclusion, spatial thinking ability is an emerged topic in current research field. 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.

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