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Effect of GIS-integrated Lessons on Spatial Thinking Abilities and Geographical Skills

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GIS를 활용한 수업이 공간적 사고능력과 지리적 기능에 미치는 영향

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Abstract : This study investigates the effect of GIS-integrated lessons on spatial thinking abilities and geographical skills using discourse analysis along with a comparative three-case case study method. A series of curricula were designed and implemented in an 8th grade classroom for a semester. The data collected consist of the dialogue transcripts of six consecutive GIS-integrated lessons. The transcripts were analyzed to identify the moves (speech acts) used by each student and to classify discourse content of spatial thinking and geographical skills. Based on three individual case studies, a cross-case study was performed to uncover any relationship between the phenomenon and the contexts. The empirical evidence from discourse analysis demonstrated that students were able to generate appropriate terms representative of spatial thinking and geographical skills although students appeared to possess primarily lower-order spatial abilities, followed by a moderate-level of spatial abilities. Considering that the unit was implemented in a biology class rather than a geography class the result reflected the fact that the student's spatial thinking and geographical skills were attributable to the GIS-integrated lessons. Thus, the results have a great implication for GIS-integrated lessons and geography education as an innovative tool for improving student's spatial thinking and geographical skills.

Key Words : spatial thinking ability, geographical skills, GIS, discourse analysis, case study

요약 : 본 연구는 GIS를 활용한 수업이 공간적 사고능력에 미치는 영향을 담화분석방법과 사례연구를 통해서 살펴보고자 한다. 분석에 사용된 자료는 6회에 걸친 GIS활용 수업에서 학생들이 주고 받는 대화를 녹취하여 수집하였다. 개별 학생들의 '발화가 수행하는 행위' (언어학의 화행론상의 행위, 담화분석의 최소단위)를 확인하고, 이를 다시 담화의 내용을 기준으로 공간적 사고 및 지리적 기능으로 분류하였다. 담화분석을 통한 실증적 연구 결과, 학생들은 주로 저차 공간적 사고능력을 지니고 있는 것으로 나타났고, 그 다음으로 중간 정도의 공간적 사고능력을 보였으며, GIS를 활용한 수업에 참여하는 동안 공간적 사고를 나타내는 적절한 용어를 생성하였다. 본 연구가 진행된 것이 지리수업이 아니라 환경과 관련한 생물 수업이었음을 감안한다면, 학생들의 공간적 사고가 GIS를 활용한 수업의 결과임을 반영한다고 볼 수 있다. 이는 앞으로 학생들의 공간적 사고를 향상시키는 새로운 도구로서 GIS를 활용한 수업과 지리교육에 함의하는 바가 크다.

주요어 : 공간적 사고능력, 지리적 기능, GIS, 담화분석, 사례연구

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1. Introduction

"Is this going to be on the exam?" This might be one of the most frequently asked questions in my geography class, especially at the beginning of a new school year. Whenever I, as a geography teacher, show them a map of natural resources in South America, language families in Europe, or religions in South Asia, students are tend to focus on factual knowledge very easily. So, they keep asking me this question although they usually stop it after a mid-term exam when realizing the teacher asks them more than that. The basic issues and ideas that underlie this question might be geographic illiteracy. Students' understanding about geography which is too narrowly defined limit the scope of its work although geographers argue geography's current and potential connections with a broader range of societal and scientific challenges and opportunities in the beginning of the 21st century. The migration of peoples, the importance of a good infrastructure, the gap between rich and poor, the influence of the climate on daily life, the relationships between world religions, the battle over resources such as oil — this is all part of modern geography (Brown, 2002). Can we help student be aware of this kind of issues as geography? I think we can do, because geography can be relevant to understanding real world issues, but whether they do or not largely hinges on the ideas that teachers offer, the way the ideas are offered to students, and how they are involved in while they rigorously investigate these ideas and issues and make them their own knowledge (Huckle, 2002).

Filling these gaps require more than addressing the problems presented by relatively small size of geography community, limited diversity of research field in geography, and insufficient external support, however. It is necessary to "strengthen its [geography as a discipline's] understanding of complex systems; interactions between scales; interactions between society and nature; and geographic learning, including the effectiveness of interactive learning tools on geographic education(Rediscovering Geography Committee, 1997, 5)."

This study examines the gap between the current settings in geography education and the geography's potential as an innovative tool for improving spatial thinking ability. At the same time, the study explores a new approach of teaching to think spatially through GIS in order to seek to bridge the gap. Thus, the primary goal of the study is to investigate the effect of GIS-integrated lessons on spatial thinking ability and geographical skills.

2. Research background

1) Spatial thinking ability and geographical skills in geography education

Kang and Kim (2001) argued that discussions on concepts in geography education so far have been overly weighted toward the fact that geography itself consists of many concepts or conceptual knowledge. As a matter of fact, the contents of geography education are comprised of long list of those concepts and factual knowledge. They unveiled a new approach for tackling this problem. That is, instead of enumerating facts, structure of knowledge should be taught. On the premise that it depends on teaching and learning method, they suggested the importance of a theoretical basis for the effective teaching-learning of the geographical concept. Ryu (1997, 2006) took a macroscopic view of the development of the hierarchical system while reconstructing geography education. He

ascertained that the main purpose of geography education is fostering geographic perspectives, or teaching to think geographically. He argued that it is essential to develop strategies in detail how to cultivate students' geographical perspectives or the view point of seeing places spontaneously while they attend geography courses in the primary and secondary school curriculum.

In recent years, there has been increased emphasis on spatial thinking and geographical skills, as higher-order thinking has come under the spotlight since mid-1980's educational reformation in Korea. There have been great advances in the research of geographical and spatial thinking, however, studies are limited to the importance of geographical thinking as an ultimate goal or objective which is just expected to be achieved by students and is too abstract in most cases (Kang, 2005). Based on this, Kang and Park (2004) insisted that we should focus on systematic explanation about how to foster students' thinking skills through teaching and learning rather than the declarative notion about how it is of importance to cultivate student's thinking skills and why we need to develop them. Furthermore, they contended that improving students' geographical thinking should be ensured with concrete examples in real classroom and that geographical skills should be specified when developing teaching-learning objectives. This argument is applicable not only to geographical thinking but also to thinking in general. Thus, it is time to reflect the methods to teach to think so far and to give careful consideration to what we can improve. As an alternative approach to teach to think, there is a general consensus among researchers, educational practitioners and teachers about the need for teaching to think in schools (Lee, 2004). Also, teaching to think is directly correlated to students' thinking ability so that we should provide students with thinking skills which is closely related to the knowledge of certain subject matters and let them apply the skills to specific learning activities. By doing this, we can allow them to think deeply and achieve higher-order thinking skills. As a matter of course, geographical thinking skills should be located at the center of geography education as a concrete objective. Also, Seo (2002) classified knowledge in geography education into two categories: declarative geographical knowledge and procedural geographical knowledge. On this basis, he pointed out the importance of the latter as an essential component in geography education, especially in this knowledge-based society. Since it is associated with practice, procedure, and performance in geography, he strongly emphasized the procedural knowledge which can enhance the level of geographical thinking and geographical inquiry.

2) GIS as an innovative tool to teach to think spatially

Over the past decades, many authors have reported on the positive correlation between GIS and spatial thinking (Albert and Golledge, 1999; Chun and Hong, 2007; Kidman and Palmer, 2006 ; Lee, 2005; Self *et al.*, 1992; Sui, 1995). Consistent with the findings of other researchers, Board on Earth Sciences and Resources of the National Research Council (2006) also reported that spatial literacy and geographic problem solving are core educational needs throughout society in a recently published book, "Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum." In addition, the committee identified and presented six reasons for the argument of GIS as a support system to teach to think spatially in K-12 education like below;

- GIS can facilitate the process of scientific problem formulation and solution, and therefore, it exemplifies many of the ideals of

discovery-based, student-centered inquiry.

- GIS can be useful in solving problems in a wide range of real-world contexts. It can succeed as a tool for both scientific research and problem solving.
- GIS has the potential to facilitate learning across a range of school subjects and to enhance interdisciplinary and multidisciplinary learning.
- GIS can provide a rich, generative, inviting, and challenging problem-solving environment. It can empower students to address significant issues with the same tools that professionals use to address issues in their work.
- GIS has the potential to accommodate and be accessible to the full range of learners, including the visually impaired. It is rigorous enough to challenge gifted students and accessible enough to reach many students who have difficulty learning in traditional ways.
- GIS can be used effectively in a variety of educational settings. This tool can be infused throughout the curriculum or used in traditional subject-based curricula. It can be employed in all grades. In addition, it enables a range of modes of use (e.g., individual and stand-alone, collaborative and networked).(218)

With current national curricular or national standards movement, students are expected to know and should be able to do at certain educational level. Across a broad range of disciplines, students are increasingly expected to use real world tools in the same hands-on manner as a scientist would to solve real world problem (Kerski, 2008, 549). This is where GIS is being watched with keen interest. The real power of GIS is placed on its design for collecting, storing, manipulating, analyzing and displaying data referenced by a spatial or geographic component.

As Audet *et al.* (1993, 38) put it, "with the aid of a GIS, the world can be studied in ways once considered impossible." GIS is unequivocally a technology based on the real world. By using local data, GIS allows students to collect, organize, store, analyze, display data and ultimately make a spatial decision with a better understanding and more information. Consequently, using GIS in the classroom can make learning more relevant and meaningful. Furthermore, the various disciplines can be integrated in the manner campaigned for by the major nationwide curriculum reform movements, because classes in which students explore their real world go beyond traditional curriculum boundaries. More specifically, Liu and Zhu (2008, 150) argued that using GIS, students can define problems, create and explore different representations of data and information, judge information, solve problems, and draw appropriate conclusions, thus developing their higher-order critical thinking skills.

However, GIS, while not new in the field of geography education, with few exceptions has been noticeably absent from research in geography education as a tool for teach to think spatially (Kim, 2007).

3. Research method

1) Discourse analysis: Structure and categories

Theories of learning have long suggested that dialogue plays an important role in shaping conceptual development. This study will focus more on the characteristics of language as communication in terms of its content as the research domain. Analysis of the student's

conversation is supported by the rhetorical structure theory (Pilkington, 1999). As Wiegand (2003, 236) notes, this contends that "the structure and hierarchy of ideas can be represented through the identification of 'rhetorical predicates,' which can be used to track the nature of an argument" as it develops from one participant to another.

These predicates can be categorized as reflection, support, monitor, critique, etc. which are used in combination with factual propositions. Pilkington's DISCOUNT scheme (1999) is a very useful tool to analyze conversation in educational research. It has been developed in order to specify the patterns of dialogue exchange, to identify the dialogue participant's turn and role in the conversation, and to investigate the activity functions of both facilitating activities (i.e., debrief, encourage, suggest, etc.) and learning activities (i.e., monitor, observe, reason, etc.). In this study, the talk between two students will be recorded, transcribed, and coded following a customized simplification of Pilkington's scheme. In order to examine the student's activity function, a list of codes has been developed (Table 1).

As a next level of analysis, each move is subcategorized using its ideational content according to the geographical skills and GIS functions. A geographic skill code list was developed following "Spatial Thinking: Geographical Skills" (Gersmehl, 2005, 97-111). In his recent book, "Teaching Geography," Gersmehl summarizes 14 geographical skills along with key questions in geography and arranged them in roughly increasing order of abstractness, from concrete to very abstract. Table 2 shows the list of subcategories for spatial thinking and geographical skills.

Note that in the DISCOUNT scheme, the most salient feature is a specific category called 'moves' or speech acts. This study will use these moves as basic units of analysis, which consists of two dimensions: its activity functions in conversation

Table 1. Code list for Moves in forms of activity functions using Pilkington's DISCOUNT scheme.

Code	Activity function	Description	Example
I	Inform	Describe/ differentiate or modify description with value or quality	It is an outfall. These are the best.
L	Logical thinking	State casual proposition	If we can get this down, then it will fall.
Iq	Inquire	Seek information or response	What is that icon? Do you mean this one?
D	Direct	Instruct to perform a task action	Put that one down.
S	Scaffolding	Suggest a task action or plan. Monitor and control their learning	Let's finish and see what happens. I know what I want to do next.
R+	Agree	Respond positively	OK ,Yes, etc.
R-	Disagree	Respond negatively	No, I don't think so, etc.
R0	No Commitment	Respond neutrally	Hmm, Gee, etc.
C	Compliment	Give a compliment	That's great.
O	Other	Open a dialogue Close a dialogue Other	Hello, Hi, etc. Let's call it a day. Thanks, Bye, etc.

Table 2. Code list for spatial thinking and geographical skills.

Code	Subcategory	Description	Exemplary questions
LC	Location	Expressing location	Where is this place? (This is the basic question that defines something as geographic. However, it turns out to be surprisingly difficult to answer unless/until a student also considers at least one of the other questions on the list below; those are the questions that define the aspects of spatial thinking.)
CD	Condition (Site)	Describing conditions at a location	What is at this place? What are some characteristic features of a place at a specific latitude, elevation, age, etc.?
CN	Connection (Situation)	Tracing connections with other locations	How is this place linked to other places? What natural processes or human transport/ communication help connect places?
CP	Comparison	Comparing locations	How are places similar or different? How does this place compare with the national or world average?
IF	Influence	Determining the zone of influence around a location	How far from a feature is its influence significant? What effect(s) does a feature have on its neighbors? How does this thing (power plant, park, mall, feedlot, etc.) affect the area around it?
RG	Region	Delimiting a region of similar places	What nearby places are similar to this one? What area (e.g. the desert, Corn Belt, Midtown) consists of places similar to this one?
HR	Hierarchy	Comprehending the whole and part relationship and its order	What larger area is this part of? What smaller areas are part of it? Where does this area fit in the hierarchy of watersheds, political jurisdictions, etc?
TS	Transition	Describing the area between places	What is the nature of the transition between places? Do things change gradually from here to there, or stay the same and then change abruptly?
AN	Analog	Fining an analog for a given place	What distant places are similar/ analogous to this one? What parts of other continents, mountains, cities, etc. are like this part of this one?
PT	Pattern	Identifying a spatial pattern	Are there biases, imbalances, clusters, strings, doughnuts, waves, and other distinctive patterns? Can your eye pick out an arrangement of things that is not random?
AS	Association	Comparing spatial patterns and finding a correlation	Are the spatial patterns similar? Does thing X always, usually, occasionally, or never occur close to thing Y?
EX	Exceptions	Determining the exceptions to a rule	Where are the places that have more or less of something than expected? Where are the places that do not seem to follow an observed "rule"? What houses are more expensive than you would expect based on their location?

Table 2. Continued

Code	Subcategory	Description	Exemplary questions
DF	Diffusion	Analyzing changes in pattern through time	How do things spread through space? What avenues allow (or barriers hinder) the spread of something through time?
SM	Spatial Model	Devising spatial models	Are places linked by a process? How might things be related in places or influenced across great distances? (The main objective of this skill is awareness of long-distance connections. The idea of making and refining a spatial model basically incorporates all of the other skills of spatial cognition described above.)

SOURCE: based on Gersmehl (2005, 97-111)

(i.e., inquire, direct, inform, etc.) and its ideational content. This table shows a simplified and modified code list following the DISCOUNT scheme.

In addition, I classified these 14 spatial thinking and geographical skills into three groups based on Gersmehl (2005): 1) lower-order (the first four spatial thinking and geographical skill codes, Location (LC), Condition (CD), Connection (CN), and Comparison (CP)); 2) moderate-level (the fifth through the eighth spatial thinking and geographical skill codes, Influence (IF), Region (RG), Hierarchy (HR), Transition (TS)); and 3) higher-order spatial thinking skills (the ninth through the fourteenth spatial thinking and geographical skill codes, Analog (AN), Pattern (PT), Association (AS), Exception (EX), Diffusion (DF), and Spatial model (SM)) for further analysis.

Table 3. Code list for GIS functions.

Code	Subcategory	Examples and exemplary questions
Dc	Data Collection	What kind of data do we need? How can we get the data? Is it primary or secondary data?
Di	Data Input	How can we input the data? What is metadata? What specific attribute information is included? How many spatial objects are there? How good are the data? What projection was used?
Ds	Data Storage and Retrieval	How can we save this file, project, and map in the computer? How can we open this file?
Dm	Data Manipulation	How can we select an area object? How can we identify a feature from a layer? How can we zoom-in and/or zoom-out to see a feature of interest?
Da	Data Analysis	Measure, classification, buffer, comparison of variables, spatial query, etc.
Do	Data Output	Map design, map layout, etc.

Table 4. Example of coding a conversation between two participants using Pilkington's DISCOUNT scheme.

Participant 1	Participant 2	Code		
		Move	Spatial thinking and geographical skills	GIS functions
Ok, then. / Let's start.		O / S		
	(finds the GIS program icon from the Desktop in the computer and double-clicks it) Yep, I opened it. / What's next?	R+ Iq		Ds
I think we need to add data. (finds an icon and clicks it. Then a window pops up asking the location of data)		I		Ds
	Hmm. / There are tons of data. (keeps scrolling down the files)	R0/ I		Ds
Wait. / What about deer-vehicle		D/ Iq		Ds
accident data in Amherst?	.....			
Where is it?		Iq	LC	
	I don't' know. / Why don't we zoom out and see if...	R0/ S		Dm
Oh, I know where it is now. / It's right next to my school!	Cool, Isn't it?	R+/ I C	LC	
Let's add another layer. (clicks "add data icon" and adds a 'town boundary' layer)		S		Ds
	So, Village of Williamsville is a part of Town of Amherst or what?	Iq	HR	
I suppose so.../ If you look into the attribute table, you can see it, maybe.		R+/ R		Dm

Next, a list of GIS functions was identified to examine the pattern or relation as a student is being exposed to GIS during the project from the basic function such as open a file, save it, add data to the advanced level such as spatial query, geocoding. Table 3 shows the code list of GIS functions that were selected for this study.

Table 4 shows an example of a coded transcript extract. Conversation turns are separated into moves using oblique strokes (/). The entire transcript was coded first according to activity function, then in turn, by spatial thinking and geographical skills subcategories and GIS functions. Each move was coded usually, but not always, either as geographical skills or GIS functions. Ideational content is indicated next to the move code with smaller type.

2) Case study

This study employed the case study method (Stake, 2000; Yin, 2003) to collect, analyze, and interpret the data. Yin (2003, 13) defines the case study as "an empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident." He argues that a case study is a comprehensive research strategy instead of merely a data collection tactic or a design feature alone since a phenomenon and its context are not always distinguishable in real-life situations. In this light, I think Yin's definition of a case study is supportive of my research design because of its all-embracing methodological perspective, from covering the logic of the research design, data collection, and data analysis to data interpretation and the drawing of conclusions.

Stake has a similar approach to defining a case study. Stake (2000) points out the pervasive misunderstanding that a case study is "essentially qualitative." He considers a case study not to be "a methodological choice but a choice of what is to be studied" (Stake, 2000, 435). In other words, the main focus is a case as an object, regardless of the method of inquiry used, whether it is quantitative, qualitative, or a mixed method.

In this study, three cases, each composed of two students were analyzed. Each case was composed of a pair of students' conversations covering six consecutive sessions of the GIS project. Each case was chosen not because it would represent the student's learning and its characteristics in the GIS-integrated classroom but because it would provide a better understanding of the student's learning as a phenomenon. Then, each case was added since there would be both similarities and differences in the characteristics of students' learning caused by different contexts. Based on three individual case studies, a cross-case study was performed to uncover any relationship between the phenomenon and the contexts.

4. Data collection and analysis

The data collected consist of the dialogue transcripts of six GIS-integrated environmental education sessions1). The transcripts were analyzed to identify the moves (speech acts) used by each student and to classify discourse content using a two- dimensional analysis: 1) spatial thinking and geographical skills and 2) GIS functions.

Given the limitation of time, sampling of the data was inevitable. Three pairs who had complete sets of all six sessions' conversation data and were engaged in the project were selected for use as sample data. This selection was cross-checked by the teacher. Thus, 18 dialogue transcripts of three selected pairs were assigned as primary documents (PDs) in ATLAS.ti for further in-depth analysis using the DISCOUNT scheme.

First, using the discourse exchange pattern analysis, the nature and degree of collaborative learning were investigated. To figure out the dialogue exchange structure between two students, the Degree of Symmetry was calculated according to a simple ratio:

Degree of symmetry=the smaller number of totaled turns between two participants/the larger number of totaled turns between two participants

A score of 1 means a perfectly symmetrical structure of conversation, which indicates that both participants contributed to the conversation equally, 50% to 50%, while a score approaching

zero shows asymmetry of the conversation where one partner is dominant.

Next, after finishing the turn level data analysis, the moves were categorized and then the ideational contents were subcategorized for further analysis. The study also investigated the temporal differences of the students' conversations in terms of spatial thinking and geographical skills and the usage of GIS functions.

Finally, the map evidence was also analyzed as an important source to examine the temporal differences in learning patterns and progress.

1) Schedule of classes

The school that the students attend uses a block scheduling system. Each block lasts about 80 minutes. However, about 30 minutes were spent on commuting to and from the middle school (15 minutes each way). Students traveled to the University using the district school bus transportation. Thus, each session in the Geographic Information Analysis Laboratory (GIAL) lasted about 50 minutes. Appendix A shows an outline of each session in the GIAL.

2) Defining variables for the research

Discourse analysis was performed on two layers: 1) activity functions in conversation (move) such as inquire, direct, inform, etc.; and 2) ideational content of both spatial thinking and geographical skills (i.e., location, region, influence, connection, etc.) and GIS functions (i.e., data collection, data input, data analysis, etc.) By coding and analyzing both functions and contents, I can explain the structure and pattern of conversation more thoroughly and achieve a better understanding of the meaning of the conversation.

The next sections of this paper will discuss the results of the case studies using discourse analysis; 1) case study 1: Becky and Debbie's conversation; 2) case study 2: Kim and Alisha's conversation; and 3) Dan and Jacob's conversation. Table 5 summarizes the variables that were transformed and used, explanation of variables, and research domains that were examined in each case study.

3) Coding results

Based on the list of codes and code definitions, I coded all PDs that were assigned in this study. Table 6 shows the coding results. The total number of codes for each category in each group's conversation was calculated. For example, all 6 PDs in Becky and Debbie's conversation were coded using the code of move

Table 5. Summary of variables, explanation of variables and research domains for case study.

Variables	Explanation of variables	Related research domains
Dg_Sym	Degree of Symmetry	Collaborative learning
Total_Move	Total number of quotations for 10 moves	Active learning
Total_S	Total number of quotations for Scaffolding (S) code among 10 move codes	Metacognition
Total_GIS	Total number of quotations for 6 GIS function codes	Learning about and learning with GIS
Total _Spatial	Total number of quotations for 14 Spatial thinking and geographical skills	Spatial thinking and geographical skills

Table 6. Total number of codes for each group.

	Move	GIS function	Spatial thinking and geographical skills
Becky and Debbie	740	199	41
Kim and Alisha	526	270	42
Dan and Jacob	576	268	54
Total	1842	737	137

to investigate the activity function in the conversations. A total of 740 quotations were marked with the code under the move category. Kim and Alisha's conversation yielded 526 quotations and Dan and Jacob 576. For this analysis, the ideational content was coded using two subcategories: (1) spatial thinking and geographical skill; and (2) GIS function. A quotation which is assigned as a move does not necessarily mean that it would be coded as either spatial thinking and geographical skill or GIS function. Additionally, it is not the case that one ideational content is incompatible with another one. As a result, the total number of moves for each group is larger than the sum of the two ideational contents codes.

5. Results and discussion

1) Case study 1: "*Where's my watershed, dude?*" (Becky and Debbie's conversation)

Becky and Debbie's group was one of the most active participant groups in this project. They successfully created their first map in the second session of the GIS lesson. Using the Microsoft PowerPoint program, they made a poster as a final product which included a map, water quality testing results, an explanation about what they had learned and suggestions. After completing a series of six GIS lessons, both of them voluntarily organized a "big poster" session, which was held in a hallway of the Town Hall, Amherst, NY.

After completing the first part of the ideational content analysis using GIS function codes, spatial thinking and geographical skills were investigated to test a hypothesis. I hypothesized that students would be able to develop spatial thinking abilities and geographic skills while they are working with GIS even though these are not intentionally taught. 14 codes were adopted as characteristics that show spatial thinking abilities and geographical skills. The null hypothesis is given below,

H_0: Students will not be able to generate appropriate terms that are coded as spatial thinking and geographical skills in the first two sessions of the study.

Discourse evidence was based on a total of 740 moves between Becky and Debbie for six consecutive sessions. They produced 41 quotations that were coded as spatial thinking and geographical skills.

In relation to the first hypothesis about spatial thinking and geographical skills, H_0, results were analyzed in terms of the amount and appropriateness of spatial thinking and geographical skill terms generated. Lists were compiled and the total number of quotations for spatial thinking and geographical skills were tallied for each code across sessions. Contrary to the null hypothesis, H_0, students were able to generate appropriate terms of spatial thinking and geographical skills in the first two sessions of the study (i.e., 2 quotations in session 1 and 8 in

session 2) although these were not intentionally taught.

Once the number of quotations of spatial thinking and geographical skills generated for each session was determined, I further categorized their responses into 14 different codes. All of the quotations under each category were summed. 8 among 14 subcategories of ideational contents for spatial thinking and geographical skills were coded. Analog (AN), Comparison (CP), Diffusion (DF), Exception (EX), Spatial model (SM) and Transition (TS) were not generated in this groups' conversation (see Table 7).

A chi-square test could not be performed. As shown in Table 7, 41 cells (97.6%) had expected counts of less than 5 and the minimum expected count was .05. Also, there was still an issue of empty cells of 6 categories of spatial thinking and geographical skills.

They were very interested in the CD (Condition) and RG (Region). They indicated their great concern about Connection (CN) and Influence (IF) while they were learning about the impact of outfalls and watershed. Understanding Location (LC) and recognizing Pattern (PT) were also found. However, their spatial thinking and geographical skills development was very limited and focused primarily on those 6 codes. Among 14 codes of spatial thinking and geographical skills, 7 codes were not assigned to any quotation: Analog (AN), Comparison (CP), Diffusion (DF), Exception (EX), Spatial model (SM), and Transition (TS). Association (AS) and Hierarchy (HR) were coded only once each.

In session 5, Becky and Debbie's interaction displays the highest number of spatial thinking and geographical skills quotations compared with other sessions. Because most of session 1 and half of sessions 4 and 6 were spent on teacher's instruction, the interaction between students was limited, and consequently the transcribed conversation produced only half the quotations as compared with other sessions (see Table 6). Further analysis is conducted to test whether there is any other factor that has an effect on

Table 7. Becky and Debbie's conversation: Spatial thinking and geographical skills.

Session number		Spatial thinking code							Total
		AS	CD	CN	HI	LC	PT	RG	
1	Count	0	1	0	0	1	0	0	2
	Expected Count[2]	.0	.9	.1	.0	.2	.1	.5	2.0
2	Count	0	3	0	0	2	0	3	8
	Expected Count	.2	3.7	.6	.2	.8	.4	2.1	8.0
3	Count	0	5	0	1	0	1	2	9
	Expected Count	.2	4.2	.7	.2	.9	.4	2.4	9.0
4	Count	0	0	3	0	0	0	1	4
	Expected Count	.1	1.9	.3	.1	.4	.2	1.1	4.0
5	Count	1	5	0	0	0	1	5	12
	Expected Count	.3	5.6	.9	.3	1.2	.6	3.2	12.0
6	Count	0	5	0	0	1	0	0	6
	Expected Count	.1	2.8	.4	.1	.6	.3	1.6	6.0
Total	Count	1	19	3	1	4	2	11	41
	Expected Count	1.0	19.0	3.0	1.0	4.0	2.0	11.0	41.0

spatial thinking and geographical skills while students use GIS in the cross-case report in the following section.

In Becky and Debbie's conversation, the most frequently coded spatial thinking and geographical skills were CD (Condition) and RG (Region). Over the course of the sessions, there is a significant increase in the instances of the codes CD and RG. In session 5, the number of CD codes decreased. However, the RG codes increased significantly. They frequently tried to place a watershed on their map and describe the condition of it and specifically mentioned the location of the watershed and the region where the watershed was located. The following excerpt from session 2 reveals their learning of geographical skills and spatial thinking while they learned the concept of watershed using GIS. As shown in this excerpt, students realized the location of the watershed where they lived and situated their watershed on the map using GIS.

BECKY: It says all the layers have to be active.
DEBBIE: We typed it into the text box.
BECKY: Need a description...in the text box.
DEBBIE: You can always change it. Stop it. You can change it later.
BECKY: We got a Niagara watershed.
DEBBIE: Don't talk to me.
BECKY: *Where's my watershed, dude?* [emphasized by the researcher]
DEBBIE: Now we insert. All the layers need to be active.
BECKY: What is the legend?
DEBBIE: Click the word next.
BECKY: Let's finish and see what happens.
DEBBIE: That is so cool.
BECKY: We need a compass. We need like a legend...our colors.
DEBBIE: Which one do you like?
(March 29, 2007 / GIS laboratory at University at Buffalo)

After completing the project, I interviewed Becky and Debbie within a week. They mentioned that they did not know what a watershed was before participating in this project.

INTERVIEWER: Do you think this project helped you get a better understanding of the community and environment? Why or why not?
BECKY: *Yes, before this I didn't know the watershed, like what we do matters to the lake and what we drink and everything.*
DEBBIE: *I didn't know we lived in a watershed.*
(June 7, 2007/ A media center in the middle school)

They explicitly expressed that they learned about the concept of a watershed and appreciated the fact that they achieved environmental awareness through learning about it. They expressed a sense of connectedness to the watershed by using maps, mostly because of the zooming capabilities and visualization provided by GIS. They also mentioned that these specific functions of GIS helped them get a sense of spatial thinking and geographical skills such as Influence (IN) and Connect (CN), which would have otherwise been difficult to understand.

2) Case study 2: "*Don't always listen to your GIS machine because it may still get you lost.*" (Kim and Alisha's conversation)

Kim and Alisha are identical twin sisters. Unlike the other identical twins (brothers) in the same class, they picked each other when asked to form a group of two for this project. They successfully created their first map in the second session of the GIS lessons. They also completed their final project using the Microsoft PowerPoint program to make a big poster in the last session. They were very interested in giving a presentation in

front of the Town's Conservation Advisory Committee. They played the role of moderators for the presentation and did a very nice job in putting everything that they learned from the lessons together and to organize everybody's ideas and suggestions neatly for this special event.

Discourse evidence was based on a total of 526 moves between Kim and Alisha for six consecutive sessions. They produced 42 quotations over 4 different categories of 14 spatial thinking and geographical skills codes.

In relation to the hypothesis, H0 results were analyzed in terms of the amount and appropriateness of spatial thinking and geographical skills terms generated. Lists were compiled and the total number of quotations for spatial thinking and geographical skills were tallied for each code across sessions. To the contrary of the first null hypothesis, H0, Kim and Alisha were able to generate appropriate terms of spatial thinking and geographical skills in the first two sessions (i.e., 1 quotation in session 1 and 10 in session 2) of the study even though these were not intentionally taught.

Once the number of quotations of spatial thinking and geographical skills generated for each session was determined, I further categorized their responses into 14 different codes. All the quotations under each category were summed.

Kim and Alisha were very interested in CD (Condition) and Location (LC). They indicated a great concern about RG (Region) while they were learning about the impact of outfall, watershed and community. Hierarchy (HR) or comprehending the whole and part relationship and its order was also appreciated. Of the 14 codes for spatial thinking and geographical skills, 10 codes were not assigned to any quotation: Analog (AN), Association (AS), Connection (CN), Comparison (CP), Diffusion (DF), Exception (EX), Influence (IF), Pattern (PT), Spatial model (SM), and Transition(TS) (see Table 8).

A chi-square test could not be performed. As shown in Table 8, 21 cells (87.5%) had expected

Table 8. Kim and Alisha's conversation: Spatial thinking and geographical skills.

Session number		Spatial thinking code				Total
		CD	HI	LC	RG	
1	Count	1	0	0	0	1
	Expected Count	.5	.0	.3	.1	1.0
2	Count	6	0	2	2	10
	Expected Count	5.5	.5	2.9	1.2	10.0
3	Count	5	2	7	3	17
	Expected Count	9.3	.8	4.9	2.0	17.0
4	Count	1	0	0	0	1
	Expected Count	.5	.0	.3	.1	1.0
5	Count	2	0	1	0	3
	Expected Count	1.6	.1	.9	.4	3.0
6	Count	8	0	2	0	10
	Expected Count	5.5	.5	2.9	1.2	10.0
Total	Count	23	2	12	5	42
	Expected Count	23.0	2.0	12.0	5.0	42.0

counts of less than five and the minimum expected count was .05. There was also an issue regarding empty cells of ten categories of spatial thinking and geographical skills.

Compared with Becky and Debbie, Kim and Alisha's spatial thinking and geographical skills were very limited to only these four categories although they produced a substantial amount of quotations overall. Because most of sessions 1 and 3 and almost half of 4 and 6 were spent on the teacher's instruction, interaction between students might have been reduced. As a result, their transcribed conversation yielded reduced quotations, which could be a possible explanation for the low levels of spatial thinking and geographical skills in sessions 1 and 4. However, that is not the case in sessions 3 and 6. Since session 3 was designed as a teacher-led step by step lesson, there was less possibility for the students to interact with each other. As stated earlier, the concept of road-density which was dealt with in this session was relatively new and involved somewhat difficult procedures including mathematics and data analysis. Instead of being frustrated or talking about irrelevant topics, Kim and Alisha asked each other questions regarding aspects of the lesson that they could not understand in order to clarify the issues, or they would ask the instructor or other friends. Two excerpts below are a good example of this type of discourse.

INSTRUCTOR: Did you get to the beginning yet?
KIM: What is it?
ALISHA: Ms. K, *we're not sure if we should press okay.* [emphasized by the researcher]
INSTRUCTOR: What is the GIS location? Yeah, just push OK. Don't worry about it, just go to start and you can go from here now. We're going to show you up here on the screen. It'll tell you what to do.
KIM: *What does it say?* [emphasized by the researcher]
ALISHA: What?
KIM: What to do? *Hey, Sara, where did you find out what to do?* [emphasized by the researcher]
KIM: Oh! ... Right on the front page.
ALISHA: Our new map? [emphasized by the researcher]
(From Kim and Alisha's transcription on March 29, 2007/GIS laboratory at University at Buffalo)

INSTRUCTOR: Yeah, you can shift them wherever you want. Just move it over. Guys, look up here, this is what you should have. 5767 is your road length and the area of the water shed is 2084. It's okay, it's okay, just write it. Is it 2084, is that what you said?
KIM: 2084?
INSTRUCTOR: Guys watch, you gonna open up the calculator. So you go to start. Accessories. Then you can just figure it out and divide it.
KIM: Divide what?
ALISHA: Divide 5767 by 2084. Here?
INSTRUCTOR: Yes, the answer is here. Here's the answer. So, 2.77 rounded by, if you know how to do that we need you to do the same thing for the study areas 2 and 3. So your first one is the watershed [area], then you want to get the road [length].
KIM: *What are we doing?* [emphasized by the researcher]
ALISHA: I don't know.
KIM: Oh! [emphasis on original]··· we're supposed to do it [calculating other watershed's road density] by ourselves. So I'm not the only one. Save as what?
(From Kim and Alisha's transcription on March 29, 2007/GIS laboratory at University at Buffalo)

In contrast, sessions 2 and 5 were mostly comprised of student-centered activities. Consequently, more active interaction between partners might be expected during these sessions, which would be an explanation for the higher level of spatial thinking and geographical skills found in session 2. However, this was not the case in session 5 in where students were much more focused on the layout of maps and their poster. They did not concentrate on contents or analysis in this session. Upon completion of the layout, they moved on to filling out the contents of the map description with active discussion in the next session. This shows a remarkably high level of spatial thinking and geographical skills for session 6, despite the reduced activity time due to the teacher-led instruction during that session.

3) Case study 3: "*Just click on everything individually*." (Dan and Jacob's conversation)

Dan is an Asian American boy who has a twin brother in the same class. Unlike the other twins in the same class, he did not pick his twin brother as a partner. Jacob is a Caucasian boy and for much of their conversation he was telling Dan what to do. Dan usually followed the direction of Jacob and he clicked the buttons and typed. Dan and Jacob's conversation has its ups and downs in terms of their interactions, activity functions, and the substantiality of the contents. Frequently they spent their time on irrelevant talk. Other times they focused on a task with very sharp observations. They successfully created their first map in the second session of the GIS lesson. In addition, using the Microsoft PowerPoint program, they made a poster as a final product which included a map, water quality testing results, an explanation about what they learned and suggestions on what can be done to protect the environment. However, due to personal reasons, both of them could not participate in a poster session and presentation in the Town Hall at the conclusion of the project.

Discourse evidence was based on a total of 576 moves between Dan and Jacob for six consecutive sessions. They produced 54 quotations that were coded as spatial thinking ability and geographical skills.

In relation to the hypothesis about spatial thinking and geographical skills, H_0, results were analyzed in terms of the amount and appropriateness of spatial thinking and geographical skills terms generated. Lists were compiled and the total number of quotations for spatial thinking and geographical skills were tallied for each code across sessions. To the contrary of the null hypothesis, H_0, students were able to generate the appropriate terms of spatial thinking and geographical skills in the first two sessions of the study (7 quotations in sessions 1 and 11 in session 2) although these were not intentionally taught.

Once the numbers of quotations of spatial thinking and geographical skills generated for each session were determined, I further categorized their responses into 14 different codes. All the quotations under each category were summed. Ten of 14 subcategories of ideational contents for spatial thinking and geographical skills were coded. Analog (AN), Association (AS), Spatial model (SM) and Transition (TS) were not generated in this group's conversation (Table 9).

A chi-square test could not be performed. As shown in Table 9, 49 cells (98.0%) had expected counts of less than 5. The minimum expected count was .13. There was still an issue of empty cells of 6 categories of spatial thinking and geographical skills. Further analysis will be conducted to test whether there is any additional factor that has an effect on the spatial thinking

Table 9. Dan and Jacob's conversation: Spatial thinking and geographical skills.

Session number		Spatial thinking code										Total
		LC	CD	CN	CP	IF	RG	HR	EX	PT	DF	
1	Count	7	0	0	0	0	0	0	0	0	0	7
	Expected Count	2.5	1.4	.3	.1	.5	1.0	.6	.1	.3	.1	7.0
2	Count	0	0	1	0	0	2	5	1	2	0	11
	Expected Count	3.9	2.2	.4	.2	.8	1.6	1.0	.2	.4	.2	11.0
3	Count	3	4	0	0	0	2	0	0	0	0	9
	Expected Count	3.2	1.8	.3	.2	.7	1.3	.8	.2	.3	.2	9.0
5	Count	3	6	1	1	4	1	0	0	0	1	17
	Expected Count	6.0	3.5	.6	.3	1.3	2.5	1.6	.3	.6	.3	17.0
6	Count	6	1	0	0	0	3	0	0	0	0	10
	Expected Count	3.5	2.0	.4	.2	.7	1.5	.9	.2	.4	.2	10.0
Total	Count	19	19	2	1	4	8	5	1	2	1	54
	Expected Count	19.0	19.0	2.0	1.0	4.0	8.0	5.0	1.0	2.0	1.0	54.0

and geographical skills while students use GIS in the cross-case report that is contained in the following section.

4) Cross-case study

Following the logical flow of the multiple case study design which was discussed previously, this section will discuss the similarity and differences across the three cases based on the analyses of individual case study reports. The Degree of Symmetry (Dg_Sym), Scaffolding (S), the total quotation number of moves (Total_Move), the total quotation number of GIS functions (Total_GIS), and the total quotation number of spatial thinking and geographical skills (Total_Spatial) will be reviewed at the aggregate level to determine if significant differences exist between each of the three participant groups in terms of the effect of spatial thinking and geographical skills in GIS-integrated learning.

(1) Descriptive statistics of spatial thinking and geographical skills

Quotations that were coded for one of the 14 subcategories of spatial thinking and geographical skills were summed for each student pair. Dan and Jacob's group generated the most quotations of spatial thinking and geographical skills (i.e., a total of 54 quotations) followed by Kim and Alisha's group (i.e., a total of 42 quotations) and Becky and Debbie's group (i.e., of total a 41 quotations). The total number of quotations that were coded as spatial thinking and geographical skills across the three participant groups was 136.

Upon finishing coding and summarizing the quotations of spatial thinking and geographical skills, I further classified these 14 spatial abilities into three groups for further analysis: 1) lower-order (the first four spatial thinking and geographical skill codes, Location (LC), Condition (CD), Connection (CN), and Comparison (CP)); 2) middle-order (the fifth through eighth spatial thinking and geographical skill codes, Influence (IF), Region (RG), Hierarchy (HR), Transition (TS)); and 3) higher-order spatial thinking abilities (the ninth through fourteenth spatial thinking and geographical skill codes, Analog (AN), Pattern (PT), Association (AS), Exception (EX), Diffusion (DF), and Spatial model (SM)).

Among the 14 subcategories, Condition (CD) made up the largest portion (36%, a total number of 50 quotations), followed by Location (LC) (26%, a total number of 35 quotations), which are generally referred to as lower-order spatial thinking abilities. However, a relatively small amount of quotations were coded as Comparison (CP, 1%) and Connection (CN, 4%). A considerable number of quotations were coded as moderate level spatial thinking abilities: Region (RG) (18%, a total of 24 quotations), Hierarchy (HR) (6%, a total of 8 quotations), and Influence (IF) (5%, a total of 7 quotations). Higher order spatial thinking abilities had very few or no quotations. The following subcategories had a relatively small amount of quotations or no quotations at all: Pattern (PT, 3%), Association (AS, 1%), Exception (EX, 1%), Diffusion (DF, 1%), Analog (AN, 0%), Transition (TS, 0%), and Spatial model (SM, 0%) (see Figure 1).

Based on the descriptive statistics of spatial thinking and geographical skill quotations, students generally appeared to possess lower-order spatial thinking and geographical skills (67%), followed by moderate-level (29%) and higher-order spatial thinking skills (5%).

At first glance, the outcome seems disappointing. However, due to the depth and width of the unit used in this project, which focused on specific topics of watershed and road-density in general, it might be difficult to expect this unit would cover all levels of spatial thinking and geographical skills. Rather, the data came from a very limited portion of lessons during six 50-minute sessions instead of an entire curriculum during an academic school year. Considering that the unit was implemented in a biology class rather than a geography class, the

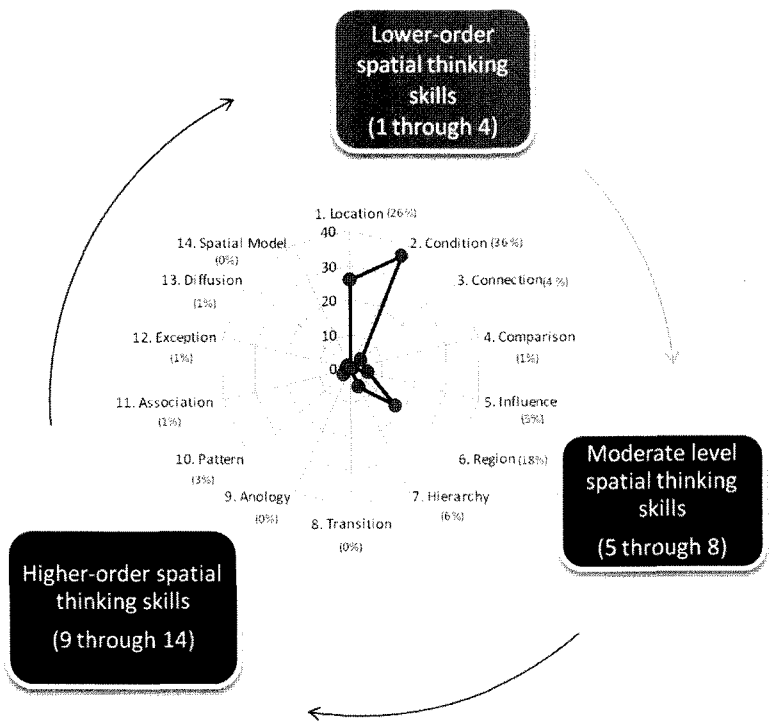

Figure 1. Percentage of spatial thinking and geographical skill quotations across lower-order, moderate-level, and higher-order spatial thinking skills.

result actually seems encouraging rather than disappointing.

(2) Bivariate statistics of spatial thinking and geographical skills

Once the amount of each subcategory of spatial thinking and geographical skills generated by each participant group for each session was calculated, correlational statistics were performed at the aggregated level to determine relationships between each subcategory of spatial thinking and geographical skill. The Pearson correlation coefficients were calculated in a correlation matrix. As shown in Appendix B, the strength of association was strong between Influence and Comparison, Pattern and Hierarchy, Association and Influence, Region and Association, Exception and Hierarchy, Diffusion and Comparison, Pattern and Exception, and Influence and Diffusion. All the correlations proved significant at the level of .01 or .05. Other spatial thinking and geographical skills showed moderate to relatively weak relationships. In addition, Appendix B shows no significant correlations with location, condition, and connection.

Results indicate that students are able to use geovisualization of GIS-integrated lessons, which is one of the most powerful tools involved in learning to think spatially. In interviews with students after the completion of the project, students mentioned that by using the basic functions of GIS such as zoom-in and zoom-out, they were able to recognize the hierarchical orders that exist beyond the boundaries of local communities. While they focused more on Pattern, they also showed interest in the Region as a broader geographical boundary. Students also commented favorably on the GIS-integrated lessons since they were able to understand similar patterns in other places (Association) and irregular patterns in other places (Exception). Further analysis, using principle components, may help in further interpretation of these data.

Kendall's tau-b was used as an index of the association between spatial thinking and geographical skills and other variables measured on an ordinal scale. At first, all variables that reflect characteristics of GIS-integrated learning (i.e., Degree of Symmetry and the total number of scaffolding, move, GIS codes, and spatial thinking and geographical skills codes) were transformed into rank orders.

As shown in Table 10, a Kendall's tau-b between spatial thinking and geographical skills and GIS functions is .42 and allows the rejection of the hypothesis of no association at the .05

Table 10. Bivariate correlation matrix of spatial thinking and geographical skills (Kendall's tau-b correlation coefficients).

	Rank of Degree of Symmetry	Rank of Scaffolding	Rank of Move	Rank of GIS code	Rank of total Spatial thinking code
Rank of Degree of Symmetry	1.00	0.45**	0.46**	0.32	0.19
Rank of Scaffolding		1.00	0.99**	0.56**	0.22
Rank of Move			1.00	0.57**	0.23
Rank of GIS code				1.00	0.42*
Rank of Spatial thinking code					1.00

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

n=18. Kendall's tau-b is often used as a correlation coefficient when variables are measured on an ordinal scale instead of Pearson correlation coefficient.

level. By comparison, the correlations between spatial thinking and geographical skills and all other variables were not significant. Students in this study tended to use more spatial thinking and geographical skills in a session where more GIS functions were used. However, relationships between spatial thinking and geographical skills and other characteristics of learning were relatively weak. Thus, the results show that a student's spatial thinking and geographical skills were mostly related to GIS functions rather than collaborative learning (i.e., measured by Degree of Symmetry), metacognition (i.e., measured by the total number of quotations of Scaffolding), and active learning (i.e., measured by the total number of quotations of Move). The results demonstrate that in order to improve a student's spatial thinking and geographical skills students need to be encouraged to use more GIS functions in the classroom.

6. Conclusion

The results based on the discourse analysis demonstrated that students were able to generate appropriate terms representative of spatial thinking and geographical skills although students appeared to possess primarily lower-order spatial abilities, followed by a moderate-level of spatial abilities. The proportion of higher-order spatial abilities was minimal. One possible explanation for this would be that due to the depth and width of the unit used in this project, which focused on specific topics of watershed and road-density, it might be difficult to expect that this unit would cover all of the levels of spatial thinking and geographical skills. Rather, the data came from a very limited portion of lessons during six 50-minute sessions instead of an entire curriculum during an academic school year. In addition, considering that the unit was implemented in a biology class rather than a geography class the result reflected the fact that the student's spatial thinking and geographical skills were attributable to the GIS-integrated lessons. Also, the results from the bivariate statistics showed that the correlations between metacognition (i.e., measured by the total number of quotations of Scaffolding) and collaborative learning (i.e., measured by Degree of Symmetry), metacognition and active learning (i.e., measured by the total number of quotations of Move), and collaborative learning and active learning were significant. GIS functions (i.e., measured by the total number of quotations of GIS functions) were significantly associated with all characteristics of learning except collaborative learning. However, relationships between spatial thinking and geographical skills and other characteristics of learning were relatively weak. Only the correlation between spatial thinking and geographical skills and GIS functions is significant. Students in this study tended to use more spatial thinking and geographical skills in a session where more GIS functions were used. The results have great implications for GIS-integrated lessons. The evidence from data demonstrates that a student's spatial thinking and geographical skills were mostly related to GIS functions rather than collaborative learning, metacognition, and active learning. Thus, in order to improve a student's spatial thinking and geographical skills students need to be encouraged to use more GIS functions in the classroom.

However, in the present study, the data are mostly at the categorical scale, especially the qualitative data such as the students' conversations which were transcribed and coded for further data analysis. Due to this, it was inevitable that the statistical analyses performed were very limited. Additionally, individual case

study reports and the cross-case study were based on only three pairs of participating students' conversations among ten. There were several missing data and the extent of involvement in the study was inconsistent. This might also set a limit to the generality of the data analysis.

Limitations of the present study might be a starting point regarding suggestions for future study. First of all, with further research on follow-up data collection and analysis, the effect of spatial thinking and geographical skills would be uncovered and a more meaningful explanation with regard to the role of GIS-integrated lessons would be revealed. Moreover, the longitudinal study is needed to deeply investigate the enhancement of the student's spatial thinking ability and the way in which his/her learning is sustained. Secondly, a further study with more varied variables and more data is needed to unearth the students' GIS learning in the different context of class focus. Also, a multi-case study with more participants across all sessions would provide a better understanding of the relationship between GIS learning and spatial abilities.

Notes

1) The participants consisted of eighth-grade students who were taught by a Biology teacher, Ms. K from a public middle school in a suburban area of western New York. The teacher and I worked together closely for one year. Prior to the start of this project, we developed a curriculum using GIS. Due to her strict schedule, I usually visited her classroom after school around once a week and taught GIS technology. I located the necessary data and GIS software to allow the teacher to be familiar with this technology. After completing the curriculum development, I instructed six GIS-integrated sessions in a GIS lab at the University of Buffalo while Ms. K also supported students' learning activities during class. All classroom activities and group discussions were audio taped and transcribed for further analysis. Data were organized and analyzed by content analysis following the DISCOUNT scheme in order to identify patterns of dialogue exchange and the effectiveness of dialogue in terms of learning function. In addition, students were videotaped in order to observe how students responded to the teacher's directions and how two members of each group worked together, acted and reacted to each other while using computers in the GIS lab. Appendix A shows the task that students were asked to complete for each session.

2) The chi-square statistic is used to test the independence of two variables. In a bivariate crosstabulation which is used in this study, the relationship between the "expected" and "observed" counts for the categories of two variables is measured. To use crosstabulation, two matrices are needed to build: one for the expected number of occurrences in each cell, and another for the observed number of occurrences in each cell. Before we can determine whether there is a relationship between sessions and spatial thinking abilities, we must first determine the "expected" result if there is no such relationship — that is, if GIS session does not affect the probability of having spatial thinking abilities and geographical skills. Note that the claim "There is no relationship between GIS session and spatial thinking abilities and geographical skills" is the Null Hypothesis for this question. The expected frequency $f(X_{RC})$ for any cell X_{RC} is calculated as $E(X_{RC})=(RC)/T$ where R is the row total, C is the column total, and T is the grand total for the table (http://simon.cs.vt.edu/sosci/index.html).

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Appendix A. Session by session class design

Session	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6
Used program	ArcGIS	ArcGIS Excel	ArcGIS	PowerPoint ArcGIS	PowerPoint ArcGIS	PowerPoint Excel ArcGIS
Instruction	1.Demonstration of how to log in 2. Introduction to ArcGIS	N/A	1. Demonstration of calculation of road-density (by the researcher)	1. Presentation skills preparation (by a social studies teacher) 2. Introduction to Amherst Conservation Advisory Committee 3. Connecting to community participation	N/A	1. Connecting with the Town and Storm water regulation (by a town planner) 2. Demonstration of how to add data files in their poster (by the researcher)
Task	1. access to each group's account and create a password 2. open GIS program, locate a data folder and add layers 3. save a project	1. log in to each group's account 2. open GIS program and locate the saved their project file 3. change the colors, order, and name of layers 4. create a map layout by inserting map elements (i.e., a title, texts, a legend, a north arrow, a scale bar, etc) 5. print out a map	1. log in 2. open GIS program and locate the saved their project file 3. calculate road-density following the direction of teacher's instruction (open the data table, look into the statistics, change the units of measurements,) 4. Select and unselect a layer, activate and cancel it. 5. Save the project file.	1. log in 2. open GIS program and locate the saved their project file 3. prepare a poster presentation using PowerPoint	1. log in 2. open GIS program and locate the saved their project file 3. add maps and photos of water quality testing field trip in a poster 4. organizing the poster using PowerPoint	1. log in 2. open GIS program and locate the saved their project file 3. add data table in a poster 3. finish their poster using PowerPoint

Appendix B. Bivariate correlations of 14 Spatial thinking and geographical skills codes

	Location	Condition	Connection	Comparison	Influence	Region	Hierarchy	Transition	Analog	Pattern	Association	Exception	Diffusion	Spatial model
Location	1.00	0.15	-0.22	0.11	-0.03	0.18	-0.03	.a	.a	-0.35	-0.20	-0.20	0.11	.a
Condition		1.00	-0.24	0.32	0.21	0.10	-0.13	.a	.a	-0.17	-0.08	-0.27	0.32	.a
Connection			1.00	0.24	0.14	-0.03	0.17	.a	.a	0.13	-0.09	0.24	0.24	.a
Comparison				1.00	0.79**	-0.06	-0.09	.a	.a	-0.10	-0.06	-0.06	1.00**	.a
Influence					1.00	0.33	-0.13	.a	.a	0.14	0.57*	-0.08	0.79**	.a
Region						1.00	0.23	.a	.a	0.41	0.61**	0.11	-0.06	.a
Hierarchy							1.00	.a	.a	0.79**	-0.09	0.91**	-0.09	.a
Transition								.a	.a	.a	.a	.a	.a	.a
Analog									.a	.a	.a	.a	.a	.a
Pattern										1.00	0.35	0.81**	-0.10	.a
Association											1.00	-0.06	-0.06	.a
Exception												1.00	-0.06	.a
Diffusion													1.00	.a
Spatial model														.a

a. Cannot be computed because at least one of the variables is constant.

* Correlation is significant at the 0.05 level (2-tailed). n=18

** Correlation is significant at the 0.01 level (2-tailed). n=18