Integrating Geospatial Technologies in Fifth Grade Curriculum: Impact on Spatial Ability and Map Analysis Skills

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Abstract

This study explores the effects of Geographic Information Systems (GIS) curriculum on fifth grade students' spatial ability and map analysis skills. A total of 174 students from an urban public school district and their teachers participated in a quasi-experimental design study. Four teachers implemented a GIS curriculum in experimental classes over six weeks while three teachers continued with regular teaching in control classes. Both groups completed pre- and post-tests measuring spatial ability and map analysis skills. Students in the GIS classes demonstrated more growth over time in spatial ability and map analysis skills than did their peers in the control classes.

Keywords: geospatial technologies, GIS, elementary grades, spatial ability, map-analysis skill.

Introduction

Improving success in science, technology, engineering, and mathematics (STEM) is a national priority (Bureau of Labor Statistics 2015; Kuenzi 2008; Landivar 2013). In numerous studies, Lubinski and colleagues indicated that spatial abilities are important for success in STEM domains (Lubinski and Benbow 2001; Shea, Lubinski, and Benbow 2001; Wai, Lubinski, and Benbow 2009). Meanwhile, student interest in STEM disciplines can be improved through early exposure to STEM related experiences (DeJarnette 2012). Moreover, spatial abilities, which predict STEM success, were found to be malleable through elementary school years (Newcome 2010; Uttal et al. 2006). However, most of the research testing the effects of geospatial technologies that can impact spatial ability has focused primiraly on high school and college students (e.g., Kerski, Demirci, and Milson, 2013; Linn, Kerski, and Wither 2005), with limited focus on middle and elementary school students (e.g., Keiper, 1999; Shin 2006).

The National Research Council (NRC) suggested that understanding the efficacy of Geographic Information Systems (GIS) is essential; if GIS is found to be constructive in developing spatial abilities and map analysis skills while also contributing to success in other academic areas, it would be an important tool for teachers in an environment with instructional time increasingly directed toward tested material (NCR 2006). Similarly, Baker and colleagues have called for an agenda to organize efforts aimed at testing the impact of GIS technologies on students learning using rigorous methods (Baker and Bendarz 2007; Baker et al. 2015). In response to the need for such research, we designed and implemented a GIS-based curriculum for fifth grade students as part of an exploratory, quasi-experimental study built on the following premises: (a) GIS is an effective tool for interdisciplinary, problem-based instruction; (b) GIS is an effective tool for promoting spatial ability; (c) fifth grade is developmentally appropriate age to introduce GIS; and, (d) early intervention will promote interest and success in STEM disciplines. In this paper we outline our justification, research design, and results related to these premises.

Why GIS?

GIS is a powerful tool for spatial analysis and problem solving. This technology can be used to store, analyze and display all forms of data that can be linked to locations. It enables users to create maps specific to their projects and to perform geo-statistical and spatial analyses to create new data which in turn can be used to answer questions and clarify relationships. It is not surprising that GIS is widely used in government, business, and industry (Azaz 2011; Birkin, Clarke, and Clarke 1999; Gewin 2004). The use of GIS in education has lagged behind its use in commercial and government settings (Baker and Bednarz, 2003; Bednarz and Audet 1999; Kerski 2003). There are several reasons for this lag: (a) most GIS software is designed for experts and therefore may be too complicated for use in classrooms (Keiper 1999; Marsh, Golledge, and Battersby 2007; Palladino 1994), (b) commercial GIS systems are very expensive, and (c) teachers may lack the expertise needed to create their own GIS projects (Drennon 2005; Wiegand 2006).

Meanwhile, GIS supports a number of educational goals, such as promoting inquiry processes in science and social studies, advancing problem-solving in real-world contexts, and facilitating learning transfer across school subjects (NRC 2006; Lemberg and Stoltman 1999; Kerski 2008). Additionally, research has identified technology-based mapping systems, such as GIS, as helpful for developing student motivation and problem solving skills (Baker and Bednarz 2003). Essentially, GIS provides a rich context for exploration and discovery, particularly in the later stages of inquiry including data analysis, presentation of results, and communication of information. As such, GIS is significant for two primary reasons: (a) its potential for positive impact across many school subjects, and (b) its potential for allowing rich, multi-faceted geographic explorations that would be practically infeasible by other means, such as paper maps.

Why Upper Elementary Grades?

In 2010, the National Assessment of Educational Progress (NAEP) geography report card revealed that fourth grade students lag in acquisition of proficient and advanced geographic skills and knowledge, with only 21% of fourth grade students testing at the proficient or advanced level in geography (NAEP 2010a). These concerns coincide with decreases in time allocated to the study of social studies in elementary school. Specifically, of the 299 school districts surveyed in a four-year national study, more than 70% reported reducing instructional time on non-tested subject matters such as science, social sciences, and art. Instead, students in these districts received twice as much instructional time on reading and mathematics, especially when they performed below grade level (Rentner et al. 2006). Similarly, Au's (2007) findings indicated that the prevalence of high-stakes testing impacted curriculum in several ways: narrowing curricular content in social studies, increasing fragmentation of knowledge, and significantly increasing teacher-centered direct instruction. These constraints in elementary schools run counter to calls for infusing interdisciplinary, problem-based experiences into classrooms (NGSS Lead States 2013; Dejarnette 2012).

GIS has previously been used in schools to integrate science and social studies with everyday problem-solving (Kerski 2003). English and Feaster's (2003) *Community Geography: GIS in Action* program provides examples of projects that can be used by middle and high school students to target real-world problems such as mapping the patterns of neighborhood crime or analyzing the patterns of invasive weed species. But most of the GIS training in schools involves older students, such as middle school (e.g., Baker and White 2003; Fazio and Keranen 1995; Goldstein and Alibrandi 2013; McGarigle 1997), high school (e.g., Demirci, Karaburun, and Unlu 2013; Kerski 2003), or college students (e.g., Hall-Wallace and McAuliffe 2002;

Kim and Bednarz 2013). Overall, this work has yielded promising results, with GIS leading to improvement in motivation and learning in a variety of contexts. However, it has been difficult to find recent studies involving elementary students (for exceptions, see Keiper 1999; Shaunessy and Page 2006; Shin 2006). Because of this gap in the knowledge base, additional research is needed to test the efficacy of GIS in promoting learning in science and social studies, especially in the elementary grades (NRC 2006).

The Spatial Ability Link

There is a strong relationship between spatial ability and success in STEM disciplines. Historically, Super and Bachrach's (1957) report, *Scientific Careers and Vocational Development Theory*, examined a number of scientists and engineers' attributes, including spatial and mathematical ability, to identify and nurture scientific potential. This led to a proliferation of studies in this field. One major study in the area, Project TALENT, began data collection in 1960. Wai et al. (2009) analyzed data from a sample of 400,000 high school students (Grades 9-12) who had been part of this project. As predicted, spatial ability was highly correlated with future selection of STEM careers and likelihood of earning an advanced degree in STEM fields.

Shea, Lubinski, and Benbow (2001) tracked 170 girls and 393 boys who were in the top 0.5% in general intelligence at the age of 13 years. Students who displayed higher levels of spatial ability were more likely to identify math and science as their favorite subject in high school, to earn undergraduate and graduate degrees in STEM related fields, and ultimately to have STEM related careers 20 years later. Studies by Lubinski and colleageus show that spatial ability scores are significantly predictive of students' selection and development of STEM related interests, beyond the variation attributable to mathematical and verbal SAT scores (see also Park, Lubinski, and Benbow 2007; Webb, Lubinski, and Benbow 2007).

The present study asserts that GIS can be an important tool to foster children's spatial ability and higher-level thinking. We posit that fifth grade is an appropriate age for introducing GIS because it takes advantage of early intervention and the rapid pace of cognitive development during the elementary years, including better ability in integrating spatial descriptions (Uttal, Fisher, and Taylor 2006), greater ability to read and handle informational text (Duke, Bennett-Armistead, and Roberts 2003), and clear improvements in speed of processing information (Kail 1991).

Method

The study described here is part of a larger study that was designed to assess the impact of a GIS curriculum on students' cognitive and social development. The study detailed here specifically tests the effects of GIS curriculum on fifth grade students' spatial ability and map analysis skills. We employed a pre- and post-test design as part of this quasi-experimental investigation. As such, we hypothesized that engaging in geospatial activities using GIS would improve students' spatial ability as measured by a standardized Cognitive Ability Test (CogAT) beyond the normal growth rate. We also hypothesized that working with digital maps would positively impact students' paper map reading and analysis skills, leading to measureable improvement in students' performance on a set of map items excerpted from the 1194, 2001, and 2010 National Assessment of Educational Progress (NAEP) geography tests.

Participants

One hundred seventy-four students (88 boys, 86 girls; M = 10 years 8 months, SD = 4.43 months) and their teachers from seven fifth grade classes in three elementary schools in a Midwestern urban public school district participated in the study. Six teachers participated, one teaching two classrooms, for a total of seven classrooms. Five teachers identified as female, and one teacher identified as male. Of the 174 students who participated in the study, 52% identified as White, 32% Black, 13% as two or more races, 2% as Asian, and 1% as Hispanic. About 70% of the students served by the participating schools came from low income families and were eligible for free or reduced price lunch. The project was approved by the university Institutional Review Board and the school district administrators and principals. Teachers provided written consent, parents provided written permission, and students provided written assent for participation prior to the beginning of the study.

Five of the six teachers had self-contained classrooms (students stay with one teacher all day with the exception of "specials" such as art, music, and physical education). One teacher in a departmentalized school (where students have different teachers for core subjects like math, science, social studies, and language arts) taught social studies and science to two fifth grade classes each day; one class participated as an experimental group while the other participated as a control group. To provide them with equal treatment, students in the control classrooms completed a minimum of three modules after all post-testing was completed.

Design and Procedure

The design consisted of four main elements: (1) the GIS-focused curriculum designed for this study; (2) a 26-hour training augmented with resources, in addition to more than 4 hours of support for participating teachers; (3) classroom implementation; and (4), data collection. All four elements are detailed below.

1. The Curriculum. The GIS curriculum designed for the study integrated science, social studies, English Language Arts (ELA), and mathematics concepts and was composed of six modules that gradually increased in complexity while balancing students' conceptual and procedural knowledge. Each module allowed students to deeply understand the core concepts of the module while developing the required skills to operate the GIS software. The modules followed a developmental progression that began with foundational ideas and moved toward greater independence in tackling authentic problems grounded in local data, with problems from other regions and time periods incorporated to facilitate transfer of learning, consistent with recommendations for elementary GIS curricula and pedagogy developed by Keiper (1999; see also Lemberg and Stoltman 1999).

Table 1 summarizes our curriculum. The targeted outcomes of our curriculum included promoting: (a) children's geospatial thinking and digital map-reading skills; (b) advanced thinking for problem solving using GIS; (c) pro-social collaborative skills amongst class peers; (d) computer skills, as well as (e) confidence and interest in using technology. The current analysis focuses primarily on the first target.

Table 1. *Six Week GIS Curriculum Overview*

Complexity Level	Modules	
Preparatory Modules:	**Module 1: Geoprocessing Tools**	**Module 2: Venn**
These modules focus on building understanding of specific concepts and development of specific skills.	Fosters conceptual understanding of set theory operations and calculations (intersect, union, difference) in addition to buffer. Students use paper-pencil activities featuring maps and regular/irregular shapes.	Fosters computer skills (saving, retrieving files), GIS functions (pan, zoom) and geoprocessing tools. Students explore the software, build on their peer's knowledge with limited teacher intervention.

Complexity Level	Modules	
Intermediate Modules: These modules are designed to build students' capacity to **integrate** the skills developed in Module Two with concepts learned in Module One. Criteria for solving problems is clearly outlined.	**Module 3*: The American Revolution** Students apply conceptual understanding and GIS skill in a series of "mini-problems" that each require students to identify a geoprocessing tool that will help them analyze data on Revolutionary War battles. Teachers can use this activity to enrich student understanding of social studies content while contextualizing use of GIS.	**Module 4: Let's Plant a Tree!** Students are presented with one problem that will require all of the concepts and skills learned so far to solve. With the expectation of significant teacher guidance, students utilize graphic organizers and answer guiding questions in the student workbook to find a solution that satisfies clearly outlined criteria, using five GIS layers.
Advanced Modules: These modules are designed to give students opportunities to **independently** solve problems, relying on resources like: narratives, informational text, and videos to identify appropriate criteria they can use to find an effective solution.	**Module 5: Sam the Ornate Box Turtle** Students identify criteria for determining a good home for an Ornate Box Turtle in their home county using a variety of resources. Using fewer than 10 GIS layers, students independently progress through familiar visual organizers and guiding questions to find a solution that requires the use of all previously acquired conceptual knowledge and technical skill. Students rely heavily on peers, while teachers provide limited guidance.	**Module 6: Crag the Bighorn Sheep** Students identify criteria for determining a suitable habitat for bighorn sheep in the southwest United States using a variety of resources. Using fewer than 15 GIS layers, students are presented with familiar *and unfamiliar* guiding questions and visual organizers. Students independently determine how they can use a new strategy to develop a solution to a familiar problem while teachers provide limited guidance.

*Note: Teachers were given the chance to implement Module 3 whenever it was more suitable with fifth grade curriculum.

Most student action took place in GIS (Modules Three-Six), which was used to solve spatial problems by using digital map layers. Our curriculum relied heavily on four *Geoprocessing Tools*: (a) buffer, (b) union, (c) intersect, and (d) difference (See Figure 1 for details). The first three tools are rooted in set theory operations; they can be expressed visually using Venn Diagrams; they can also be represented using basic logic or Boolean functions *and, or,* and *not*. Piaget indicated that these functions start developing around the age of 7-9; however, they are not fully integrated into a child's thinking until age of 14 (Piaget and Inhelder [1958] 2003). Likewise, Battersby, Golledge and March (2006) suggested that these skills are not incidentally developed until high school. As a result, we included a significant focus on these concepts in Module One prior to introducing GIS to students. In Module Two, students are introduced to QGIS through a brief, exploration-based activity to develop competence with the necessary "buttonology" and mechanics. Following these introductory modules, students worked with sets of GIS map layers in context-rich problem-based scenarios. The children manipulated and overlapped these layers to uncover spatial patterns and relationships using the four geoprocessing tools.

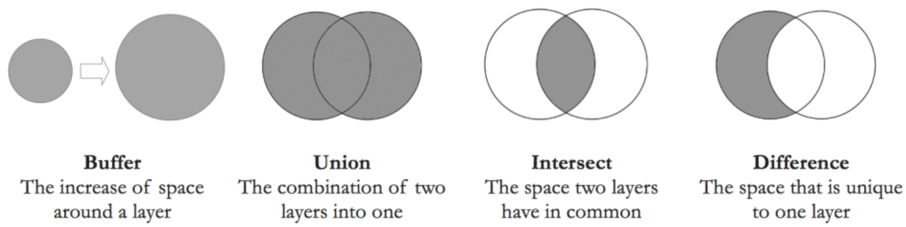


Figure 1. Set operations expressed using Venn diagrams. These operations were implemented using GIS geo-processing tools and map layers.

QGIS, a free, open-source software that displays data spatially in multiple "layers," was selected for its potential to overcome possible financial limitations on widespread implementation. Moreover, QGIS operates reliably on standard laptops available in many elementary schools, helping alleviate obstacles due to technology infrastructure. Students learned how to utilize QGIS to view map layers and use the geoprocessing tools (Figure 2A). Students developed general digital literacy and more specific skills for QGIS through guided and independent activities carried out with peer partners. For example, they learned the mechanics of QGIS through independent exploration with only a checklist to guide them, but for more advanced operations (like using the geoprocessing tools), they were provided with step-by-step instructions.

In addition to fostering improvement in spatial ability and problem-solving, the curriculum was designed to promote students' collaboration and digital literacy. Students completed the curriculum activities working with partners, discussing answers, exchanging perspectives, and helping others. This collaborative approach is consistent with recommendations for elementary GIS curricula and pedagogy developed by Keiper (1999; see also Leinhardt, Stainton, and Bausmith 1998). Most of the activities were completed using laptop computers; the students learned how and where to save data files, how to retrieve them, how to keep their files organized, how to read digital maps, and how to examine final solutions using Google Earth.

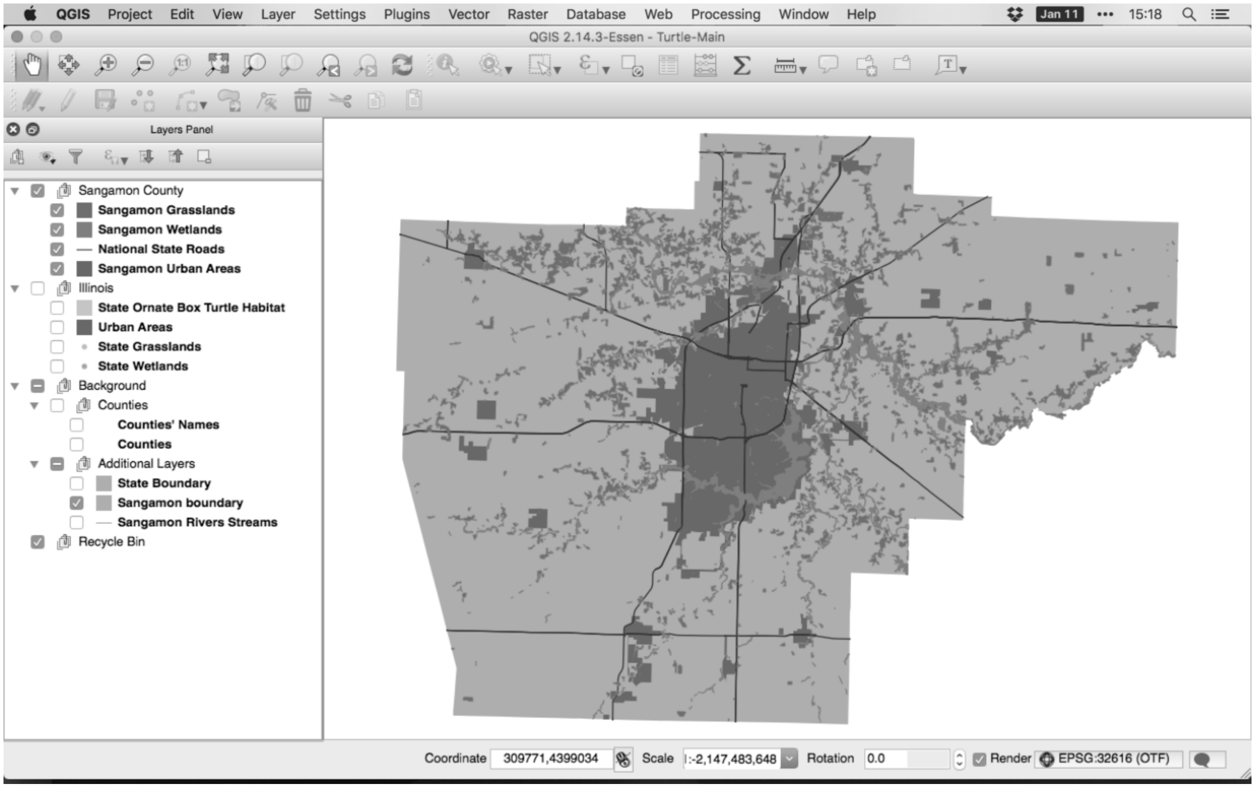


Figure 2A. A screen capture of QGIS, featuring data provided to students at the beginning of Module 5. QGIS provide data layers in colors which are easier for the students to interact with than the black and white image here.

To illustrate the activities students completed we will use the fifth module as an example. In Module Five, students begin by reading a story—written for this project—about a boy who finds an Ornate Box Turtle in front of his home. In the story, the boy brings the turtle to his school and his teachers helps the class learn about what a box turtle needs to survive. The story provides opportunities for students to learn facts about ornate box turtles while also considering ethical dimensions of interfering in nature. After reading the story, the class is informed that they will be locating the best possible habitat for a box turtle within their county. In addition to the story they read, students are presented with videos and informational texts that help them learn about the turtle in a rich context. Only after interacting with these resources, students open the GIS data for the module and progress through a series of worksheets that help them solve the problem.

Once students begin the problem solving portion of the activity, they share a computer with a partner for the duration of the activity. In this module, students begin with state-level data but continue their work with county-level data for grasslands, wetlands, highly populated areas, and roads (Figure 2-A). At the outset, students work with partners to determine how this data fits into their understanding of what a box turtle needs in their habitat, *and* what the box turtle will need to avoid. Students also discuss what additional data they need to consider in a more in-depth GIS investigation. Despite the limited data-set, the activity allows students to practice problem-solving strategies and technical skills. The worksheets provide students with visual organizers (to organize data layers that are "good" and "bad" for the turtle, to keep track of ways they manipulate the data), guiding questions (to prompt students to consider what comes next), short response questions (to gauge student understanding), and technical instructions for previously unlearned GIS mechanics. Students progress independently, working with their partner and the surrounding pairs with little teacher assistance. Teachers use checkpoints to monitor progress and prompt classroom discussions about the activity.

The students must identify which layers of data to buffer, and then how to use intersect, union, and difference to isolate the best possible habitat for a box turtle – a place that is far from roads and heavily populated areas, but near grasslands and wetlands (Figure 2B). In addition to determining how to use the geoprocessing tools, students must apply the tools. Because module one focuses on the geoprocessing concepts, and module two focuses on GIS mechanics including the geoprocessing tools, students should by this point be focused on how they can apply the tools in problem solving. When they have isolated the most appropriate locations for a turtle in their county, students follow technical instructions included in the module to open these locations in Google Earth, introducing a skill that students will need in future activities. Once opened in Google Earth, the students can observe actual satellite imagery of the location or locations they chose. The activity ends by asking students to decide if they are content with their solution, what other data they should consider for a better solution, the benefits of the technology they used, and the ways in which the technology may have been insufficient (Figure 2C).

At the teacher's discretion, students are encouraged to work ahead at their own pace. Students who finish the assignment for the day (or finish the whole activity early) are encouraged to help other students in the class – only after they have checked their own work, of course.

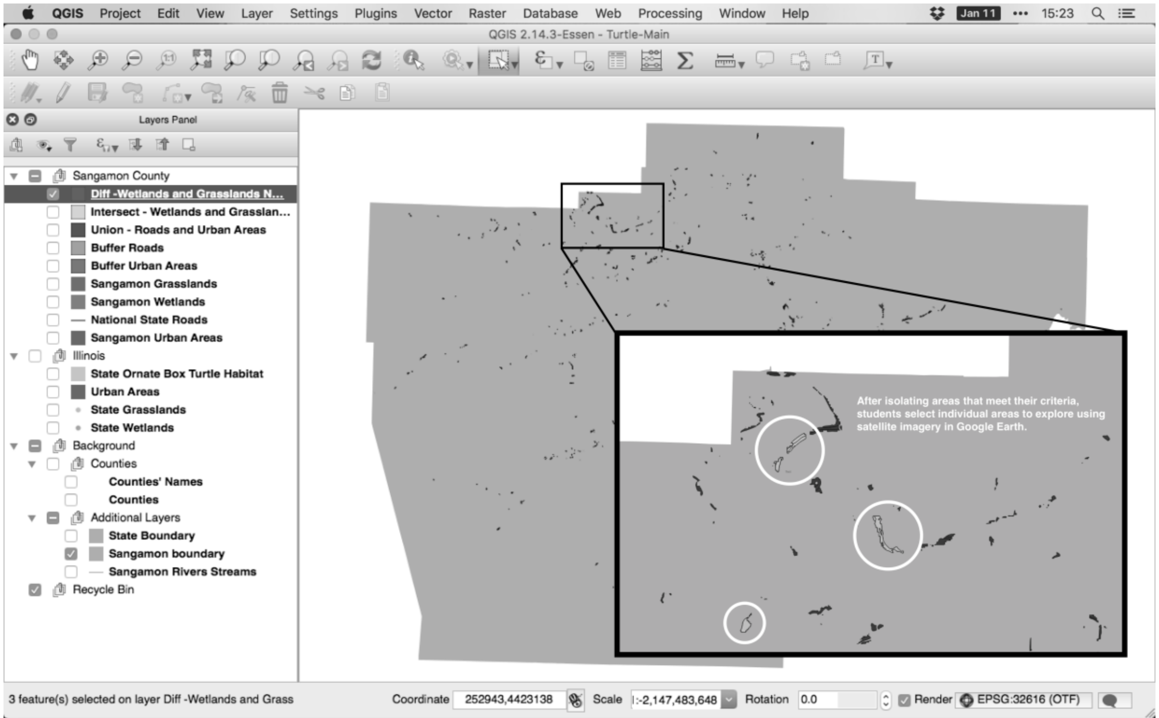


Figure 2B. A screen capture of QGIS from the final section of Module 5. Students will have created multiple layers, utilized the Geoprocessing Tools, and isolated areas appropriate for an Ornate Box Turtle. Students then select and highlight areas they wish to explore in Google Earth.

Figure 2C. An image from Google Earth, featuring the areas selected by students (see Figure 2B). The locations are automatically exported to Google Earth where students can examine satellite imagery and, if available, a street level view. One of the areas, enlarged in the frame, contains a road and bridge coming from an unknown facility nearby, something we could not see in the GIS data. This is one example of how the Google Earth investigation allows students to use multiple tools to identify better solutions. This image was prepared using Google Earth Pro, according to Google's usage guidelines.

2. Teacher Training. Participating teachers received 26 hours of training over the summer prior to the intervention. Both experimental and control teachers participated in the training (with the exception of one control teacher due to a staffing change). This was necessary because one teacher simultaneously taught an experimental and control class. Additionally, the training was intended to impact instructional strategies, such as questioning and discourse methods. As such, it was important for all teachers to engage in the training to better isolate the curriculum itself as the source of any changes.

The training, which took place over two weeks, was led by the researchers. Teachers broke into pairs or groups of three to work through the activities that students would complete with guidance from the researchers in the teacher's role. After completing the activities, the teachers taught portions of the curriculum to their peers, worked together to consider how they would implement the activities in their classroom, and taught the first module to a small group of students participating in a summer camp. Teachers received feedback from their peers and researchers throughout the training. On a survey taken after the training, teachers overwhelmingly indicated that they felt prepared although nervous to teach without additional support.

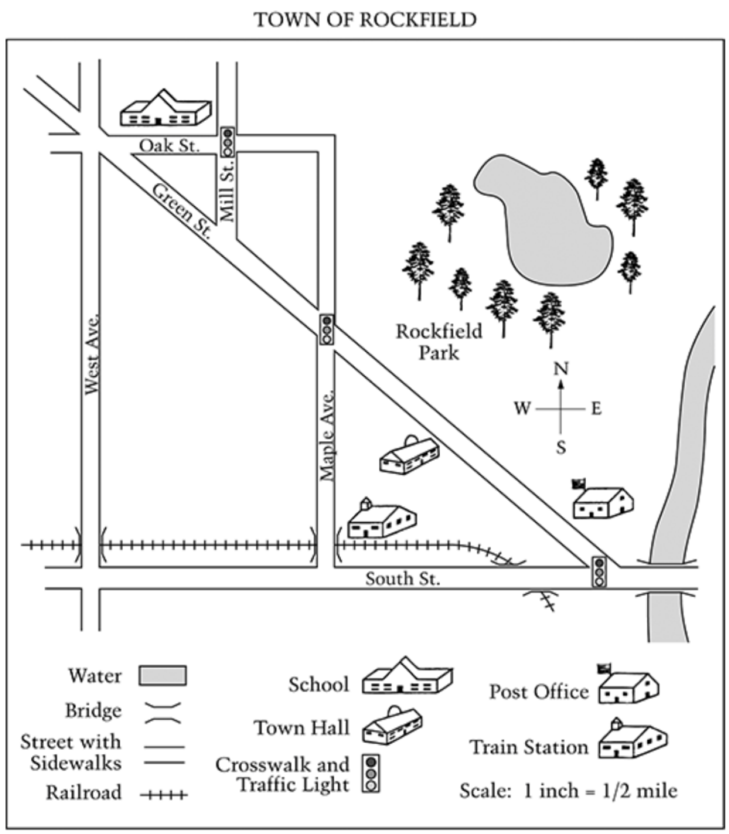
Prior to and throughout the implementation, experimental teachers received up to four hours of individualized support from the researchers. Twice a week a researcher was available to meet in person on request. The researchers verified that classroom computers were prepared for the activities, supplied materials, and were available to respond to questions and concerns by e-mail and phone. In addition, all teachers had access to more than two and a half hours of video tutorials to assist in reviewing the activities and concepts prior to teaching.

3. Classroom Implementation. Four of the seven participating classes were assigned to the experimental group while the remaining served as control. Teachers of experimental classes implemented the GIS curriculum over six weeks in the fall with external support from the researchers throughout the intervention; teachers of control classes were instructed to teach as usual. During that time period, the implementation of the GIS curriculum varied among experimental classrooms as class sizes, ability, and schedules – among other teacher-specific variables – were diverse. Similarly, different curriculum and instructional strategies were utilized in the control classes varying by teachers' styles. This variation was permitted in respect to the exceeding demands faced by elementary school teachers and the diversity of expectations and resources in each school. The implications of these concessions are addressed further in the Study Limitations. Outside of the GIS curriculum used in experimental classrooms, none of the experimental or control classes had significant exposure to geography content beyond the incidental reference of maps in social studies texts.

4. Data Collection. All students in experimental and control conditions completed the same set of tests before and after the six-week intervention time period. Per the current study, the researchers administered two measures to assess students' spatial ability and map analysis skills in the fall semester.

Cognitive Abilities Test Nonverbal Reasoning Scales (*CogAT*; Lohman and Hagen 2001). The three nonverbal reasoning scales from the CogAT, Form 7, Level 11 were used to measure abstract spatial ability. Figure Matrices included 22 items. Each item displayed a 2 x 2 matrix of figures. Students determined the relationship between the figures in the top row and applied the same relationship to the bottom row, selecting the missing item from among 5 choices. Paper Folding included 16 items. Students determined how a piece of paper would look when folded, holes punched, then unfolded by selecting the correct answer from 5 options. Figure Classification included 22 items. Students were shown three figures in the top row and asked to choose the fourth figure of the set by selecting from the 5 options provided. Each subtest was administered and scored according to standard procedures, including instructions, practice items, and time limits. Standard age scores were used in all analyses (n = 143 with complete data).

National Assessment of Educational Progress (NAEP) Geography Assessment. Each test included 9 map-based items selected from public-domain NAEP geography assessment, matched on difficulty and question type (NAEP 1994, 2001, 2010b). The questions, pooled from spatial dynamics and space and place scales, relied heavily on paper map-reading and map-analysis skills and included a variety of answer formats, including map construction, short answer, and multiple choice. Each question included a map or required students to construct a map. An example of questions that the students responded to is depicted in Figure 3 Administration and scoring were handled according to standard procedures, including instructions and time limits. Composite scores were used in analyses, with higher scores (up to 16 points possible) indicating more refined map-analysis skills. Pre- and post-test NAEP assessments from 35 participants (out of 164 with complete data) were scored by two independent raters to assess inter-rater reliability, representing 21% of the sample. Intraclass correlations were .98 for the pre-test and .99 for the post-test, indicating very high inter-rater reliability.



At the Rockfield town meeting, the mayor tells the people that there is money in the town budget to put up one more traffic light. There is the same amount of traffic on all streets in town. Where is the traffic light needed most?

A. The intersection of South Street and West Avenue

B. The intersection of Oak Street, Green Street, and West Avenue

C. The intersection of Mill Street and Green Street

D. The intersection of South Street and Maple Avenue

Question ID: 2010-4G3 #9 G028601

Figure 3. An example of a NAEP Geography item included in our assessment, from the NAEP Geography Assessment for Grade 4 in 2010. The correct answer is: *B. The intersection of Oak Street, Green Street, and West Avenue.*

Results

The first goal of this study was to test whether our GIS curriculum led to improvements in spatial ability. To test this hypothesis, CogAT scores were analyzed using a Condition (experimental, control) x Time (pre-test, post-test) mixed model Analysis of Variance (ANOVA), with condition as a between-subjects factor and time as a within-subjects factor. As expected, the main effect of time was significant, F (1, 141) = 77.92, $p < .001$, *Partial Eta*^{2} = .36, indicating that post-test spatial ability scores were significantly higher than pre-test scores. Importantly, the analysis also revealed a significant Time x Condition interaction, F (1, 141) = 4.03, $p < .05$, *Partial Eta*^{2} = .03. Simple effects tests revealed significant growth in spatial skills over time for both groups of students (Figure 4). Visual inspection of the results displayed in Figure 4 reveals that the experimental group evinced greater growth over time (7.48 points) than did the control group (4.72 points). These findings support our hypothesis that students in the GIS classes would demonstrate more growth over time in spatial ability than would their peers in the control classes.

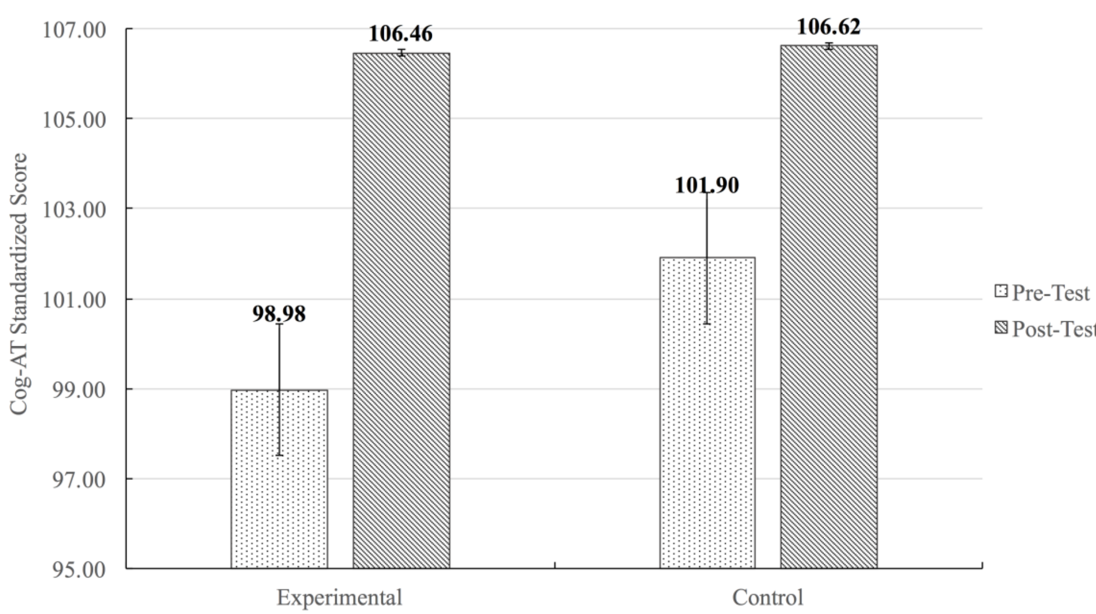


Figure 4. Pre- and post-intervention nonverbal (spatial) scores from the Cognitive Ability Test for the experimental and control groups. Error bars represent standard error.

A second goal was to determine the effectiveness of our curriculum in improving map-reading and map-analysis skills. To test the effect of the GIS curriculum, NAEP scores were analyzed using a Condition (experimental, control) x Time (pre-test, post-test) mixed model ANOVA. The main effect of time was significant, F (1, 162) = 291.43, $p < .001$, *Partial Eta²* = .64, indicating that post-test map-analysis scores were significantly higher than pre-test scores. This main effect was subsumed by a significant Time x Condition interaction, F (1, 162) = 5.59, $p < .05$, *Partial Eta²* = .03. Simple effects tests revealed significant growth over time for both groups of students (Figure 5). Visual inspection of the results displayed in Figure 5 reveals that the experimental group showed more growth over time (4.59 points) than did their peers in the control condition (3.62), supporting our hypothesis about the effect of our GIS curriculum on map-analysis skills.

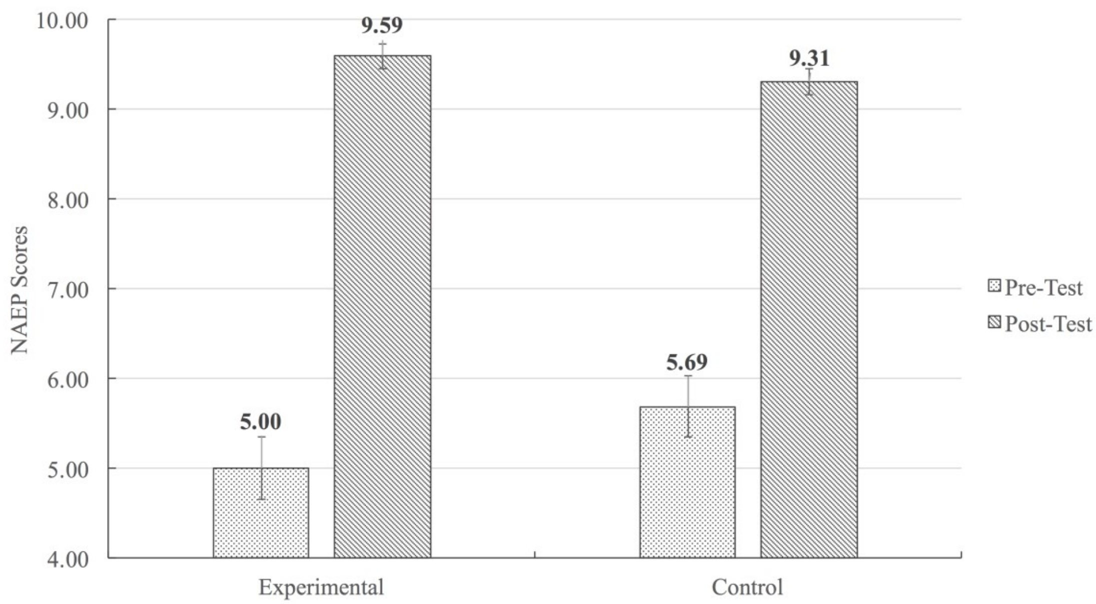


Figure 5. Pre- and post-intervention geography test scores (for items focused on map-reading and map-analysis skills extracted from public-domain NAEP [National Assessment of Educational Progress] assessments) for the experimental and control groups. Error bars indicate standard error.

Study Limitations

The quasi-experimental design included numerous limitations and constraints. The implementation in experimental classrooms varied at the discretion of each teacher. In experimental classes, the amount of time spent on each module by each teacher varied, and each class completed varying amounts of the curriculum (though all classes completed at least four modules including Module Five). Each experimental teacher also independently determined in what ways our curriculum would substitute or supplement their typical activities and assignments in other subjects. Likewise, the curriculum and instructional strategies used in each of the control classes varied, including the instructional time devoted to each subject area, the content of instructions, and the assignments and assessments that students completed. None of the teachers, in experimental and control classes, utilized a traditional geography curriculum, and geography was not a substantial component of any of the teachers' curriculum for other subjects. While the kinds of analysis students did in our curriculum would be impractical without GIS, curricula utilizing other technologies or pencil-paper activities, particularly geography curricula, may produce similar results. While our findings do suggest that problem-based GIS use can have a positive impact on spatial ability and map-reading and map-analysis skills, our findings do not indicate that GIS is the *only* means of producing these results. Similarly, these results should not be taken to indicate that GIS is powerful in the absence of a well-conceived curriculum designed around effective instructional design techniques. In absence of suitable standard measures for the broad set of *geospatial skills* we believe to be impacted by our GIS-focused training, we assumed development of these skills would be detectable using *abstract spatial* tests. Additionally, while the intervention primarily utilized *digital maps,* our measures exclusively relied on *paper maps*. Finally, we did not complete an analysis of non-geographic contributors to spatial development, such as training in mathematics (e.g., geometry), art, or physical education, in teachers' curriculum.

Discussion

The goals of this project were to test the effects of GIS curriculum on fifth grade students' spatial ability, map-reading and map-analysis skills. As predicted, students who completed six weeks of GIS instruction demonstrated stronger gains that are statistically significant in these areas than did students in control classes. However, the general performance of students in the experimental classes on the pre-assessments was lower than the performance of their peers in the control classes. While the experimental group did demonstrate larger growth from the pre to post assessments, the groups performed similarly on the post test, as though the experimental group "caught up" to the control group. In other words, the obtained results were only statistically, not not practically, significant. The low variance of scores in both conditions on the post assessment might suggest that this is attributable to incidental development among all students at this age; however, this finding might also suggest that appropriate intervention can address performance gaps between high and low performing students.

While the measures used in our study captured a difference in growth between the experimental and control groups, these measures proved insufficient for determining the impetus for growth that can be attributed to a GIS-infused curriculum. These measures were standardized instruments (i.e., the CogAT nonverbal reasoning ability scales and selected NAEP geography items). Some possible limitations that might have contributed to the obtained results are:

- Study Duration: Six weeks may have been an insufficient intervention period.
- Context: The CogAT non-verbal sets depended on abstract geometrical shapes whereas the GIS modules provided geospatial context; expecting a far transfer of skills.
- Modality: Transition from digital maps in GIS (where visuals can be manipulated) to static paper maps in NAEP (where manipulations can only happen mentally) may have impacted student performance.
- Our GIS intervention may have allowed students to rely on intellectual strategies enabled by GIS, while NAEP and CogAT relied more heavily on visual identification.
- Our GIS intervention was collaborative, so students may not have performed as well when forced to respond to the questions independently from their peers.

It is our belief that new instruments need to be developed and rigorously tested to ensure the valid assessment of specific geospatial skills. Only through the development of specific and targeted measures can we accurately assess and better understand the scope of changes in children's spatial thinking and map-analysis skills due to GIS impact. To assess the impact of GIS, we recommend that special attention be paid to the transfer of skill from digital to non-digital activities and vice versa. We also recommend designing standardized assessments that allow for collaboration, particularly if students collaborate throughout the intervention.

There is considerable discussion in geography education regarding conceptualizations of spatial thinking, which has led to the development of alternative measures used with high school and college students (Lee and Bednarz 2009; Lee and Bednarz 2012). Developing similar measures of spatial thinking suitable for elementary students would be helpful. Because spatial ability is linked to interest and success in STEM fields, it is essential to focus on these skills as early as elementary school, warranting further research and an increased effort to develop practical and effective assessments of spatial ability for young students. It is important to note that the goal of developing such assessments should not be to validate the use of GIS, though GIS-focused research would certainly benefit.

Beyond Spatial Ability

Our initial interest in GIS was rooted in spatial thinking rather than spatial ability. However, over the course of our study we grew to understand the complexity of a broader set of skills within spatial ability. But we were also increasingly impressed by the possibility of other benefits from our intervention. Even if additional research establishes that GIS does not significantly contribute to elementary students' spatial ability, researchers should examine the potential for other impacts of GIS use in the classroom. For example, there have been promising qualitative indications that GIS is engaging for students, both in our work and previous studies (Keiper 1999; Shaunessy and Page 2006). We also have quantitative indications that both students and teachers were excited by GIS use (results to be published). We believe that there are benefits to students' discourse, problem solving, and computer skill, among other factors. We recommend that researchers utilize qualitative approaches to identify previously unconsidered advantages to GIS use. For example, we have identified engagement and motivation as benefits of GIS use, and encourage researchers to adopt a quantitative approach to measure those variables going forward.

Terminology

Our review of literature has resulted in concern regarding the shifting and indecisive use of overlapping terminology such as spatial thinking, spatial reasoning, spatial ability, spatial cognition, compounded by the unique qualities of *geo*spatial skills, thinking, and ability. It is imperative for research in this field to identify a consensus on clearly defined terminology around which interventions and measures can be designed.

Conclusion

Without hesitation, we can say that upper-elementary grade students are capable of using GIS for meaningful problem solving activities. This expands on previous research that has largely focused on middle school and high school students, and limited the use of GIS with young students to exclude the problem-solving components and multi-layer analysis students completed successfully in our intervention. While we expected students in the GIS group to demonstrate significantly higher growth in spatial ability and map-analysis than students in the control group, the growth we observed was not large enough to make definitive claims about our intervention or GIS as a tool. Future research should focus on developing assessments that better measure elementary students' spatial ability and map analysis and provide a better understanding of ability transfer from digital to paper settings. Finally future research utilizing GIS should focus on a broad range of skill development beyond only spatial ability.

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NOTE: This material is based upon work supported by the National Science Foundation . Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.