JOURNAL OF GEOSCIENCE EDUCATION **61**, 161–169 (2013)

The Use of Geospatial Technologies Instruction Within a Student/Teacher/Scientist Partnership: Increasing Students' Geospatial Skills and Atmospheric Concept Knowledge

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ABSTRACT

Many 21st century careers rely on geospatial skills; yet, curricula and professional development lag behind in incorporating these skills. As a result, many teachers have limited experience or preparation for teaching geospatial skills. One strategy for overcoming such problems is the creation of a student/teacher/scientist (STS) partnership within schools. This study investigated the extent to which the use of geospatial technologies (GST) within a STS partnership improved the geospatial skills and atmospheric science concept knowledge of high school and junior high school students who were primarily from high-needs schools. During the course of a 5 d summer institute, scientists who use GST in their research taught teachers how to use the geospatial technologies of remote sensing, geographic information systems, and global positioning systems. This phase was followed by instruction in standards-based activities, taught by a master teacher, which participating teachers could use to integrate GST in their curriculum. During the school year following the summer institute, teachers taught their students the use of the geospatial skills. Students then applied these skills to collect field data, which were shared with scientists. Instruction culminated in the preparation of individual inquiry-based student projects that were presented to scientists, fellow students, and community members at a mini-conference. The research methodology involved testing students before any instruction in GST and then retesting them twice: (1) once during the elaboration phase of instruction, subsequent to formal instruction and field data collection, and (2) again during the evaluation phase of instruction, after student engagement with their individual projects. Substantial gains were found from the pretest to the evaluation phase test in both geospatial skills and atmospheric concept knowledge. No interaction effects of gender and socioeconomic status were found. © *2013 National Association of Geoscience Teachers*. [DOI: 10.5408/11-237.1]

Key words: geospatial technologies, spatial skills, atmospheric science, concept learning, inquiry, STS partnership, teacher development

INTRODUCTION

Teachers tend to have limited experience in, or preparation for, teaching geospatial skills (Briggs, 2007), even though these skills are seen as required for many 21st century careers (DeRocco, 2003). Curriculum and professional development efforts lag behind in helping teachers incorporate these skills in the classroom. One strategy for dealing with this lag is the creation of partnerships among students, teachers, and scientists who use these skills. Student/teacher/scientist (STS) partnerships focus on providing student access to authentic science experiences (Tinker, 1997). This goal underscores the need for sustained involvement, long-duration experiences, and ownership by all participants, including students, teachers, and scientists, within STS partnerships (Rahm et al., 2003). An STS partnership, therefore, must meet a number of requirements in order for it to succeed: (1) Teachers and students must be able to understand the science involved; (2) the cost of instrumentation must be low; (3) the research in which the teacher and students will participate should require more manpower or observers than scientists alone can provide, and (4) the research must be conducted in multiple locations that are geographically diverse (Tinker, 1997). Some research areas that Tinker (1997) suggests as particularly suitable to these partnerships include: environmental studies on a long-term basis, large-scale biodiversity studies, epidemiologic studies of low-level diseases like the common cold, ozone and ultraviolet studies, image analysis of pictures of Mars and outer space to find supernovae and other transitory events, data gathering and analysis of social and cultural issues, and educational issues like the tracking of the impact of technology and school reform.

An STS partnership focusing on the use of geospatial technologies has added legitimacy because these emergent technologies are the third-fastest-growing career path in the United States according to Johnson et al. (2009) and the U.S. Department of Labor (DeRocco, 2003). Geospatial technologies are a group of technologies that study the spatial aspects of Earth. The technologies are divided into three types: remote sensing, geographic information systems (GIS), and global positioning systems (GPS). Remote sensing is the collection and use of digital information about Earth utilizing Earth's reflected and emitted energy without the instrumentation actually coming in contact with Earth. Examples of remote sensing include satellite images of weather, crop identification, land use, and military assessments. GIS is a computer-assisted study of data that can be analyzed, managed, and displayed in a geographically referenced format. GIS includes mapping of tornado

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Received 27 April 2011; revised 17 January 2012, 28 September 2012; accepted 24 October 2012; published online 21 February 2013.

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destruction, point sources of contamination, urban sprawl, and mapping of points of high-security risk for the Department of Homeland Security. GPS is a satellite-based technology that calculates velocity and location at any time of the day at any place on Earth. Examples of GPS include navigation systems in cars, boats, airplanes, cell phones, and in pastimes like geo-caching.

Thinking spatially has been shown to be a key factor in certain types of academic success (National Research Council, 2006). Spatial thinking is a collection of skills. "The key to spatial thinking is a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning" (National Research Council, 2006, p. 12). The concepts can be further explained by the following constructs (NRC, 2006): (1) concepts of space, which include the relationship between units, understanding different coordinate systems, and the difference in the nature of two- and three-dimensional space; (2) relationships, which refer to differences in views—plane versus elevation, the effect of projections, and the principles of graphic design; and (3) reasoning, which relates to the different ways of thinking about shortest distances, the ability to extrapolate and interpolate information from data presented, and to make decisions based on given information. Since it is both explicitly stated in the National Council of Teachers of Mathematics' standards (2000) and implicitly shown in the relationship between mathematics and science that spatial thinking is necessary for success in science education (NRC, 1996), we can assume that spatial thinking should be an integral part of science education practice. Whether out in the field collecting data or in the classroom, students can use geospatial technologies to develop an awareness of where data come from and what they mean (Briggs, 2007). Landenberger et al. (2006) also underscored the use of these technologies to teach inquiry-based science and spatial thinking skills. As in the STS partnership described here, their investigations engaged the students in conducting field investigations, data collection, and analysis. Landenberger et al. (2006) showed that using an STS partnership helped students understand the relationship between land use and the quality and quantity of local freshwater. Including these technologies within the school curriculum, therefore, seems like a prudent idea if, in fact, educators want students to be prepared for life after their school years. Just as computer usage is considered a life skill today, geospatial technologies may be tomorrow's life skill; however, even though the use of these technologies is growing in society at large through sports, census work, cars, boats, and mapping, the usage of these technologies remains lacking in schools (Briggs, 2007). One reason for this gap is that visual-spatial learning takes a subservient role to alpha-numeric encoding skills (i.e., skills in reading, writing, and arithmetic) in classrooms and textbooks (Mathewson, 1999).

We investigated the impact of a specific STS partnership on student knowledge of the atmosphere and geospatial skills. The STS partnership focused on geospatial techniques that were applied to the study of the "urban heat island effect." The heat island effect is defined as elevated temperature associated with an urban area caused by significant impervious surface coverage from buildings and pavement (Bornstein, 1968). This STS partnership fits the criteria for a successful STS partnership. It provides teachers with extensive content preparation by research scientists in the technologies, help with integration of the technologies by a master teacher using standards-based lessons and activities, free instrumentation, field data collection on an environmental problem that is affecting the entire world, an inquiry-based research project based on data collected/other databases, and continued involvement with the research scientists.

NEED FOR STUDY

A key principle of STS partnerships is that all participants benefit from the collaboration. In the case of this STS partnership, scientists benefit from the atmospheric data collected and entered on an environmental data storage Web site by students, and we hypothesize that students studying the urban heat island effect and its effect on climate change will benefit by learning specific science content about the energy budget and atmospheric science concepts through the use of geospatial technologies. Anecdotal evidence from teachers involved in the use of geospatial technologies within a previous STS partnership supports the claim that their participation was beneficial to them and their students (Hedley and Struble, 2004). Some of this anecdotal information includes students having a greater interest in science and students in inner city schools staying in school because they found that participating in the scientific research made it worth coming to school. As encouraging as these results are, little statistical data exist to substantiate and quantify this evidence. To increase the specificity of information concerning the impact of the use of geospatial technologies upon students, this study focuses on two areas: atmospheric science concepts and geospatial skills.

Research Questions

The specific questions addressed in the research are the following:

1. Will the use of geospatial technologies within an STS partnership improve the knowledge of atmospheric science concepts of students in grades 7–12?
2. Will the use of geospatial technologies within an STS partnership improve the geospatial skills of students in grades 7–12?
3. Do all students in grades 7–12 who participate in the use of geospatial technologies within an STS partnership benefit equally in terms of atmospheric science concepts learned and improved geospatial skills regardless of gender and socioeconomic status?

To answer these research questions, a hybrid study that used two types of experimental methodology was designed. The first methodology of the study involved a quasi-experimental design. This component tried to establish a cause and effect relationship between the dependent and independent variables using nonrandom assignment of subjects (Smith and Glass, 1987).

Once the overall effects were determined, the second methodology of the study was conducted. In this methodology, a causal–comparative design was used. In this design, the researcher looks at the effects of the treatment on specific groups within the study group (Smith and Glass, 1987). In particular, the study used a between-groups design to compare the differences in results in the geospatial skills and science knowledge: (1) between males and females, and (2) between those receiving free/reduced lunch and those who did not (proxy variable for socioeconomic status).

METHODS

This section is divided into three distinct parts. The first part will describe the format of the STS Partnership. This section will detail the teacher preparation, the field campaign data collection protocol, the inquiry-based project, and the mini–science conference. The second part will describe the studied population. The third part will describe the methodology of the study, including the instruments, the method of testing, and the attrition of subjects.

Format of the STS Partnership

The STS partnership in this study involved teachers from five school districts, their students, and research scientists whose research utilizes these technologies. Three of the school districts were listed as "high-need" districts in Ohio at the time of the study.

Teacher Preparation

Pre- and post-testing has shown that many in-service teachers have misconceptions in the geosciences that can be addressed by targeted instruction in this area (Libarkin and Brick, 2002). Teacher instruction in areas of atmospheric science and the use of geospatial technologies was provided in a 5 d institute session at the Ohio Aerospace Institute in Cleveland, OH. The institute was held in July 2007, the summer before the teachers implemented the program with their students. Teachers were instructed in remote sensing, GIS, and GPS. Teachers learned protocols to use these technologies in field research. A master science teacher, who had 30 y of science teaching experience and who held a doctorate in science education, provided instruction in the pedagogy required for integrating these technologies in their classroom. Inquiry-based science was stressed throughout the 5 d. Activities were aligned with the Science, Mathematics, Technology, Social Studies, and English Language Arts Ohio Content Standards. The final part of the session was dedicated to an individual inquiry project based on data the teachers collected, and on several other databases, including those on the Global Learning and Observations to Benefit the Environment (GLOBE) web site: http://www.globe.gov. Teachers learned how to instruct their students in the use of the technologies, to set up their school's research sites, and to collect field data. The teachers participated in all the activities that the students would be engaging in during the school year. Each teacher completing the summer institute received a GPS unit, an infrared thermometer for remote sensing, GIS software, and standards-based lesson plans for integration of these technologies in their curriculum.

Field Campaign Data Collection Protocol

The field campaign of the program had a twofold purpose: (1) It utilized the geospatial technologies the students had learned, and (2) it allowed the students to do real science by doing actual field research into global climate change. The students at each school first set up their school's two field research sites. One of the sites was a grassy field and the other was a paved area like a parking lot. The ideal site was considered to be 30 by 30 m, since that is the size of the swath the *MODIS* satellite takes as it passes over the area. The students provided ground truthing of data the satellite was collecting. Students described their areas as to type of ground cover, and trees or buildings near the area that would cause shading, the size of the area, and the GPS coordinates of the center of each site. GPS coordinates were taken so that data could be geolocated. This was essential for this type of data collection. If the ideal area was not available, the students could still collect the information from smaller sites. The specific data the students were collecting was the temperature of surface of the grassy and paved areas, surface conditions (wet, dry, snow covered, ice covered, etc.), and atmospheric conditions, including type and percentage of cloud cover, present weather conditions, and type of aerosols in the air if any were present. Students collected nine sets of surface temperature using an infrared thermometer (IRT) at random areas within the study areas, avoiding any shaded areas. This was repeated at both study sites. These temperatures were then averaged to give the average for each site at that time. Data were collected ideally within an hour before or an hour after solar noon in each study location. That time was chosen since that best coordinates with the satellites passing over the area. If the data were not collected at that ideal time, it was still valuable, and all data collected were time stamped. Universal Greenwich Time (UGT) is the time used by the researchers around the world, so students learned how to convert their local time to UGT before they entered it on the GLOBE Web site. The GLOBE Web site collects data from students around the world for the surface temperature protocol. Scientists, students, and teachers in their study of global climate change and urban heat island effects then can use these data. Data were collected for 10 consecutive school days between Thanksgiving and Christmas/winter break 2007. Each teacher chose which 10 d best fit his or her school's schedule. This time period was chosen as the best possible time that snow might be present at the school's site. Snow and clouds both have approximately the same reflective index, and the surface temperature protocol used by the students has helped in modifying the *MODIS* satellite's algorithm to better distinguish between snow and clouds, and this represents a benefit to scientists in their study of global climate change.

Inquiry-Based Project

The National Science Education Standards (NRC, 1996) state that students should learn the concepts and facts of science, obtain reasoning and procedural skills of scientists, and understand the nature of science as a particular form of human endeavor (National Research Council, 2000). This policy statement means that students must actually do science, rather than only study the facts of science. With this in mind, this program was structured so that the students learned the science of geospatial technologies, used them in a field study, and then conducted their own inquiry-based research project using the geospatial technologies. Students could do the project as an individual, or they could choose to work in teams of up to three students. Each student or team was required to design a project that in some way addressed either the topic of global climate change or the urban heat island effect. Each project was required to follow the Intel®

International Science and Engineering Fair (Intel® ISEF) Science Fair project guidelines. The Intel ISEF guidelines were used so that students could also present their projects at local, district, and state science fairs. The student's inquiry-based research project utilized their knowledge and allowed them to become actively involved in solving a question they proposed using the data they collected and/or data from other databases. Doing their own research project allowed them to mirror the reasoning and procedural skills that scientists follow when they conduct their research. Project questions were chosen by the students with guidance from the teachers. Teachers gave input to the students about the feasibility of the study in regard to their ability to collect the data needed, either by active experiment or available databases, time needed to complete the project, cost to do the study, available background information, and appropriateness to the overarching topic of global climate change. Some of the project questions studied were how clouds affect global climate change; whether global warming is actually occurring; whether temperatures in the area are actually increasing above the normal expected cyclical fluctuations; whether surface temperatures differ in rural areas compared to local school grounds; and whether what is occurring with the weather is cyclical or actually a result of climate change. If the students used any of the GLOBE protocols in their research, they were encouraged to enter their collected data on the GLOBE Web site. The students were required to utilize at least one of the geospatial technologies (remote sensing, GIS, or GPS) in their research project.

Presentation of Inquiry Projects to Colleagues

In order to emulate the ways scientists present their research for review, the program required all students involved in the STS partnership to do a project. The opportunity to present research findings is a way for students to show they truly understand the way scientists work and to appreciate their own work as "scientists." The students' projects were presented and judged within each participating teacher's classroom/school. Participating teachers and students chose one project from each class involved in the STS partnership to represent their class and present their research findings at the mini–science conference. The 1 d science conference was held at the Great Lakes Science Museum in Cleveland, OH, in February 2008. Students' project boards were placed in the halls of the museum and remained on display throughout the day. Students stood by their posters during scheduled poster session times to explain their work and be judged by pairs of scientists and educators. The scientists who judged the students were scientists from Ohio universities who used geospatial technologies in their own research. The educators who judged the projects were STS partnership teachers who had all received the summer institute training. Educators did not judge their own students at the conference. A National Aeronautics and Space Administration climate change scientist gave the keynote address at the conference. A tour of the museum was included for all participants as part of the conference program. In total, over 500 students, teachers, parents, scientists, and other members of the public who visited the museum that day attended the mini–science conference.

Studied Population

The STS partnership involved 303 students, 207 high school students and 96 junior high students in grades 7–12 from Ohio. These students were all the students in science class sections of teachers that participated in the STS partnership. These teachers had previously attended the summer institute focusing on the use of these geospatial technologies in the classroom. Students from five high schools and four junior highs participated in the study. All of the schools except for one high school were public schools. Schools from large urban districts accounted for the majority of the schools. Four of the five high schools were classified as high needs, and three of the four junior highs participating were considered as high needs, meaning that they mainly serve students from groups historically considered as "minorities" or students with low socioeconomic status, according to the Ohio Department of Education statistics. Eight of the nine schools involved in the study were in "academic watch" or "academic emergency." In Ohio, the academic watch designation is defined as a school: (1) meeting only 9–12 of the state's academic indicators, (2) scoring between 70 and 79.9 out of 100 on the state's Performance Index, or (3) not meeting Adequate Yearly Progress (AYP). The academic emergency designation is defined as a school: (1) meeting 8 or fewer of the state's educational indicators, (2) scoring less than 70 out of 100 on the state's Performance Index, or (3) not meeting AYP. Demographic analysis was performed on a subsample of the larger group. The subsample was chosen by the participating teachers to be a group that typified their student population. This subset totaled 94 students of the original 303 students (31.0% of the total group). When listwise deletion was used to eliminate those students who did not take all three tests, there were 150 students left of the original 303. Listwise deletion left 71 students (40.7% of the 150 students) who had supplied demographic data remaining in the analysis. Consistent with the terms of the university's Institutional Review Board approval of this study, a signed informed consent document was collected from a parent or guardian of each student from whom demographic information was collected. Each student participating in demographic data collection also gave his or her assent to participate in the study by signing the informed consent document.

Methodology

During the school year following the summer institute, students took a pretest before any instruction was given in the technologies. After formal instruction and field data collection, the students were tested again. This testing occasion shall henceforth be designated the "elaboration phase test," because it occurred as students were in the process of elaborating their atmospheric science knowledge and geospatial skills in accordance with the STS partnership plan. Students used the data they collected from the field campaign or from other databases to complete work on their own inquiry-based research project. Approximately one month after the elaboration phase test, the students were tested again to gauge how the inquiry project affected student learning of geospatial skills and atmospheric science concepts. (This testing occasion may also be measuring some long-term retention of the concepts learned.) This testing occasion shall henceforth be designated the "evaluation phase test," because it occurred as students were in the process of completing their individual projects, which functioned as a final student performance assessment within the STS partnership plan.

Instruments

The pretest, elaboration phase test, and the evaluation phase test each consisted of the same 26 multiple-choice questions. See the Supplemental Materials available at http://dx.doi.org/10.5408/11-238s1. The first 16 questions assessed spatial skills in the context of geospatial technologies (Lee, 2007). The author, Jongwon Lee, and the publisher, Association of American Geographers, of the standardized spatial skills (SSK) test gave written permission for the use of the test for the duration of this study and its disclosure here.

Lee and Bednarz (2009) found that other psychometric instruments of spatial ability do not measure geospatial skills but rather test small-scale spatial abilities constructs such as rotation of two-dimensional objects and folding of two-dimensional objects in three dimensions. Such measures, they argue, ignore commonly used geospatial skills such as geographic relief, spatial interactions, movements, or basic distributions/patterns of phenomena as surfaces. In contrast, this instrument (Lee, 2007) attempts to measure these constructs. Lee and Bednarz (2009) conducted a study that gathered validity evidence and checked the reliability of this instrument. In terms of validity evidence, the following findings were noted: (1) SSK scores positively correlated with the amount of geotechnology coursework completed (Pearson correlation coefficient = 0.578) (Lee and Bednarz, 2009, p. 187); (2) SSK post-test scores positively, although only marginally, correlated with final content exam scores (0.329, $p = 0.108$) (p. 193); and SSK post-test scores correlated more strongly with geotechnology laboratory exercise scores (0.405, $p = 0.044$) (p. 193) than with other forms of instruction. Lee and Bednarz (2009) reported that the reliability of the SSK test (Cronbach's alpha = 0.7034) is "just above the commonly recognized threshold for acceptability in social science" (p. 191).

The atmospheric science concept questions were composed through collaboration between the third author (a meteorologist, remote sensing scientist, and instructor at the summer institute) and the first author (a master science teacher and instructor at the summer institute). Questions were written to address Ohio Academic Content Standards related to: (1) the energy budget, (2) clouds, and (3) weather. The distractors chosen were common misconceptions students have that are related to these concepts. For the study reported here, we found acceptable reliability for the geospatial skills section of the test (Cronbach's alpha = 0.845) and lower reliability for the science section of the test (Cronbach's alpha = 0.607).

Methodology of Study

Using an interrupted time-series design, the students were pretested at the beginning of the school year before any discussion of geospatial technologies and atmospheric science content took place, Participating teachers then introduced geospatial technologies and atmospheric science content through the teachers' use of PowerPoints and classroom implementation of lesson plans and activities. The scientists and science educator at the institute had previously presented these materials to the teachers. Students used the technologies in field campaign and then were tested (elaboration phase test). One month after the elaboration phase test and while the students were in the process of completing their projects, students were tested (evaluation phase test) again. According to Smith and Glass (1987), the time-series design is useful when all the students in the study are given the treatment, and there is no untreated group for comparison. Pretesting and post-testing of students is useful to both researchers and teachers using programs being tested in schools (McDermott, 2003). After the introduction of these technologies and their use in the field campaign, the students took the elaboration phase test. The students took the evaluation phase test after they had worked on their own inquiry-based research project using the technologies. Table I indicates who received a particular treatment and when they were expected to receive it.

TABLE I: Time line of program elements by participant group.

Program Element	Participant	Time
Teacher training	Teachers	July–August
Pretest	Students	September–October
Field data collection	Students	November–December
Elaboration phase test	Students	December
Inquiry-based project	Students	December–February
Presentation of projects to colleagues	Students	February
Evaluation phase test	Students	February

Having an interval of several months between the pretest, elaboration phase test, and evaluation phase test phases was intended to minimize any "practice" effect (Smith and Glass, 1987). The practice effect can increase a student's score. Students may either remember the test questions, or they may develop test-taking strategies that can increase their scores. Since geospatial technologies are not part of any of the participating school's curriculum and spatial skills were not presently emphasized at any of the schools, a threat to the validity of the study was minimized, because it was unlikely that any increase in students' geospatial skills came from other instruction they received in school. Maturation was not a threat to validity, since the 5 mo between the September and February testing should not lead to large changes on average.

Attrition of Subjects

Of the 303 students who took the pretest, 153 students (50.5%) did not complete the program and did not take the evaluation phase test. Of the 150 students who remained in the study, 34 were junior high students, and 116 were high school students. Of these 303 students, a subgroup had demographic information taken. Using listwise deletion, the demographic data collected were limited to 70 gender identifications and 60 socioeconomic status identifications. This demographic group typified their classes according to the teachers. There were 34 males in this subgroup and 36 females. In addition, the subgroup had 27 receiving free or reduced lunch and 33 who did not receive free or reduce lunch. Free and reduced lunch was used as a proxy for socioeconomic status. When the study began, five high schools and four junior high schools were involved in the

TABLE II: Descriptive statistics for the geospatial skills section of test.

Test	*M* (SD)[1]	Low Score	High Score
Junior high			
Pretest	5.1 (2.6)	1	13
Elaboration phase test	7.1 (3.1)	0	15
Evaluation phase test	7.9 (4.0)	0	15
High school			
Pretest	8.0 (2.6)	1	14
Elaboration phase test	10.4 (3.2)	1	15
Evaluation phase test	9.8 (3.2)	2	16
Total sample			
Pretest	7.4(2.9)	1	14
Elaboration phase test	9.6(3.5)	0	15
Evaluation phase test	9.4(3.5)	0	16

[1] *M* = mean—the arithmetic average of scores in a distribution (Hinkle et al., 1988, p. 51); SD = standard deviation—the positive square root of the variance expressed in the same units as the original measurement of the variable (Hinkle et al., 1988, p. 81). Variance is the average of the sum of squared deviations around the mean (Hinkle et al., 1988, p. 58).

TABLE III: Descriptive statistics for the science section of test.

Test	*M* (SD)[1]	Low Score	High Score
Junior high			
Pretest	3.1 (1.8)	0	8
Elaboration phase test	4.0 (2.5)	0	10
Evaluation phase test	4.9 (2.7)	0	10
High school			
Pretest	3.7 (1.6)	0	9
Elaboration phase test	5.7 (2.5)	0	10
Evaluation phase test	5.0 (2.1)	0	10
Total sample			
Pretest	3.6 (1.7)	0	9
Elaboration phase test	5.4 (2.6)	0	10
Evaluation phase test	5.0 (2.3)	0	10

[1] *M* = mean—the arithmetic average of scores in a distribution (Hinkle et al., 1988, p. 51);
SD = standard deviation—the positive square root of the variance expressed in the same units as the original measurement of the variable (Hinkle et al., 1988, p. 81). Variance is the average of the sum of squared deviations around the mean (Hinkle et al., 1988, p. 58).

research; however, one high school and one junior high were lost to the study because the teachers did not carry out the program to the finish. While the attrition rate seems very high, it is not unusual for urban schools. There is a high rate of movement of students from one school to another, high dropout rates, and high suspension and expulsion rates. Teachers involved in the study reported large changes in class rosters throughout the school year. The one school that had few changes throughout the study was the one private high school. The possibility of the attrition of students was known at the beginning of this study, but the benefits that were anticipated for the students that remained outweighed the inconvenience of the loss of data.

Data Analysis

The study looked at a number of different questions, and therefore the analysis required several different steps. The analysis first looked at an increase or decrease in both geospatial skills and in science content using the parameters of gender and free/reduced price lunch. The total score on the test was subdivided into the geospatial skills and the science content scores. SPSS software was used to carry out the analysis, and listwise deletion was used for subjects who had missing data for one or more of the follow-up tests. A repeated measures analysis of variance (ANOVA) was then used to test for statistical significance, a paired sample t-test served as a post-hoc test, and Cohen's d was used to judge the effect size of the paired sample t-tests.

RESULTS

The mean and standard deviation of the geospatial skills and science sections of the test for junior high, high school, and total student sample are shown in Table II and Table III. For both the geospatial skills and the science sections of the test, the total sample mean score increased overall from the pretest to the evaluation phase test; however, a slight decrease was noted between the elaboration phase test and the evaluation phase test on both the science and geospatial skills sections of the test. These declines result from observed drops in high school student scores (see Tables II and III). High school teachers speculated that these declines may have resulted from high school graduation test preparation that was co-occurring in the high schools at that time; thus, high school students may not have been as focused on the evaluation phase test.

Tests for Statistically Significant Results

The repeated-measures ANOVA test was chosen to assess the statistical significance of data gathered from the test taken by students at three different times. A post-hoc analysis was conducted using protected dependent t-tests. To decrease the Type I error rate, a significance level of .017 (.05/3) was used when comparing the tests in the post-hoc analysis. Covariates were used in a repeated measures ANOVA to check for the effects that time, gender, and socio-economic differences (free or reduced lunch was used as a proxy variable for socioeconomic status) may have on student scores. Cohen's d was calculated for six different paired samples (results calculated separately for the science and the geospatial skills sections of the test) from the protected dependent t-tests to determine effect sizes of the observed differences across the three testing occasions: (1) pretest, (2) elaboration phase test, and (3) evaluation phase test.

Geospatial Skills (GS) Section of the Test

A one-way repeated-measures ANOVA was calculated comparing the geospatial skills test scores of the students at three different times (see Table IV). A statistically significant main effect for time was found (p = .000). Gender and socioeconomic status did not significantly interact with the main effect of time. These findings indicate that both male and female students experienced approximately the same level of increase in scores over time. Likewise, socioeco-

TABLE IV: Within-subject effects for the geospatial skills section.

Source	F value[1]	df[1]	Significance Level
Time	22.037	2	.000
Time × gender	1.659	2	.198
Time × free	0.590	2	.558

[1] F value = the ratio of the variance of group means compared to the mean of the within-group variances (Hinkle et al., 1988, p. 280); df = degrees of freedom—the number of observations less the number of restrictions placed on them (Hinkle et al., 1988, p. 197).

nomic status did not interact with the main effect of time, meaning that all students experienced approximately the same level of improvement in geospatial skills over time, regardless of their socioeconomic status.

Science (SCI) Section of the Test

A one-way repeated-measures ANOVA was calculated comparing the science test scores of the students at three different times (Table V). A statistically significant main effect for time was found ($p = .000$). Like the GS portion of the test, gender and socioeconomic status did not significantly interact with the main effect of time for the science (SCI) portion of the test. These findings indicate that both male and female students experienced approximately the same level of increase in science knowledge over time. Likewise, socioeconomic status did not interact with the main effect of time, meaning that all students experienced approximately the same level of improvement in science knowledge over time, regardless of their socioeconomic status.

Effect Sizes

Effect sizes were calculated and interpreted for the differences between: (1) pretest and elaboration phase test, (2) elaboration phase test and evaluation phase test, and (3) pretest and evaluation phase test, for the geospatial skills (GS) and science (SCI) sections of the test, respectively. The effect size is equal to the mean difference between the initial and final measurements divided by the standard deviation of the initial measurement (negative numbers ignored). Cohen's standards suggest an effect size of approximately 0.2 is small, 0.5 is medium, and 0.8 is large.

For the GS portion of the test, these calculations yielded: a medium effect between the pretest and evaluation phase test (0.7); a negligible effect between the elaboration phase test and the evaluation phase test (0.1); and a large effect between the pretest and elaboration phase test (0.8) (see Table VI).

TABLE V: Within-subject effects for the science section of the test.

Source	F value[1]	df[1]	Significance Level
Time	17.631	2	.000
Time × gender	0.294	2	.746
Time × free	2.418	2	.098

[1] F value = the ratio of the variance of group means compared to the mean of the within-group variances (Hinkle et al., 1988, p. 280); df = degrees of freedom—the number of observations less the number of restrictions placed on them (Hinkle et al., 1988, p. 197).

TABLE VI: Cohen's *d* (effect size) for the geospatial skills section of the test.

Pair	*M* (SD)[1]	Cohen's *d*[1]
Pretest & elaboration phase test	2.2 (2.9)	0.8
Elaboration phase test & evaluation phase test	−0.2 (2.4)	0.1
Pretest & evaluation phase test	2.0 (3.0)	0.7

[1] *M* = mean—the arithmetic average of scores in a distribution (Hinkle et al., 1988, p. 51); SD = standard deviation—the positive square root of the variance expressed in the same units as the original measurement of the variable (Hinkle et al., 1988, p. 81). Variance is the average of the sum of squared deviations around the mean (Hinkle et al., 1988, p. 58); Cohen's *d* = mean difference divided by the standard deviation of the pooled sample (Hinkle et al., 1988, p. 306).

Effect size calculations for the SCI portion of the test yielded: a medium effect between the pretest and the evaluation phase test (0.6); a small effect size between the elaboration phase test and the evaluation phase test (0.2); and a medium effect between the pretest and elaboration phase test (0.7) (see Table VII).

Summary of Results

Based on these results, the following summary statements can be made about the use of geospatial technologies within an STS partnership using an inquiry-based pedagogy:

1. Student's geospatial skills improved statistically significantly with instruction as measured across time. In addition, a medium effect was found between the pretest and the evaluation phase test.
2. There were no statistically significant interaction effects by gender or by socioeconomic status in the improvement of student's geospatial skills.
3. Student atmospheric science knowledge improved statistically significantly across time from the pretest to the evaluation phase test.
4. There were no statistically significant interaction effects by gender or by socioeconomic status in the increase of specific atmospheric science content.

It is important not to overgeneralize, but the results that were acquired in this study certainly point to the potential of STS partnerships featuring inquiry using geospatial technol-

TABLE VII: Cohen's *d* (effect size) for the science section of the test.

Pair	*M* (SD)[1]	Cohen's *d*[1]
Pretest & elaboration phase test	1.8 (2.6)	0.7
Elaboration phase test & evaluation phase test	−0.4 (2.5)	0.2
Pretest & evaluation phase test	1.4 (2.5)	0.6

[1] *M* = mean—the arithmetic average of scores in a distribution (Hinkle et al., 1988, p. 51). SD = standard deviation—the positive square root of the variance expressed in the same units as the original measurement of the variable (Hinkle et al., 1988, p. 81). Variance is the average of the sum of squared deviations around the mean (Hinkle et al., 1988, p. 58); Cohen's *d* = mean difference divided by the standard deviation of the pooled sample (Hinkle et al., 1988, p. 306).

ogies to increase the geospatial skills and science content knowledge of students.

DISCUSSION

This study produced results that differ with previous studies. Past studies (Rosenthal and Rubin, 1982; Gaulin and FitzGerald, 1986; Dabbs et al., 1998; Nordvik and Amponsah, 1998; Silverman et al., 2007) have all shown that males in general do better in spatially oriented testing. This study, however, did not substantiate the findings of these researchers. The results of this study showed no interaction effect by gender. The finding that female students were not disadvantaged within this STS partnership requires further research to determine which of the following is the main cause of this lack of interaction effect by gender: the use of geospatial technologies, the implementation of an active STS partnership, or the pedagogy of inquiry-based science with the use of projects, or the combination of these three.

There are several studies that show that females do not do as well in science testing as their male counterparts (Blecker and Jacobs, 2004; Spelke, 2005; Halpern et al., 2007); however, the results in this study showed no statistically significant interaction effect by gender. This finding can be interpreted that the use of geospatial technologies within an inquiry-based approach to learning could be a factor in this study that enabled females to overcome the tendency to do less well in science testing. Although the relative contributions of geospatial technology use and inquiry-based teaching methods cannot be evaluated in this study, the finding that female students were not disadvantaged within the STS partnership also calls for further research.

Geospatial technologies have been shown to be effective in increasing academic achievement in several research studies (Baker and Case, 2000; Akerson and Dickinson, 2003; Baker and White, 2003). The significant difference in gain of geospatial skills and science content in this study substantiates this research. Although the numbers of students and type of school districts were limited, the findings are significant enough to warrant further study because the sample used in this study is not unlike other urban school districts.

The study results showed no statistically significant interaction effect of socioeconomic status in either the science or spatial skills test. These results are particularly exciting. If the use of geospatial technologies can be used as tools to enhance the learning of socioeconomic disadvantaged students, the use of these technologies would be a positive addition to any school curriculum. Further research will be necessary to see if it is the geospatial technologies that are the only factor in the leveling of the playing field for these socioeconomically disadvantaged students or if it only occurs within a STS partnership using inquiry-based science with projects.

Part of the success in the use of geospatial technologies in this study can be attributed to the type of education the teachers received in the use of technologies and their application in the STS partnership classroom. Research suggests that exemplary education must give students three kinds of scientific skills: learning the concepts and processes of science, acquiring the reasoning and procedural skills of scientists, and understanding that the nature of science is a particular form of human endeavor (National Research Council, 2000). It was important that the teachers not only learned to use the geospatial technologies themselves but also that they were able to use them as tools to answer questions they had about science topics. By actually using the technologies in activities and specific lesson plans, students learned the procedural skills of "scientists" and were able to apply them to their own research project. Teachers were able to effectively incorporate these technologies in their classrooms. The effective incorporation of these technologies within the STS partnership was evident by the increase in the students' geospatial skills and science concept understanding as measured by the research instruments and as expressed within the inquiry projects that students produced.

IMPLICATIONS FOR FUTURE RESEARCH

The overall positive results of this study warrant further research to determine if the results can be reproduced with a larger, more diverse group of students. For example, the present study looked at urban students, most of whom were living in poverty, within a single state; future studies could investigate the effects of the use of geospatial technologies on students from different geographic regions and with greater diversity in socioeconomic status. Moreover, the present study used an STS partnership model featuring the use of geospatial technologies within an inquiry-based pedagogy heavily supported by scientists and with an intensive and ongoing teacher development focus. Questions remain as to whether geospatial technologies would be as effective if employed in school curriculum without an inquiry-based model and with less scientist support. Examples of future research questions in this regard are: (1) What roles do scientists play in the use of geospatial technologies that support student geospatial skills and concept understanding? (2) What models of teacher preparation and teacher development best support science concept learning and the achievement of greater geospatial skills? (3) How can the use of geospatial technologies, as learning tools, be maximized for increasing science conceptual understanding and geospatial skills?

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