The Effects of a Geospatial Technology-Supported Energy Curriculum on Middle School Students Science Achievement

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Abstract

Geospatial technologies are increasingly being integrated in science classrooms to foster inquiry. This study examined whether a Web-based inquiry curriculum supported by geospatial technologies promoted urban middle school students' understandings of energy concepts. The participants included one science teacher and 108 eighth-grade students classified in three ability level tracks. Data were gathered through pre/posttest content knowledge assessments, daily classroom observations, and daily reflective meetings with the teacher. Findings indicated a significant increase in the energy content knowledge for all the students. Effect sizes were large for all three ability level tracks, with the *middle* and *low* track classes having larger effect sizes than the *upper* track class. Learners in all three tracks were highly engaged with the curriculum. The effectiveness and practical issues involved with using geospatial technologies to support science inquiry are discussed.

Keywords: Geospatial technologies, Geographic Information Systems, Google Earth, science inquiry, energy, middle school

A central component of science inquiry is appropriate use of technology to support learning goals (AAAS, 1993; Bransford, Brown, & Cocking, 2000; NRC, 1996; 2000). Many authors have espoused the potential for geospatial technologies to enhance science inquiry and to promote student understanding of content (Baker & White, 2003; Bodzin, Anastasio, & Kulo, in press; Bodzin & Cirucci, 2009; Schultz, Kerski, & Patterson, 2008; Stahley, 2006). Geospatial technologies such as geographic information systems (GIS), global positioning systems (GPS), and global visualization tools (for example, Google Earth, Arc GIS Explorer, and WorldWind, etc.) are increasingly being incorporated in science classrooms to promote student problem solving, data analysis, and spatial thinking. Such technologies allow for mapping, visualizing, and analyzing multiple layers of geographically referenced scientific data and information (Broda & Baxter, 2002; DeMers, 2005; ESRI, 1993).

Bednarz, Acheson, and Bednarz (2006) contended that the ability to use images and geospatial technologies intelligently and critically is becoming a requirement to participate effectively as a citizen in modern society. Students can use a GIS to solve real-life investigations and to draw on skills crucial to developing higher-order thinking and problem solving (Bodzin & Anastasio, 2006; Kerski, 2008; Ramirez & Althouse, 1995; Sanders, Kajs, & Crawford, 2002). According to Audet and Ludwig (2000), geospatial tools create a learning environment in which students can visually explore, analyze, and make decisions about problems in an interactive and challenging manner providing authentic, inquiry-based learning within the K-12 classroom environments (see also Bednarz & Audet, 1999).

As part of a larger science education and urban school reform initiative to enhance the teaching and learning of environmental issues in the school curriculum, our Environmental Literacy and Inquiry group developed an eight-week interdisciplinary science inquiry *Energy* unit for diverse middle school students. We designed the unit using Wiggins and McTighe's (2005) *Understanding by Design* framework that aligns instructional materials and assessments with the learning goals. The unit was designed to be implemented with all ability levels of culturally diverse urban eighth-grade students and it includes supports for curriculum adaptation and educative curricular materials; that is, materials designed to promote teacher learning in addition to student learning (Davis & Krajcik, 2005). The *Energy* curriculum incorporates Google Earth and GIS to foster student understandings of the world's energy resources and their impacts on the environment, energy use and misuse practices, and ways to sustain the future of our environment with alternative energy resources. The learning activities address common student misconceptions and knowledge deficits about energy concepts that have been discussed in the literature (for example, Arcury & Johnson, 1987; Barrow & Morrisey, 1989; Blum, 1987; Boyes & Stanisstreet, 1990; Farhar, 1996; Gambro & Switzky, 1999; Holden & Barrow, 1984; National Assessment of Educational Progress 1975; Rule 2005). Students build on concepts and skills with every geospatial technologies-supported activity as they progress through the unit.

The *Energy* curriculum was implemented in five eighth-grade classes at a culturally diverse urban school. We sought to answer the following questions:

1. Does an inquiry unit supported by geospatial technologies promote urban middle school students' understandings of energy concepts?
2. Are there any differences among ability level tracked middle school students?

Energy Curriculum

The Energy curriculum consists of a forty-day instructional sequence. In the initial learning activities, students are introduced to energy and concepts about electricity. They calculate their personal and household energy consumption to get a sense of how much energy they use and how much money it costs their families. Next, students complete a lab on solar energy, using solar cells to power different appliances. In the first geospatial technology-supported activity, students are presented with the driving question: *Where is the best place to locate a new solar power plant*? In this activity, students use Google Earth to view solar power plants around the world to examine ground cover and measure their perimeters. They then use *My World* GIS to analyze annual average sunshine data to determine optimal locations to build new very large solar power plants (see Figure 1).

--------------------- INSERT FIGURE 1 ABOUT HERE ----------------------

In the next set of activities, students learn about wind energy and then investigate, *Where is the best place to locate a new wind farm?* They use Google Earth to view wind farms around the world to examine land cover, topography, perimeter, and wind speed at each location. Students then examine wind speed and land use patterns in Pennsylvania to determine the optimal place to locate a new wind farm in their neighborhood. Students next learn about tidal energy and use Google Earth to determine relational patterns between tidal ranges and shapes of the water bodies. After that, students learn about hydroelectric energy and then use Google Earth to explore hydroelectric dams around the world. In the learning activties, they examine dam widths, height, capacity, surrounding area, shape and size of the reservoir on the upstream and the river on the downstream side of the dams, and the distance from each dam to nearby population centers. Students use *My World* GIS to query and investigate features of hydroelectric dams in the United States. The activity concludes with students using Google Earth to investigate specific features of five major energy-generating facilities on two major rivers in Pennsylvania. In the next activity, *Where is the best place to locate a geothermal power plant?,* students use

Google Earth to identify Earth features that are evident of geothermal activity. They then examine population centers in the northwest USA and areas where the Earth is hot to determine an optimal location to place a geothermal power plant (see Figure 2).

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Students learn about biomass/biofuels and conduct a lab that models how raw materials are refined to process liquid fuels. They then explore US energy production by geographical region and energy consumption by sector. Students next learn about fossil fuels (coal, petroleum, and natural gas) and then use *My World* GIS to investigate world-wide fossil fuel reserves, production, and consumption. Students recalculate their personal and household energy consumption and compare their new values with the initial values to assess whether there is any difference in their energy consumption habits over the course of the unit. Students then learn about energy conservation and complete an energy efficiency lab. Next, students learn the advantages and disadvantages of the various energy resources. In the culminating activity, students use *My World* GIS to explore energy resources of a fictitious island. Students are put in groups and assigned one of three provinces of a fictitious island. They analyze their province's energy resources; and determine the best location to place power plants while keeping in mind resource extraction and transportation requirements to move energy source materials to power plants, as well as developing grid infrastructure to deliver usable energy to consumers. They then develop an energy policy for their province that recommends the most efficient combination of energy sources that will have the least impact on the environment.

Student's instructional handouts are heavily scaffolded with step-by-step instructions of how to complete the learning task that include screen captures with arrows to alert learners to the location of the task on the GIS and Google Earth interfaces. We include procedural facilitators on the worksheets in the form of prompts, questions, and hints to guide the students' responses. Similarly, the teacher guides are scaffolded and also include helpful hints and implementation suggestions to help the teacher to adapt instruction to the needs of the students in the different ability level tracks. We also use thematic icons on the instructional materials to reinforce concepts. For example, in the hydroelectric energy activities, we use an icon of moving water to reinforce the fact that hydroelectric energy comes from the force of moving water.

Methodology

Research Design

This study employed design-based research methodology which combines a formative evaluation of a design and an analysis of the implementation process in actual learning settings (Reigeluth & Frick, 1999; Richey, Klein, & Nelson, 2004). Design-based research studies are guided by partnerships of different experts who bring diverse but relevant expertise to the effort (Bell, Hoadley, & Linn, 2004). Our design partnership included experts in science education, Earth and environmental science, environmental education, instructional design and development, Geographic Information Systems and eighth-grade science teachers. A primary goal of design-based research is to improve the initial design as informed by the formative evaluation (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). The evaluation of the design is an ongoing iterative process that changes as the design changes. We conducted a prototype implementation of the *Energy* unit to examine what worked well, what did not work well, and what revisions needed to be made to the curriculum unit. We revised the curriculum based on the findings from the prototype implementation after which we conducted this pilot implementation study.

Participants

The study was implemented in five eighth-grade classes in a culturally diverse urban middle school located in northeast United States. The middle school has an ethnically diverse population of approximately 630 students, most of who come from low-income households. About four-fifths of the students (80%) participate in the free and reduced lunch program. The school has a large migratory population, with 20% of the students transferring to the school during the academic year. Nineteen percent of the students are learning English as a second language (ESL). Student classes are tracked by mathematics ability level determined by their score on the state's standardized test. *Low track* students scored below grade level, *middle track* students scored at grade level, and most *upper track* students scored above grade level on the standardized test. The sample included one 8th-grade science teacher who had twelve years of classroom science teaching experience and 108 eighth-grade students with diverse ethnic backgrounds (54% Hispanic, 30% White, and 16% African American) from five of her classes. Ten students had Individual Education Programs (IEPs).

Instrumentation and Data Collection

Data were gathered through content knowledge pre/posttest assessments, daily classroom observations, daily reflective meetings with the teacher to discuss the day's lesson and share perspectives about what worked well, what did not work well, and what revisions needed to be made to the materials. The pre/posttest assessments were administered to the students at the beginning and at the end of the implementation of the energy curriculum. The content knowledge assessment consisted of 39 multiple-choice items with a maximum possible score of 39 points.

The items align to energy learning goals noted in national science education frameworks (AAAS, 1993; 2007) and assessed both content knowledge and spatial thinking. The items are grouped into three subscales (1) energy acquisition, (2) energy generation, storage, and transport, and (3) energy consumption and conservation.

The content and construct validity of the instrument were verified by the Earth and environmental scientists and science educators. To obtain reliability of the instrument, we administered the instrument to 1,043 students who had taken the district-adopted curriculum. The reliability (Cronbach alpha) for the instrument was .78. Subscale reliabilities were .60 for energy acquisition, .57 for energy generation, storage, and transport, and .48 for energy consumption and conservation. We administered the multiple-choice energy content knowledge assessment to all students on the first day of the unit and at the end of the implementation. We also calculated the reliability of the instrument with the 108 students after the implementation of the unit. Cronbach alphas for the entire instrument and subscales were .81 (entire assessment), .67 (energy acquisition), .56 (energy generation, storage, and transport), and .57 (energy consumption and conservation).

We held reflective meetings with the teacher daily to discuss what worked well, what did not work well and, thus, needed to be improved. The teacher shared her perspectives about the science instruction, instructional activities and materials, and student engagement. We conducted classroom observations everyday in all five classes to assess how the teacher implemented the curriculum across the classes and to evaluate student performances such as on task behavior, learner independence, and teamwork. We rated student performances on a scale ranging from 0 to 5 as follows,

0 = performance not done by students/teams in the class.

1 = performance done by less than 25% of students/teams in the class.

2 = performance done by between 25% and 50% of students/teams in the class.

3 = performance done by about 50% of students/teams in the class.

4 = performance done by between 50% and 75% of students/teams in the class.

5= performance done by more than 75% of students/teams in the class.

Findings

A paired sample *t*-test was conducted to compare pre- and posttest scores on the content knowledge assessment. Data analysis was done for only those students who had completed both tests. Table 1 displays the results for the paired *t*-test for all students overall and for each of the three ability levels. The results revealed that there was a statistically significant difference between the pretest and posttest scores. Students' mean score was higher on the posttest than on the pretest. Analysis of student achievement by ability level revealed that there were statistically significant differences between the pre- and posttest scores for all three ability levels as evidenced by the effect sizes. Effect size is a standardized metric for evaluating the strength of student gains in the populations across the student ability groups (Henson & Smith, 2000). It indicates the average gain on the posttest measured in pretest standard deviation units. According to Cohen (1988), an effect size of 0.2 is small, 0.5 is medium, and 0.8 is large.

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Table 2 presents the achievement by content subscales for all students and for each ability level. The effect sizes for all three content subscales were statistically significant for all students overall and for all three ability levels. Eleven out of twelve effect sizes were large and one subscale for the *upper* track class had an effect size of slightly above medium. These results show that students gained substantial energy content knowledge.

--------------------- INSERT TABLE 2 ABOUT HERE ---------------------

We conducted a one-way repeated measures analysis of variance (ANOVA) to examine if the scores for the three ability level tracks differed significantly from each other. The results indicated that there were statistically significant differences for the entire assessment ($F_{(1,102)}$ = 198.15, $p < .001$); energy acquisition ($F_{(1,102)}$ = 103.42, $p < .001$); energy generation, storage, and transport ($F_{(1,102)}$ = 96.48, $p < .001$); and energy consumption and conservation ($F_{(1,102)}$ = 89.74, $p < .001$). Item analysis revealed that students enhanced their knowledge about nonrenewable and sustainable energy sources, energy efficiency, personal and societal energy consumption, and energy resource transformation processes. Furthermore, a subset of assessment items on spatial thinking revealed growth in spatial thinking and analysis skills with regards to energy.

The classroom observations indicated that the teacher implemented the curriculum unit differently across the five classes. Even though the instructional materials had sufficient scaffolding and instructional support such that learners could work independently without much teacher intervention, the teacher provided more scaffolding such as modeling tasks and providing worked examples in the *low* track classes compared to the other classes. She also had *upper* track students complete more worksheet questions and do extension lab activities. Analysis of the student performances data overall revealed that one *low* track class had 74% of the students on task while the other four classes had more than 75% of students on task. More than 75% of the teams in four classes shared and discussed activities whereas 70% of teams in one *low* track class shared and discussed activities. The *upper* and *middle* track classes had more than 75% of the students working independently without much teacher intervention. The two *low* track classes had 60% and 68% of the students working independently.

Discussion

This study found that the use of geospatial technologies promoted students' understandings of energy concepts. The statistically significant increase in the posttest means suggests that students in all three ability level tracks gained energy content knowledge. In all but one subscale (energy acquisition), the effect sizes for both *middle* and *low* track students were higher than those for *upper* track students. This could be attributed to the way the teacher implemented the curriculum differently by providing less scaffolding in the *upper* track class. Alternatively, the *upper* track students might have had substantial prior knowledge of energy causing their learning gains to be slightly less than those of the other classes.

The sufficient scaffolding in the instructional materials helped most learners to work independently and not to waste time waiting for teacher intervention, thus, staying highly engaged. Helpful scaffolds and modeling included prompts to focus learners on specific spatial aspects of visual data displays, using screenshots of the interfaces to assist learners with procedures, and step-by-step instructions for manipulating the geospatial tools to assist with pattern finding and data analysis. After a long period of not using the GIS, learners at all ability levels tended to forget how to use it and experienced some difficulty and frustration because they had to relearn how to use the GIS.

The educative curriculum materials helped the teacher model and scaffold learning activities and promoted the teacher's spatial thinking skills. The materials included content knowledge to increase the teacher's knowledge as well as helpful hints, implementation suggestions, and recommendations to help the teacher adapt and/or modify instruction. We placed the hints, suggestions, and recommendations in the teacher guides and in the instructional sequence on the curriculum unit's Web site to ensure that the teacher saw them.

Conclusions

This study describes the usefulness of integrating geospatial technologies to help diverse urban middle school learners learn science with inquiry-based learning activities. The findings from this study provide evidence that geospatial technologies can foster inquiry, promote student learning of content, and increase student science achievement. The effectiveness and practical issues involved with using geospatial technologies in middle school science classrooms might inform curriculum developers and researchers who are interested in integrating geospatial learning tools into science curriculum.

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Table 1

Overall achievement and achievement by ability level track for pre/posttests

Track	Pretest Mean (SD)	Posttest Mean (SD)	Gain (SD)	*t*-Value[a]	Effect Size
All (N=105)	14.01 (5.54)	21.69 (6.33)	7.68 (5.44)	14.47**	1.39
Upper (n=31)	17.97 (5.41)	23.68 (5.90)	5.71 (4.79)	6.64**	1.05
Middle (n=46)	12.76 (4.97)	21.98 (5.41)	9.22 (4.94)	12.67**	1.86
Low (n=28)	11.68 (4.25)	19.00 (7.38)	7.32 (6.25)	6.19**	1.72

Note. [a]Two-tailed paired *t*-test.
**$p < .001$.

Table 2

Overall achievement by content subscale and ability level track

Subscale	Track	Pretest Mean (SD)	Posttest Mean (SD)	*t*-Value[a]	Effect Size
Energy Acquisition (13 items)	All (N=105)	5.21 (2.37)	8.06 (2.67)	10.67**	1.20
	Upper (n=31)	6.45 (2.50)	8.77 (2.55)	4.47**	0.93
	Middle (n=46)	4.33 (2.01)	8.11 (2.55)	10.01**	1.88
	Low (n=28)	5.29 (2.21)	7.18 (2.83)	4.16**	0.86
Energy Generation, Storage, and Transport (13 items)	All (N=105)	4.76 (2.28)	7.21 (2.37)	10.00**	1.07
	Upper (n=31)	6.19 (2.12)	8.42 (2.20)	6.21**	1.05
	Middle (n=46)	4.54 (1.97)	6.91 (2.03)	6.98**	1.20
	Low (n=28)	3.54 (2.03)	6.36 (2.61)	4.56**	1.39
Energy Consumption and Conservation (13 items)	All (N=105)	4.04 (2.11)	6.42 (2.45)	9.68**	1.13
	Upper (n=31)	5.32 (1.83)	6.48 (2.42)	2.73*	0.63
	Middle (n=46)	3.89 (2.19)	6.96 (2.02)	9.52**	1.40
	Low (n=28)	2.86 (1.43)	5.46 (2.90)	4.96**	1.82

Note. [a]Two-tailed paired *t*-test.
*$p = .01$. **$p < .001$.

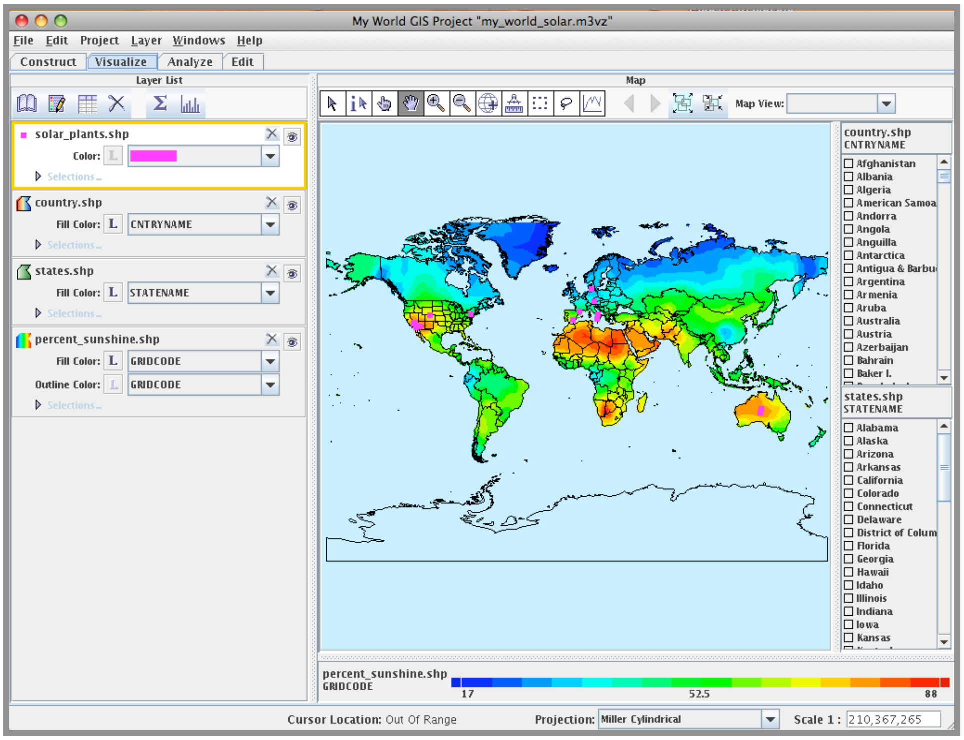

Figure 1. My World GIS interface displaying global annual average sunshine data and locations of 14 solar power plants.

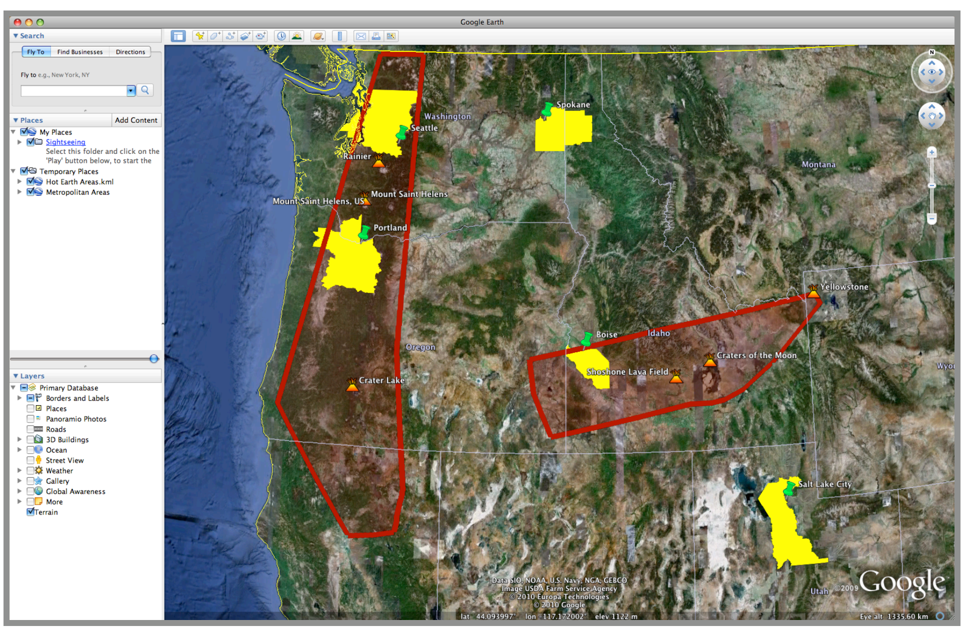

Figure 2. Google Earth interface displaying five metropolitan areas in the northwest US and overlays of areas where the Earth is hot. (Image extracted from Google Earth. © 2010 Google)