Examining the Implementation of a Geospatial Information Technologies-supported Energy Unit in an Urban Middle School

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Abstract

This paper describes the implementation of an interdisciplinary *Energy* unit developed for diverse middle school students. The *Energy* unit takes advantage of geospatial information technologies (GIT) including Google Earth and GIS to support student understanding of the world's energy resources while promoting spatial thinking skills. The *Energy* unit focuses on 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 sources. The learning activities address common student misconceptions and knowledge deficits about energy concepts. The study was implemented in five eighth-grade classes in a culturally diverse urban middle school. Data were collected through daily classroom observations, daily reflective meetings with the teacher in addition to weekly curriculum design team meetings, and student artifacts. Findings revealed that implementing GIT in an 8th grade science *Energy* unit helped students construct relevant science knowledge and develop spatial analysis skills. Students were highly engaged with the learning activities and analyzing data using GIT helped students apply energy content knowledge to real-life applications.

Recent education reform initiatives emphasize the significance of developing thinking skills, data analysis skills, understanding real-world applications, and utilizing the power of technology in teaching and learning (ISTE, 2000; NRC, 1996, 2000; NAAEE, 2004). Newer interactive technologies that may hold promise in supporting science inquiry in the classroom are geospatial technologies. Geospatial information technologies (GIT) including geographic information systems (GIS), global positioning systems (GPS), virtual globe tools (such as Google Earth, WorldWind, Arc GIS Explorer, etc.), and Web-based 2D and 3D visualizations of Earth, landforms, and/or other geographic data allow for visualizing, mapping, and analyzing multiple layers of geographically referenced information. Bednarz, Acheson, and Bednarz (2006) contended that the ability to use images and spatial technologies intelligently and critically is becoming a requirement to participate effectively as a citizen in modern society. In fact, K-12 educators are harnessing the power of geospatial technologies to support standards-based science, social studies, and mathematics curricula (Bodzin, 2008; Holzberg, 2006).

Many writers praise the potential for GIT to enhance student learning. GIT can assist with inquiry-based investigations and promote spatial thinking (Bodzin, Anastasio, & Kulo, in press; Bodzin & Cirucci, 2009; Schultz, Kerski, & Patterson; 2008; Stahley, 2006). Alibrandi (2002) contended that one of the most important benefits of including a GIS among a school's instructional technologies is that it can provide opportunities for students to conduct research leading to viable, sustainable communities. Students can use a GIS to solve real-life problems and to draw on skills crucial to developing higher-order thinking and problem solving (Bodzin & Anastasio, 2006; Kerski, 2008; Ramirez, 1995; Sanders, Kajs, & Crawford, 2002). GIT create a learning environment in which students can visually explore, analyze, and make decisions about problems in an interactive and challenging manner (Audet & Ludwig, 2000) providing authentic, inquiry-based learning within the K-12 classroom environments (Bednarz & Audet, 1999).

Despite the promising nature of geospatial technologies to support inquiry-based learning environments, there are a number of barriers to implementing them in the K-12 classrooms. These include technical issues pertaining to the interface design of software, time for classroom teachers to learn to use the software and teach it to students, lack of existing basal curriculum materials that integrate geospatial technologies, lack of time to develop learning experiences that integrate easily into existing school curricula, and lack of content pedagogical knowledge conducive to GIT (Baker & Bednarz, 2003; Baker & Case, 2000; Bednarz, 2003; Keiper, 1998; Kerski, 2003; Meyer, Butterick, Olin, & Zack, 1999; Patterson, Reeve, & Page, 2003; Sanders *et al.*, 2002; Shin, 2006).

To help alleviate those barriers, our Environmental Literacy and Inquiry (ELI) group developed an eight-week interdisciplinary science inquiry *Energy* unit for diverse middle school students. The *Energy* unit was developed to align instructional materials and assessments with learning goals (Wiggins & McTighe, 2005) and was designed to be used with all ability levels of urban 8th grade students. The unit includes supports for curricular adaptation and educative curricular materials; that is, materials designed to promote teacher learning in addition to student learning (Davis & Krajcik, 2005). The *Energy* unit takes advantage of GIT including Google Earth and GIS to promote 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 sources. The learning activities address common student misconceptions and knowledge deficits about energy concepts. Students build on concepts and skills with every GIT-supported activity as they progress through the unit.

Design Principles

Design principles speak to the pragmatic aspects of practice while also informing theories of learning (Bell, Hoadley, & Linn, 2004). Like other design principles used in education (Kali,

2006), our principles are designed to focus not only on local classroom implementation, but also for more generalized classroom learning environments. These design principles are a product of a series of design-based research studies conducted in diverse educational settings over the past six years whose primary aim has been to promote innovation in earth and environmental science learning. It is our intent that the ideas presented in this section will serve as recommendations to curriculum developers who intend to use Geospatial Information Technologies in their design and development work.

1. Design curriculum materials to align with the demand of classroom contexts. Schools across the USA have made significant investments in technology such as high-bandwidth wireless networks and widely available laptop computers in classroom instructional settings. We acknowledge that one instructional model or distinct set of learning activities may not accommodate every learner, classroom teacher's pedagogical style, or classroom learning environment. Activity structures from available curricula, whether designed by commercial publishers or from educator-developers vary significantly. We recognize that developers of such activities have an intended target audience and that audience may not have the same prerequisite skills or content background of other classroom learners. In addition, such curricula may not take into consideration teacher time constraints on curriculum implementation and mandated academic year content coverage. We develop our learning activities in ways that teachers may customize the instructional sequence and still meet the learning goals of the units. We incorporate design features in instructional materials so that low-level readers and low-ability students can understand scientific concepts and processes in addition to learners whose cognitive abilities are at or above the intended grade level. For example, we provide animations and images on many content Web pages to help learners visualize scientific concepts that occur over

time such as the formation of fossil fuels. In addition, we design activities to promote active

learning with GIT to promote high learner engagement with this learning tool.

2. Design activities to incorporate two main properties: scalability and portability. Scalability

refers to the need for the investigative experiences addressed by the learner to be small enough

that they can derive conclusions in a reasonable length of time, but also be of sufficient detail

that by completing them, the students will make connections to larger and more complex

environmental problems. Portability means the problems addressed in the activities should

involve concepts and practices that are applicable to diverse locations and situations, allowing

learners to extrapolate their derived understandings to problems other than those to which they

were exposed (Bodzin & Anastasio, 2006). We structure learning experiences in ways that allow

students to see connections from local to global, and between the specific cases and generalized

settings in order to maximize educational value (Bednarz, 2004).

3. Use motivating contexts to engage learners. It is important to provide middle school learners

with a motivating entry point to set the stage for their investigations. Using a locally relevant

problem or real-life occurrence that a student can easily experience is important to engage

students in learning (Bodzin & Shive, 2004).

4. Provide personally relevant and meaningful examples. To make earth and environmental

science learning accessible, we seek out and include examples that are personally relevant to

students. By including issues pertaining to students' everyday experiences, we make science

learning meaningful and relevant. In our implementation studies, we have found that students

become more motivated to understand environmental issues when they recognize that the issues

involved are directly connected to their daily lives. For example, the use of Google Earth to

analyze nearby area locations for placing renewable energy power plants provides learners with a

meaningful context for considering the environmental impacts of these new facilities.

5. Promote spatial thinking skills with easy to use geospatial learning technologies.

 Instructional activities should include easy to use tools to support spatial thinking and reasoning activities. We identify readily available remotely sensed aerial and satellite images from Google Earth as tools to be used to support such learning. We compose screen placemark images at specific sizes and scales to help learners understand the scale and spatial distribution of Earth features and guide learner attention by automatically delivering sequential image examples that reinforce the educational concepts. For example, in a MyWorld GIS investigation of hydroelectric power dams, we start nationally then zoom to Pennsylvania, and finally the Susquehanna River. Then we sequence a Google Earth exploration of energy generating hydro and nuclear power plants on the same river, bringing the students to their home region and recognizable geography. Our materials instruct students and teachers to display certain layers, such as the *Terrain* layer to emphasize natural geographic features such as mountain ranges and canyons. In addition, we develop files using Google Earth tools such as polygons and image overlays to assist students with understanding the spatial relationship among different features. For example, we created colored polygons to enable learners to see greater metropolitan areas in the northwest USA.

6. Design image representations that illustrate visual aspects of scientific knowledge. Earth scientists have years of training and experience with recognizing salient information in visual material. For example, a geologist is more likely to identify prominent information in a satellite image of a volcanic mountain area than a non-scientist. Yet, visualizations can distract learners rather than encourage understanding. We use Google Earth to take advantage of a scientist's craft by designing Google Earth images that clearly display aspects of scientific understanding. For example, when one uses the Google Earth search feature to observe Mt. Fuji, the resulting image display does not prominently illustrate key features that identify Mt. Fuji as a volcanic

mountain (Figure 1, left image). When we design our placemark images, we take advantage of the ability to resize, rotate, and adjust the angle of the image to provide learners with an initial image display that highlights prominent physical features. This helps novice learners to better understand the connection between Earth and environmental processes and the landscape. For example, we created the right image on Figure 1 to enhance the prominence of the features that allow a trained eye to conclude the image is of a volcano. The salient observations include that this is a cone shaped mountain rising above a surrounding plain. The radiating gullies confirm the cone shape. The snow line on the flanks support the conclusion that the feature has a high altitude and the numerous switchbacks in the flanking roads suggest the feature is steep. The tilted image better shows the crater depression on the crest. When taken together the crater-topped, steep, high, conical mountain is correctly interpreted to be a volcano, a characteristic of empirical science inquiry.

Figure 1. The left image shows Mt. Fuji as displayed with the Google Earth search feature. The right image is created to display prominent volcanic features by tilting the viewer's perspective.

7. Develop curriculum materials to better accommodate the learning needs of diverse students.

Today's classrooms are quite diverse with learners of varied cognitive abilities, language skills, and special learning needs. We incorporate design features in our instructional materials to accommodate varied learning needs. We reduce the complexity of examples and visualizations

by eliminating details that may distract learners from understanding the main concepts. In our

instructional materials, we keep language simple and use graphical features in the instructional

materials to help learners understand content as well as procedures for using geospatial learning

tools. For example, Figure 2 shows how large numbered red arrows are added to a screen capture

of the *layers* window of Google Earth to help students understand image display procedures.

Bold and italicized text fonts are used to draw learners' attention to key words in the procedure.

Step 2: Turn on the Populated Places and Terrain layers.

a.   In the ***Layers*** window (lower left panel), click the arrow to the left of ***Borders and Labels*** (see arrow #1 below).

b.   Click the box to the left of ***Populated Places*** to **place a checkmark** in the box. (see arrow #2 below).

c.   Click the box to the left of ***Terrain*** to **place a checkmark** in the box (see arrow #3 below).

Figure 2. Google Earth procedure from the *Exploring Hydroelectric Dams with Google Earth* activity

that provides graphical features and specialized text font.

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8. Scaffold students to explain their ideas.

Many students have problems being successful with open-ended investigations and complex

activities where data are analyzed and evidence is carefully considered to formulate conclusions.

We design materials with embedded prompts in the learning activities to help students focus their observations. Such prompts help learners articulate their thoughts, and think critically about observed phenomena. Table 1 includes some examples of prompts used in the *Exploring Hydroelectric Dams with Google Earth* activity designed to help learners examine and think about features of hydroelectric power dams. The prompts in Table 1 are designed to help students focus on key features of dams and the area surrounding them such as reservoir shape and size and proximity to populated areas.

Table 1.

Select prompts used in the *Exploring Hydroelectric Dams with Google Earth* activity.

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- Do all dams have the same **shape**? Do all dams have the same **length**? Do all the dams have the same **height?** What do they look like?

- Is the **area surrounding** each dam similar or different? What does the area around each dam look like?

- Why do you think dams are built on rivers?

- What are the **advantages** of building a dam near a **large population area**?

- Which dams were built **furthest away** from large population areas? Why do you think these dams were built in these locations?

- What does the river look like on each side of the dam? How are the **shape** and **size** of the reservoir different from the shape and size of the river on the downstream side of the dam? Is the water area larger and wider on one side of the dam? By looking at which side of the dam has a larger body of water, can you tell which way the river flows? Remember the reservoir is located on the upstream side of the dam. Water flows downstream.

- What are some **advantages** of having one side of the dam contain a **much larger volume of water** than the other side?

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9. Use icons that portray the real-world concept. Google Earth provides different icons that can be used as placemarks, and it also allows for using custom icons. Instead of using the default

pushpin, we use icons (images) that depict the concepts being learned. This might help the learners to form an association between the icon and the concept it represents which may enhance recall. In Figure 3, for example, we used the sun icon to put placemarks at locations of solar power plants and the water icon to put placemarks at locations of hydroelectric dams. This may help learners recall that solar energy comes from the sun and hydroelectricity comes from the force of moving water. According to Paivio (1971), images act as mediators in learning and memory tasks, and can be amazingly effective as memory aids.
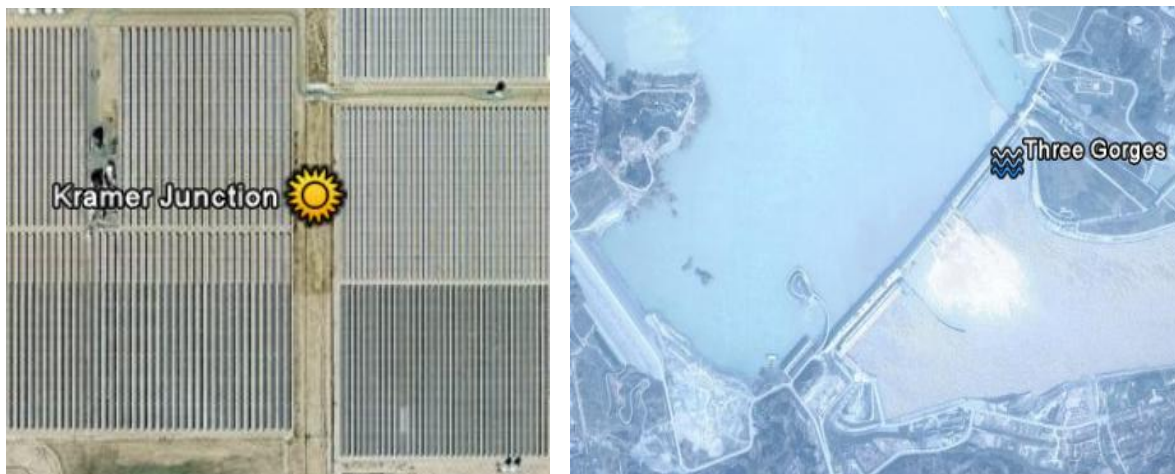
Figure 3. The sun icon was used as a placemark at the Kramer Junction solar power plant in the left image. The water icon was used as a placemark at the Three Gorges hydroelectric dam in the right image. Images from Google Earth.

Description of Activities

In the first activity, students are presented with the driving question: *Where is the best place to locate a new solar power plant*? Students use Google Earth to view different solar power plants around the world to examine the ground cover around them. They then measure the perimeters of the solar power plants in miles. Next, students use My World GIS to analyze worldwide annual average sunshine data to determine optimal locations to build new very large solar power plants. The next driving question is: *Where is the best place to locate a new wind*

farm? Students use Google Earth to view wind farms around the world to examine land cover, topography, and wind speed at each location. They also measure the perimeter of the wind farms in miles. Students then use My World GIS to examine wind speed and land use patterns in Pennsylvania to determine the best place to locate new wind farms in Pennsylvania and the Lehigh Valley.

In the next activity, students use Google Earth to view locations with high and low tidal ranges and compare the shapes of the water bodies at those locations. For hydroelectric energy, students use Google Earth to view hydroelectric dams around the world to examine their widths, capacity, surrounding area, shape and size of the river on the upstream and downstream sides of the dams, and the distance from each dam to nearby population centers. Students then use My World GIS to analyze and examine 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 Rivers in Pennsylvania. Another driving question is: *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.

Students next use My World GIS to investigate which countries have fossil fuel reserves, fossil fuels production and consumption for different countries, and their relation to the population of those countries. In the culminating activity, students use My World GIS to explore energy resources of a fictitious island, the Isle of Navitas. They then develop an energy policy for the island that recommends the most efficient combination of energy resources that maximizes the use of sustainable energy resources and minimizes the impact on the environment, keeping in mind the infrastructure for production and distribution requirements.

Purpose of the Study

The prototype *Energy* unit was implemented in an urban middle school in a culturally diverse NASA Explorer School. This curriculum implementation study sought to answer the following questions:

1. How can the use of GIT promote urban middle school students' understandings of energy concepts?

2. How did students and their teacher perceive the implementation of GIT in an inquiry-based science curriculum?

Methodology

Research Design

This study employed design-based research methodology. According to Richey, Klein, and Nelson (2004), design-based research methodology combines a formative evaluation of a design and an analysis of the implementation process in naturalistic learning settings (see also Reigeluth & Frick, 1999). Design-based research studies are guided by partnerships (Bell et al., 2004). Partnerships are interdisciplinary teams that include teachers, technologists, education researchers, and disciplinary experts who bring diverse but relevant expertise to the effort. Our design partnership includes science educators, scientists, instructional designers, and classroom teachers.

Population and Sample

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. The sample included one 8th-grade science teacher and 110 8th-grade students with diverse ethnic backgrounds (67% Hispanic, 19% White, 13% Black, 1% Asian), and included 11 students with

Individual Education Programs (IEPs). The school contains 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). Based on the state's 2009 standardized tests, the eighth-grade students had 59% reading proficiency and 22% science proficiency.

Procedure

The prototype unit implementation lasted 34 days. Data were collected through daily classroom observations, daily reflective meetings with the teacher in addition to weekly curriculum design team meetings, and student artifacts. The classroom observations included records of daily activities, teacher-student interactions, students-student interactions and comments, and how students interacted with the instructional materials. During the implementation, daily debriefing sessions with the teacher were conducted and lasted between 20 and 30 minutes. In addition, the design team held weekly meetings that lasted between one and a half and two hours each. The purpose of those meetings was to discuss what worked well, what did not work well, and what revisions needed to be made to the materials.

The student artifacts included an energy concept map, journal entries, and written responses embedded in the instructional materials. A basic energy concept map was provided to students at the beginning of the unit. The concept map included four prompts: *definition of energy, forms of energy, uses of energy,* and *sources of energy* (with the sun, moon, and Earth as the ultimate sources). Students brainstormed individually and added to the concept map what they knew about energy. Those initial concepts maps were submitted to the teacher electronically. In the course of the unit, students updated their concept maps periodically with what they had learned. At the end of the unit, students finalized their concept maps and submitted them to the teacher. The journal entries included answers to questions presented in the

anticipatory set, predictions of experiments, and what the students liked or disliked about using Google Earth and My World GIS to complete the instructional activities.

<center>Findings</center>

Student Artifacts

We developed an expert concept map to use as a rubric for assessing students' final concept maps. First, we compared the students' initial and final concept maps. Analysis of the initial concept maps revealed that students had little prior understanding of where the different sources of energy originate. For example, most students did not have anything listed under the moon as a source of energy; most students placed fossil fuels under the Earth as a source of energy. Analysis of the final concept maps showed that students correctly labeled the energy sources they had wrong, for example, they put tidal energy under the moon and geothermal energy under the Earth. Students had also updated their concept maps to include additional relationships among different constructs.

Students had both positive and negative reactions with regard to using Google Earth and My World GIS to promote spatial learning. Analysis of student journals revealed using Google Earth and My World GIS helped most students develop spatial skills. Some comments obtained from the students' journal include, "*I liked how we can find the places where solar power is made*," wrote one student about the exploring solar power plants with Google Earth activity; "*I liked being able to see the different designs and positions of the panels*," wrote another student. A third student wrote "*You could see a lot about the US. For example you could check how much sunlight hit one spot.*" A few students did not like, however, the learning tasks that had to be done beyond touring the power plants. For example, after students explored the solar power plants, they used the Google Earth ruler tool to measure the perimeter of the different solar power plants. One student wrote, *"What I disliked is we had to find perimeter."*

Comments regarding using My World GIS to do learning activities included, *"I really like My World a lot because you learn a lot of things,"* another student wrote, *"I thought it was cool, it gave a lot of information."* Another comment was *"I think My World is good to find data about different countries."* Despite the positive comments about using GIT tools, students also experienced some frustration. One student's comment about My World GIS was, *"It was very slow, it was also complicated to understand."*

Classroom Observations

The students and the teacher's general perceptions of using Google Earth and My World GIS were positive. Students were highly engaged and curious about the functionalities of those applications. On the first day of using the GIS, they went far beyond what they were required to do in the task. The task only had students learning about the basic map tools such as the *zoom in tool, zoom out tool, move map tool* then use the *get information tool* to get the names of two countries. The students went far beyond this task and continued following the instructions on their handouts to finish the rest of the task, which had students finding the insolation data at different solar power plant locations as well as their latitudes and longitudes. One student said aloud *"this is easy."*

The teacher asked aloud in class what the students liked or disliked about the first Google Earth activity. Some student responses included, *"I learned a new thing the ruler and how to use it,"* another student said, *"I liked solar panels and different places on Earth,"* *"I could see solar panels,"* said a third student. One student said the solar panels *"didn't have 3D version."*

Students lost motivation when completing many consecutive GIS learning activities. For instance, completing the fossil fuels activities took at least six days. The nature of the individual activities (coal, oil, and natural gas) had a similar format in which students first examined the countries that had say coal reserves, then second they examined the top five countries that

produced the highest amount of coal in both 1980 and 2004, third they examined the top five

countries that consumed coal in both 1980 and 2004. Lastly, they examined the population and

population change of countries in both 1980 and 2004. Students then answered analysis

questions that had them examine if there was any pattern between coal consumption and

population of countries. Since the coal, oil, and natural gas activities had that same format and

they were done consecutively, students' motivation was low by the time they reached to the

natural gas activity.

   Although most learner-centered instructional handouts were developed that students

could easily follow, the teacher modified the first activity that involved learning how to use the

analyze mode of My World GIS to be predominantly teacher-directed. This activity involved

querying layers to create new layers, creating histograms, and sorting the data table. The

handouts had step-by-step instructions with screen shots of how to do each step but most learners

experienced some difficulty using the *analyze mode* of My World GIS. The teacher then did a

whole-group instruction in which she was doing the task on the LCD projector and the students

followed along on their computers.

   Much student-student interactions occurred during the GIT-supported activities. Students

helped each other out when their peers experienced difficulties or did not understand how to do a

learning task and did not wait on the teacher while she was guiding other students. The GIT

activities highly engaged the students and held their interest. Students were highly motivated and

wanted to find out on their own what else could be done using the GIT tools. Although the tasks

were to be completed individually, some worked with their friends and taught others what they

had learned.

Design and Reflective Meetings

Most GIT-supported activities took students longer to complete than intended. Students took twice as long to finish most tasks especially the My World GIS activities.

The initial instructional handouts included many step-by-step procedural instructions and were quite "text-heavy" for our student population to use.

Students in the five classes were sharing one class-set of laptops. Multiple downloads of the same files and leaving them on the desktops tended to slow down the computers. Also, having multiple Google Earth files in the 3D viewer, either the same file or different files was confusing to the students in terms of the display they were supposed to see.

Some students changed the default appearance of the GIS layers that caused their maps to look different than what appeared on their handouts. Some GIS activities spanned two days and involved students querying the layers to create new layers. If the class ended in the middle of a querying activity, students had to start the query all over again in the following class. This frustrated some students.

Discussion

It is likely that students took longer than expected to complete the GIT tasks because they were using My World GIS for the first time. Those students had used a different GIS application, *ArcExplorer Java Edition for Education* (AEJEE), when they were in seventh grade. This application is not, however, as robust as My World GIS. Therefore, we streamlined the GIT learning activities so that students could complete them in adequate time. We shortened the length of the tasks and reduced the number of analysis questions. Given that our student population had a 59% reading proficiency and 20% were learning English as a second language, we reduced the amount of text on the handouts and provided more scaffolding. The scaffolds included screen shots with arrows and prompts. We included a screen shot of every instruction

on the handout adjacent to the instruction and an arrow to show exactly how the task was to be done. We included prompts to help the students answer the questions, for example in describing the topography and land cover at wind farms, we included prompts such as *flat, hilly, open, forested*, etc. We also put a lot of white space on the handouts to increase readability.

To lessen student frustration with the technology in terms of slow computers, we had students get rid of files on their desktops when they finished activities. With regard to frustration that had to do with the GIT activities, students were instructed not to change anything on the layers list because that would change the appearance of the map and they would not be able to complete the task based on the different map display. In the cases where students created layers and needed to continue using the new layer the next day, we had students save their files and then continue from where they left off.

Conclusion

Implementing GIT in an 8th grade science *Energy* unit helped students construct relevant science knowledge and develop spatial analysis skills. Students were highly engaged with the learning activities and analyzing data using GIT helped students apply energy content knowledge to real-life applications. The teacher found the teacher resources and content support materials very useful. The materials helped the teacher model and scaffold learning activities, and promoted the teacher's spatial thinking skills.

Much scaffolding within the instructional materials in addition to classroom modeling by the teacher was needed to assist students with completing the learning activities. Helpful scaffolds and modeling included prompts to focus learners on specific spatial aspects of visual data displays, using screenshots of the GIT interfaces to assist learners with procedures, and step-by-step instructions for manipulating GIT tools to assist with pattern finding and data analysis.

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