Teaching and Learning About Energy Resources with Web GIS

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Abstract:
Effective teaching and learning of energy resource issues involving spatially referenced data with GIS requires teacher pedagogical content knowledge. Toward that end, we have developed a 40-day energy curriculum (http://www.ei.lehigh.edu/eli/energy) for middle school students that include seven Web GIS investigations. To address the need to support science teachers' development of pedagogical content knowledge necessary to promote geospatial thinking and reasoning skills, the curriculum includes materials to promote effective teaching with Web GIS. We present our instructional design model for teaching science with Web GIS and our pedagogical support materials.

Energy resources are a major staple of our society and understanding the nature and role of these resources in our daily lives is a fundamental component of scientific literacy. Energy is needed to create goods from natural resources and it provides us with many services such as electricity and fuel for transportation that we take for granted in our daily lives. The intense need for energy resources pervades all sectors of our society including industrial manufacturing, transportation, commercial, and residential. The availability of an adequate and reliable supply of energy is important for economic development and improved standards of living. Our food, housing, transportation, communications, recreation, and technologies that we use to make our lives more productive all rely on energy resources. Understanding fundamental knowledge about energy resources including their limitations, as well as the environmental issues of their use, are important for citizens to make informed decisions to effectively confront the energy issues that face the environment (U.S. Department of Energy, 2012).

Understanding energy resource issues involve spatial analysis and reasoning skills. For example, many countries are currently determining their future energy policies to supply electricity to their citizens and industries. To make an informed decision about the type of energy resources a country may wish to select as source material for a new electrical power generating plant involves examining the spatial relationship among many variables. These include analyzing the locations of energy resource materials and proposed new power plant locations, the existing infrastructure available to transport an energy resource to a power plant, the availability of electrical grid infrastructure to distribute electricity from the power plant to consumers in an efficient way, and analyzing environmental characteristics of an area to consider the impact a new power plant may have on the existing environment. Geospatial technologies (GT) such as

Google Earth and Geographic Information Systems (GIS) can be used to support related spatial analysis problems in energy curriculum learning activities. GT, as a curriculum learning technology, can be used to enhance inquiry-based environmental investigations, promote spatial thinking, and draw on skills crucial to developing higher-order thinking and environmental problem solving (Bodzin, 2008; 2011; Bodzin & Anastasio, 2006).

The adoption of an energy resources curriculum that integrates GT with investigative learning activities to promote energy literacy goals is timely and leverages current national and global attention on energy resources and related environmental issues such as the contribution of energy consumption to climate change. However, the adoption of such a curriculum is a significant departure from traditional classroom science instruction that typically occurs in the "business as usual" manner in which teachers use an adopted science textbook curriculum program to guide curriculum and instructional decision-making. Studies of middle school science textbook programs (Kesidou & Roseman, 2002; Stern & Roseman, 2004) found that most dealt with an extremely broad range of topics, did not align curriculum with learning goals based on a set of core scientific ideas, and did not provide materials to engage students with relevant phenomena or support students' content understandings and reasoning skills.

In response to these issues, we developed a new GT-integrated middle school science energy resources curriculum unit that aligned to the energy resources learning goals identified in national and Pennsylvania state standards (Kulo & Bodzin, 2011). The unit represents a considerable departure from typical "business as usual" approaches to energy resources instruction since it employs the use of reform-based practices that use GT 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. In this paper, we describe our curriculum approach for teaching energy resources to middle school students and provide examples of embedded support materials that are educative for teachers.

The Energy Resources Curriculum Geospatial Learning Design Model

The energy resources curriculum employs a geospatial learning curriculum design model that builds on the work of other successful technology-integrated curriculum projects (Bodzin, 2011; Edelson, 2001; Krajcik, McNeill, & Reiser, 2008; Linn, Davis, & Bell, 2004). The curriculum design model incorporates a curriculum framework, design principles, and an instructional model that provide guidance to the development of the GT-integrated instructional materials. The curriculum framework includes:

1. Align materials and assessments with learning goals.
2. Contextualize the learning of key ideas in real-world problems.
3. Engage students in scientific practices that foster the use of key ideas.
4. Use geospatial technology as a tool for learners to explore and investigate problems.
5. Support teachers in adopting and implementing GIT and inquiry-based activities.

Like other research-based science curriculum projects (Edelson, 2001; Kali, 2006; Lee et al*.*, 2010; Linn, Davis, & Bell, 2004) we use a series of design principles (Bell, Hoadley, & Linn, 2004) to promote geospatial thinking skills with the curriculum materials:

1. Design curriculum materials to align with the demand of classroom contexts.
2. Design activities to apply to diverse contexts.
3. Use motivating contexts to engage learners.

4. Provide personally relevant and meaningful examples.
5. Promote spatial thinking skills with easy-to-use geospatial learning technologies.
6. Design image representations that illustrate visual aspects of scientific knowledge.
7. Develop curriculum materials to better accommodate the learning needs of diverse students.
8. Scaffold students to explain their ideas.

See Bodzin, Anastasio, and Kulo (in press) for a more detailed explanation of each design principle.

We employ an instructional model that includes eight key elements to guide the development of each GT-integrated learning activity in the curriculum. The instructional model incorporates a sequence of instructional events that are based on current learning theories that are applied to the design task of promoting teaching and learning of science with GT. The model includes the following key elements:

1. *Elicit prior understandings of lesson concepts*. This element incorporates the first stage Eisenkraft's (2003) "7E" instructional model to strengthen scientific inquiry, *elicit prior understandings*, and a feature of Dick and Carey's (1996) systems approach model, *identifying and analyzing entry behaviors and learner characteristics*. In this stage, the teacher determines what knowledge and skills students bring to the learning task. In the curriculum, this is accomplished by asking learners to respond to questions about the key lesson concepts and through analysis of student-created concept maps.

2. *Present authentic learning task*. An authentic task is presented that learners will complete. This element reflects a feature of Jonassen's (1997) task analysis framework to select an appropriate task for learners to do. The learning tasks are situated in authentic settings, thereby providing useful and meaningful contexts to the learner (Keller, 1987). We design instructional materials to present geospatial learing tasks in different ways to vary cases systemically (Collins & Stevens, 1983). For example, in some tasks, learners use GT to investigate regional or worldwide geographic cases prior to more local cases. In other tasks, learners analyze local cases prior to regional or worldwide cases.

3. *Model learning task*. The teacher and/or the instructional materials demonstrate to the learners how to perform a learning task with GT through task modeling (Black & McClintock, 1996; Jonassen, 1999). GT investigations involve using specific tools to display data or produce new visualizations that will be analyzed by students. For example, this stage may involve showing how a query tool may be used to examine differences in world-wide fossil fuel production or how to use a suite of analysis tool to produce a new visualization that shows global per capita consumption of a particular fossil fuel for each country.

4. *Provide worked example*. The teacher and/or the instructional materials provide a worked example to help guide the learner in performing a task. Geospatial investigations are often considered to involve complex learning tasks that involve learning outcomes that result from problem solving. As such, this stage incorporates Jonassen's (1997) ideas to provide a worked example to support problem-solving skill devlopment. As an example from the curriculum, students are given the problem to identify a suitable location to place a hydroelectric power plant. When presented with this task, one must consider a variety of factors including topography, an area to make a reservoir upstream from a dam, access to the grid for power distribution, and an analysis of potential environmental impacts that may result due to dam construction. The curriculum

materials provide a worked example that models how students may approach this problem-solving task using both positive and negative examples to highlight important aspects that will help them complete the learning task (Collins & Stevens, 1983).

5. *Perform learning task*. Learners perform the task in this stage. We design our geospatial learning investigations to involve data explorations and analyses that are tied to investigative questions. In this stage, learners construct their own understandings by being actively engaged with the learning task.

6. *Scaffold learning task*. The teacher and/or the instructional materials provide guidance to the learners as they engage with geospatial learning tasks. Our use of scaffolding emphasizes coaching by the teacher and provisions of instructional materials designed to provide cognitive tools to support learners' performance at critical times (Collins, 1988; Herrington & Oliver, 2000; Jonassen, 1999; Quitana et al., 2004). In our GT investigations, the instructional handouts provide scaffolding in the form of helpful hints and screen shots of visualizations in identified places where learners may have difficulty completing a learning task. The intent of such scaffolds is to provide learners with opportunities to complete learning tasks independently if needed.

7. *Elaborate task with additional questions.* The teacher and/or the instructional materials pose analysis and synthesis questions to foster learners' content and geospatial understandings. This stage reflects the *elaboration* phase of the 5E learning cycle model (Bybee et al., 2006) in which learners apply concepts in varied contexts and extend their content understandings and geospatial thinking and reasoning skills. In the instructional materials, learners repond to higher-ordered questions, formulate conclusions, and reflect on how science concepts are related and interconnected to each other.

8. *Review activity concepts*. The teacher reviews the science concepts learned in the activity to reinforce student learning and to clarify any concepts students did not understand. This instructional element is designed to enhance learner retention and transfer of science concepts and geospatial thinking skills to different situations (Gagné, 1985; Perkins & Salomon, 1996).

Energy Resources Curriculum

The energy resources curriculum (henceforth *Energy*) is a middle school unit designed to promote learner understandings of sustainable and non-renewable energy resources; energy generation, storage and transport; and energy consumption and conservation. The curriculum is aligned to energy resources learning goals that are articulated in the AAAS *Atlas of Science Literacy* (AAAS 2007) and AAAS's Project 2061's (2007) *Communicating and Learning About Global Climate Change*. The learning activities are designed to address common student misconceptions and knowledge deficits about energy resources (see Bodzin, 2012). The curriculum includes five interrelated topic areas that include energy and its everyday uses, sustainable energy sources, US energy production and consumption, nonrenewable resources, and energy efficiency and conservation. *Energy* takes approximately 8 weeks to complete in the classroom. Approximately half that time is dedicated to five Google Earth explorations and seven GIS investigations including an extensive culminating project. We developed the GIS investigations with Web GIS using Flex and Silverlight since it enables us to design a user-friendly interface for use in school settings and provide enhanced initial data visualization displays that are provided to learners, thus reducing a significant barrier to GIS implementation that has been reported in previous studies (Baker & Bednarz, 2003; Kerski, 2003).

Students begin the *Energy* curriculum by calculating their personal and household energy use and then analyzing their energy consumption patterns. By the end of this initial activity, they understand that they use energy for many purposes including lighting, heating, transportation, entertainment, food preparation, cleaning, and communications and that there is a monetary cost associated with their consumption habits. They also begin to formulate conservation practices that can reduce both their personal energy use and their household energy use.

The sustainable energy topics include an instructional sequence of geospatial learning activities and "hands-on" inquiry-based laboratories and demonstrations to develop understandings about contemporary energy sources including solar, wind, tidal, hydroelectric, geothermal, and biomass/biofuels. In the first geospatial learning 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 explore solar power plants around the world to examine ground cover, topography, and the space needs of the power plant area. They then use GIS to analyze annual average sunshine data to determine optimal locations to build new very large solar power plants. In the next set of curriculum 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 ground cover, topography, space requirements, and wind speed at each location. Students then examine wind speed and land use patterns in Pennsylvania to determine the optimal places to locate new wind farms in different geographical areas. 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 use Google Earth and GIS to examine features of hydroelectric dams around the world including their widths, height, capacity, surrounding area, shape and size of the reservoir, and the distances of each dam to nearby population centers. The hydroelectric energy activities conclude 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. Students learn about biomass/biofuels and complete a laboratory investigation to learn how raw materials are refined to process liquid fuels.

In next series of learning activities, students explore U.S. energy production and consumption patterns by geographical regions and across industrial, transportation, commercial, and residential sectors. They analyze electricity distribution data to understand that the current U.S. grid for electricity distribution is not efficient. By the end of these learning activities, they learn that coal is the energy source that is used to produce the most energy in the U.S. and that most of this energy is used to generate electricity.

The next topic area focuses on nonrenewable resources. Students learn how fossil fuels originate, how long they take to form, how they are transported from their sources, and how they are altered for energy use. A series of three GIS investigations are completed in which students investigate global coal, petroleum, and natural gas production and consumption patterns. During these investiagtions, they analyze the relationships among countries' coal, petroleum, and natural gas consumption and their populations.

Energy efficiency and conservation is the main topic area of the next set of curriculum activities. Students recalculate their personal and household energy consumption and compare these new values with their initial values that were calculated at the beginning of the curriculum to assess whether any difference in their energy consumption habits have occurred. Students then learn about energy conservation and complete an energy efficiency lab. Next, they learn about the advantages, disadvantages, and environmental impacts of using the various sustainable and nonrenewable energy resources.

In the culminating activity, students use GIS to analyze the energy resources of one of three provinces in a fictitious island and develop an energy policy statement for their province that is based on the energy needs of their province, available energy sources, and infrastructure for production and distribution. For perspective, the population, land area, and energy needs of the island are roughly comparable to those of the state of Pennsylvania. During the activity, students analyze their province's energy resources and determine the optimal locations 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. In the process of making these decisions students are confronted with real-world problems including transportation distance, limited infrastructure, and resources located in environmentally sensitive or culturally significant areas. Students recommend the most efficient combination of energy sources and have to justify their choice with the benefits, costs, and environmental impact assessments.

Energy **Educative Curriculum Materials**

The *Energy* curriculum is housed on a Web site and includes certain educative features designed to support teachers as they enact the curriculum. These educative curriculum materials recommend baseline instructional guidance for teachers and provide implementation and adaptation guidance (Ball & Cohen, 1996; Davis & Krajcik, 2005). The instructional materials are designed to anticipate and interpret what learners might think or do in response to a learning activity and provide support materials that expand both teachers' content knowledge and their geospatial pedagogical content knowledge. The educative curriculum materials also provide teachers with rationales for instructional decisions. Teachers are known to draw on their own resources and capacities to read, make meaning, evaluate and adapt curriculum materials to the needs of their students (Remillard, 2005). If teachers understand the rationale behind a particular instructional recommendation, they may be more likely to enact the curriculum in keeping with the developers' intent (Davis & Varma, 2008).

We present here four main educative support features on the Web site and then illustrate how these features support the development of teacher's geospatial science pedagogical content knowledge for curriculum enactment. The support features include:

- *Instructional Framework* section. This section provides teachers with an overview of the curriculum framework, design principles, and the instructional model for teaching with geospatial technologies. This section also presents the enduring understandings, essential questions, standards alignments, and learning activity overviews of the curriculum.
- *Teacher Guides.* Instructional guides designed to support a teacher's implementation of a specific learning activity. They include detailed information for viewing and analyzing spatial data during the learning activities and also include implementation suggestions and ideas to adapt a learning activity for different types of learners.
- *Support Materials* section. This section includes (1) Web pages that contain text, graphics, animations, and videos designed to enhance a teacher's content knowledge about a particular energy resource topic and (2) GT tutorial videos that provide overviews of each GIS and Google Earth learning activity.
- *Instructional sequence* Web pages. These Web pages include a recommended implementation sequence for each instructional day, implementation suggestions, and hypertext links to content supports and specific materials needed for the learning activities including spatial data files, assessments, student investigation sheets and handouts, teacher guides, and GT tutorial videos.

These materials are designed to promote and support teachers' learning of important science subject matter about energy resources, geospatial pedagogical content knowledge, and spatial thinking skills that are geographic. This is accomplished by providing teachers with multiple points of access to important energy content and pedagogical supports throughout the curriculum. For instance, the *instructional sequence* Web pages include a variety of implementation suggestions for teaching students with special learning needs. These include low-level readers, English language learners and students with disabilities. As an example, the instructional sequence page for the *Energy Resources for the Isle of Navitas* learning activity includes the following implementation suggestions:

> For classes with students with special needs, you may wish to provide additional modeling, prompts and guidance for each energy source. You may wish to guide students through each question for the first energy source on the investigation sheet (hydroelectric power) before continuing to the next energy source (tidal energy).
>
> Show students examples of a good location on a river to locate a dam to produce hydroelectric energy and another location on the same river that would not be a good location to build a dam for a hydroelectric power plant. Emphasize to students that areas that do not have changes in elevation or are not located near a confluence in a river are not optimal locations to place a dam.
>
> In some provinces, renewable resources exist in areas of natural significance. You may wish to highlight an example (such as high wind speed areas and geothermal areas in Gaul) to discuss with students the trade-offs for acquiring a renewable resource in an area of natural significance. (Kulo et al., 2010, online).

Since there is no guarantee that a teacher will carefully read the *instructional sequence* Web page of a learning activity, all implementation suggestions are also duplicated in the

Teacher Guide for each learning activity. Likewise, the content knowledge materials in the *Support Materials* section are also provided at the bottom of each instructional sequence Web page in a section labeled "Teacher Resources/Content Support" to enhance accessibility to important supporting materials.

The curriculum materials are designed to provide additional supports for teachers who work with a variety of learner contexts, such as different academic ability levels or students with special needs. As noted earlier, it is unrealistic to assume that one set of curriculum materials can be designed to effectively accommodate the diverse nature of all learners in middle school science classrooms. Therefore, all instructional handouts are available in Microsoft Word documents to enable teachers to adapt or modify important instructional elements including key questions, the use of visual cues, instructional scaffolding, and embedded assessment items to accommodate the various learning needs in a particular classroom setting.

The educative curriculum materials are also designed to help teachers promote geospatial thinking skills with their students. When using GT to promote geospatial thinking skills, there is a need for explicit instruction in geospatial analysis to help diverse learners understand visual representations in remotely sensed images (Bodzin, 2011; Bodzin & Cirucci, 2009). For example, in the learning activity, *Where is the Best Place to Locate a Geothermal Power Plant?,* students use Google Earth to explore features of "hot Earth" areas in Iceland and in the United States and then determine the best place to locate a geothermal power plant in the northwestern area of the USA. The instructional support materials for this learning activity are designed to help teachers display imagery in Google Earth using specific overlay features such as the terrain layer, metropolitan areas of the Northwest United States, and embedded regional overlays of hot Earth areas that we have developed (such as the Yellowstone Hotspot and Cascade Range). These supports are designed to assist teachers with modeling the process of identifying and interpreting important geospatial relationships among Earth features to their students.

The *Teacher Guides*, in addition to student instructional handouts for the *Energy* learning activities, are highly scaffolded and include many design elements to facilitate geospatial instruction with GT. Instructional supports in the *Energy* curriculum include screenshots of geospatial data layers with added graphical arrows adjacent to the instructions in order to simplify the procedures involved with the learning task or to assist in learning new GT software applications. Such design features are key elements to assist teachers who work with lower academic ability level students or students with special needs to help them to understand how to manipulate a GIS or Google Earth viewer for displaying spatial data of interest. For each geospatial learning activity, teachers are provided with instructional prompts for each spatial data layer they need to focus on to analyze geospatial relationships.

Instructional guidance to support teachers with geospatial analysis is also provided. For example, in the *Isle of Navitas* activity, to analyze whether hydroelectric energy is a viable energy resource for their province, the *Teacher Guide* models a thought process for determining suitable locations for the placement of a hydroelectric dam:

> The factors needed to determine the ideal location of a hydroelectric dam include the topography, a canyon that can be dammed, and an area to make a reservoir upstream of the dam. Zoom in to where the streams start in the mountainous areas

(light green or white). Hydroelectric power requires a power plant at the dam site and access to the grid for power distribution. (Kulo et al., 2010, online).

Teachers are then prompted to display the lakes, major rivers, electrical grid, and the national significance layers in their GIS. The national significance layer contains areas that are environmentally sensitive or culturally significant.

In addition to the instructional scaffolds in the *Isle of Navitas Teacher Guide*, we developed a series of teacher supporting materials that include visual guides for each province that contain important background information of each energy resource. The visual guides include a screenshot of the location of each energy resource and discuss the feasibility of each energy resource use for the provinces. If an energy resource is available in a province, we indicate the most ideal location to place a power plant with regards to the proximity of the electrical grid, transportation infrastructure, and the city locations. The visual guides also include examples of tradeoffs that students may need to consider if they choose various energy resources for their province. For example, a location may receive enough average annual sunshine to make it suitable for solar power generation but the area is under cultivation. Teachers, therefore, need to consider the tradeoffs involved in converting productive farmland into a solar power plant or using that area for growing food or switchgrass for biomass/biofuels production.

We contend that the use of the *Energy* educative curriculum materials in and of themselves provides a form of professional development since they include designs to promote teacher learning and support effective teacher decision-making for implementing curriculum materials. These materials may be used independently or with other forms of teacher learning such as face-to-face or Web-based professional development experiences. Remillard (2000) describes using curricular materials to "speak to" teachers about rationales behind instructional decisions. Since the classroom teacher is the agent who ultimately decides and structures what is to be taught, our educative supports should help teachers to understand how science learning with GT fits contextually within the curriculum.

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