

# CHAPTER 5

## Extending Inquiry With Geotechnologies in the Science Classroom

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Geography has always played a pivotal role in the development of scientific thought. Alfred Russell Wallace (1885), recognizing the spatial proximities of related species, concluded that “Every species has come into existence closely coincident both in space and time with a pre-existing closely allied species,” bringing to light one of the most basic phenomenon of nature, biologic evolution. Similarly, the identification of spatial clustering of disease outbreaks led John Snow to map and examine causal relationships (against popular medical opinion) that suggested a single water well in downtown London served as a point source for cholera. Snow’s (1856) keen insight into the geographic relationships of people contracting cholera helped him formulate new ideas about the nature of disease and disease transmission.

Scientific data with a spatial component are critical for understanding a vast array of scientific and social issues, including species distribution, molecular modeling, urbanization models, geologic stratification, natural resource management, glacial retreat tracking, weather and climatology, global tectonic activity, and much more. Geotechnologies are tools that allow your students to learn the skills of collecting and analyzing data and creating representations of data with an emphasis on spatial relationships. These processes are critical in nearly every environmental and social investigation conducted in an inquiry-oriented classroom.

Geotechnologies (also called geospatial technologies) are hardware and software that use location-based data and analysis tools to accomplish tasks ranging from determining a location to creating dynamic models for visualizing real-time, map-based displays. Geotechnologies typically include Geographic Information Systems, the Global Positioning System, and remotely sensed data (e.g., aerial photography and satellite imagery). Other visualization technologies, including geographic animation, geographic data explorers, and immersive and stereoscopic displays, are also typically considered geotechnologies.

### MORE ABOUT GIS

GIS systems can vary greatly in terms of cost and functionality. On the high end, professional grade GIS software commercially retails for thousands of dollars and requires substantial computing power that typically demands hardware upgrades to school computers. However, many of the leading GIS companies, such as ESRI, Inc. ([www.esri.com/k-12](http://www.esri.com/k-12)) have K-12 programs and pricing that allow for the placement of these high-end tools in schools. Northwestern University's GEODE Initiative ([www.worldwatcher.northwestern.edu](http://www.worldwatcher.northwestern.edu)) has also created a GIS specifically for K-12 students.

Geographic data explorers are commonly considered to be the younger sibling to a full-fledged GIS. These data explorers are free or low cost but have limited analytical functionality. Google Earth (<http://earth.google.com>) and ESRI's ArcGIS Explorer (<http://esri.com/arcexplorer>) are two geographic data explorer mainstays. Although all schools will find that using geographic data explorers are a good introductory step for integrating GIS into the curricula, schools with limited budgets will find that using data explorers also provides a flexible yet fascinating way for students to collect and view data.

Geographic Information Systems (GIS) are computer-based mapping programs designed for collecting, manipulating, and displaying data with a geographic component (such as latitude-longitude). A GIS organizes data into thematic layers. The concept is analogous to stacking multiple transparencies on an overhead projector to show how different information relates spatially. In a GIS, it is common to see a layer of roads, set atop a layer of hydrology, set atop a layer of vegetation. In this way, when you look at a GIS, the map of roads, hydrology, and vegetation all appear as a single map, yet the layers can be individually displayed or analyzed.

A GIS can also map more complex data, such as density and frequency of particular events (e.g., rates of disease outbreaks, occurrences of an invasive species, or locations of recent wildfires). A GIS can also perform geostatistics or correlations of data to a nearby area of interest. A GIS can even display real-time data, showing change over time or displaying data in an immersive or stereoscopic display.

The Global Positioning System (GPS) is a constellation of 24 satellites situated about 20,000 kilometers above Earth's surface. These satellite transmitters circle the earth every 12 hours, constantly producing timing signals that are received by handheld devices on or above the Earth's surface. When a handheld GPS receiver intercepts signals from at least three satellites, it trilaterates a latitude and longitude. Essentially, the GPS network gives every point on Earth a unique location identifier, much like an address. Oftentimes, a GPS receiver can plug into a laptop running a GIS to produce real-time maps. A more sophisticated GPS receiver may have maps with navigation and points of interest on board.

GPS receivers are becoming smaller all the time and embedded into other technologies, such as cell phones, cameras, watches, Personal Digital Assistants, automobiles, and boats. The price of a GPS receiver usually corresponds to its positional accuracy and extra functionality (like altimeters, maps, compass, etc). Retail stores around the United States provide base models for as little as \$60 for a receiver. High-end, professional-grade receivers can cost tens of thousands of dollars.

Remote sensing (RS) is typically considered to be the gathering of electromagnetic energy, using a variety of satellite or aerial instruments and sensors. Although RS cameras and radars can create stunning imagery of our Earth, RS data can also be quantitatively analyzed using the raw numerical data, suitable for exploring nearly any area of interest, such as land use, geology, hydrology, vegetation, urbanization, and soils. In collecting imagery, different remote sensors are particularly well suited to gathering information about specific surfaces or phenomena, principally based upon the “bands” (identified portions of the electromagnetic spectrum) that are most informative. In terms of the geography, in a single pass, some remote sensors can collect information from areas as large as a continent or as focused as the garden in your backyard.

Since many of the RS satellites repeatedly monitor the same geographic area in a relatively short time frame, creating change-over-time mapping and analysis applications is common. With current and historical RS datasets, scientists can create models that predict annual vegetation growth, monitor change in species’ habitats from human impacts, or estimate water quality based on changes in land use. Additionally, long-term RS data archives are now available online (e.g., Landsat imagery). Depending on the source and age of the RS data, price can vary greatly. For those schools with limited budgets or new to RS data, one approach is to use the free imagery available through geographic data explorers (see *More About GIS*, p. 44). This free imagery is downloaded into the geographic data viewers as it is needed, requiring less stringent computing resources.

### **What the Research Says**

Geotechnologies in the science classroom are usually justified through one of three explanations: (a) support for spatial thinking, (b) support for workforce preparation, and (c) support for extending scientific inquiry.

The recent National Academies Press publication, *Learning to Think Spatially: GIS as a Support System in the K–12 Curriculum*, argues for the inclusion of spatial reasoning across the K–12 curriculum with special emphasis in geography and science. Spatial thinking, identified as the “cognitive tools... that allow for a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning,” is integral to everyday life and too often neglected in the

curriculum (NRC 2006). Improving spatial thinking is a primary reason schools should consider integrating GIS as a primary tool across the K–12 curriculum.

The need for technically skilled American workers in the field of geotechnologies has been underscored by the Department of Labor, citing the geotechnical industry as one of the three fastest-growing technology industries in America this decade. The geotechnical industry is expected to show at least a sixfold increase immediately and is identified by the Bush administration’s “High-Growth Jobs Initiative.” The first listed priority for the geotechnical industry by the DOL is, “expanding the pipeline of youth entering the geospatial technology industry.” This bodes well for high school science instructors using geotechnologies to support and extend classroom inquiries, activities that increasingly mimic the field techniques of skilled professionals in science, technology, and engineering industries.

When geotechnologies are used as an instructional support in inquiry or problem-based learning, researchers have typically found improvements in both student attitude toward science and their ability to conduct scientific investigations (Kerski 2000; Olsen 2000). Improvements in student achievement can be seen in the accuracy of data analysis and the development of research conclusions within classroom scientific inquiry (Baker 2002; Crabb 2001). However, without prior instruction in map-based data manipulation and representation, the effects of geotechnologies appear to be dramatically reduced (Doering 2002).

GIS, specifically, can aid in identifying expert learner traits in problem-solving and navigational strategies (Wigglesworth 2000). Incorporating GIS into a curriculum has shown mixed research results for improving recall of content knowledge (Kerski 2000). Generally, the conclusions of researchers should not be surprising; the use of a suite of geographic data analysis technologies helps to extend the processes of scientific inquiry in the classroom.

### **Guidelines for Best Practice**

Several recommendations can be garnered from educational research and development activities from the past 10 years of GIS in precollegiate education. Although the subsequent suggestions are intended for classrooms that use scientific inquiry or problem-based learning, they are equally appropriate to many instructional methodologies.

#### **(1) Prepare students to use maps and spatial analysis tools effectively.**

Basic map reading and interpretation can be difficult for students, particularly when using a GIS with several complex datasets. Prepare to explicitly teach map reading and analysis activities prior to expecting students to use map-based analyses as a part of an inquiry. Hang laminated vegetation, migratory, geology, or hydro-

ogy maps on the classroom walls. Mark interesting or unique points on the map with transparency markers. Depending upon the GIS software you intend to use, a variety of materials are available to teach about GIS and map analysis. See the suggested reading list at the conclusion of this chapter for more information. Also consider having students find their home, school, and popular hangouts on a map or image of their hometown.

## (2) Plan for a phased-in instructional approach when using GIS to support inquiry.

Based in part on Recommendation 1, using a GIS in a classroom requires planning and a patient, stepwise approach to successful integration. Instructionally, GIS is akin to a word processing or spreadsheet program, expecting the user to enter data and direct the GIS to “do” something with that data. Unlike a word processor or spreadsheet, the data available in a GIS can become staggeringly complicated due to data formats, projects, datums, accuracy issues, and the content of the data (e.g., What do these data mean? How accurate are these data? Why don’t certain features align correctly?).

Use gradually increasing GIS technology, map interpretation, and inquiry skills in a progressive framework, such as the one used by the NSF-funded *Extending Scientific Inquiry Through G.I.S.* program (NSF #0096679). The framework increases the complexity of technology use and application to inquiry by first presenting maps and data to students through creating data and multidimensional visualizations:

- ▶ **Presentation:** You or your students show maps from a science textbook or website to an audience. The audience does not interact with the map, but views the information and context selected by the map presenter.
- ▶ **Exploration:** The task of exploration is one of data discovery, investigation, and searching. At this point, students start to “fool around” with GIS software and data. Students may turn data layers on and off, make layers active, or even add/delete existing data layers in a GIS or data explorer. Exploration is a stage where students can view immediately available data layers and simply see what’s there. For example, students may use a geographic data explorer to see in what watershed their school lies as a precursor to a water quality study. Similarly, students might use websites (e.g., the MapMachine at <http://nationalgeographic.com/mapmachine>) to study conservation and historical hurricane maps.
- ▶ **Analysis:** In the analysis phase, data layers are compared and contrasted against one another. In some cases, data are identified based upon relationships with other data. Analysis tasks could include identifying what’s inside, outside, or nearby another object or class of objects. For example,

students working collaboratively might study phenology using GIS to gather and spatially analyze the variables identified in Hopkin's Law of Bioclimatics (elevation, latitude, and longitude) in addition to other suspect variables such as temperature, moisture, and light. Students collect their own indicators of spring (i.e., frog calls, cricket sounds, first dandelion) and create a GIS project in which each data layer can be examined for spatial correlation with student-collected indicators of spring, confirming or extending Hopkin's Law.

- ▶ **Synthesis:** Creating new data layers and/or recombining existing data layers into new, previously unknown patterns is the hallmark of synthesis. Students take the knowledge they have previously learned about science and GIS use and apply the knowledge to a new, unknown situation. For example, students may create a single new layer from three of the environmental factors listed in the analysis phase (e.g., elevation, precipitation, and temperature), in an attempt to create a single composite data layer. The single, new data layer can then be used to assess student-collected data.
- ▶ **Visualization:** Visualization is the process of searching for new patterns within the data layers and includes the manipulation of the way map data are represented. Alterations of the classification (including color palette and legend types) or map styles are considered potential visualization approaches. More recently, three- and four-dimensional modeling, animations, and stereoscopic displays have been considered among the foremost efforts to create geographic visualizations.

### **(3) Guide students through inquiries that are local in focus and bring in collaborators.**

Inquiry investigations that have deep roots in students' communities elevate motivation through a sense of ownership in the problem and solution. For many Earth science and environmental investigations, a personal knowledge of the geographic area is critical to the success of the study. Data collection technologies, like a GPS receiver, are naturally best suited to local investigations, but so is the use of GIS. Not only are you more likely to have a greater volume of local data at your disposal, the data is also more likely to be current.

Although substantial amounts of data can be freely downloaded from commercial and governmental websites, a far more expansive array of data most likely sits in your county's mapping or GIS office. Establish and nurture an ongoing relationship with professionals in that office. Often, you'll find that your local county mapping office can provide data, create poster-size prints of maps, and even provide some degree of technical support. An excellent opportunity to establish this relationship is by calling your county's mapping office and inviting a GIS analyst to speak to your class on GIS Day, an annual event occurring in mid-November.

#### (4) Scale the technology with your personal comfort level and the school's technical capacity.

Geotechnologies, particularly GIS, are available to classrooms at a variety of levels:

- ▶ Step 1: For those new to GIS, creating maps with a desktop GIS or map-making website and then incorporating those images into presentation software is a good first step for creating presentations. In this way, the use of GIS can facilitate many different instructional strategies, including scientific inquiry.
- ▶ Step 2: Moving students into internet-based mapping is often the next step in the technical progression. Internet-based mapping sites are becoming increasingly common and increasingly more powerful as tools for exploring map data—a good approach to supporting the collection of background information for an inquiry.
- ▶ Step 3: The third step usually involves downloading and installing a free GIS data viewer to school computers. ESRI's ArcExplorer for Education or Google Earth are geographic data viewers that allow for importing a variety of data with some cartographic or mathematical analysis tools. Many of these free viewers also give students their first opportunity to incorporate data they have collected with a GPS and satellite imagery they have downloaded from the internet.
- ▶ Step 4: The fourth step is often purchasing and installing a full-fledged GIS. In recent years, Northwestern's MyWorld, ESRI's ArcView, and Intergraph's Geomedia have become increasingly popular in schools. These applications support the widest variety of GIS, RS, and GPS data while supporting a wide array of analysis tools. The potential payoff for using these more robust GIS applications is the facilitation of school-to-career paths for students and better compatibility with collaborators, such as your county mapping office.

#### Examples of Best Practice

A variety of examples can be found where this integrative suite of technology blends physical, Earth, and biological sciences within inquiry. The examples that follow illustrate a few common cases for geotechnology inclusion in the secondary science class.

##### *Water Quality*

In Kansas, where water quality and quantity are politically sensitive issues, students at a local high school travel to a nearby stream, measuring chemical, biological,

visual, and location information. The collected data is returned to the classroom, where student teams map and study their results using a GIS with supporting data from the county mapping office (including hydrology, soils, vegetation, and land-use data). Later in the school year, the students will use previous GPS receiver readings to locate the exact location of their previous data collections, so that they can document and study seasonal changes in water quality. By using standardized collection and analysis protocols, the students are subsequently able to share and discuss their water quality data with other schools in the county.

### *Ecological Patterns*

The study of Wisconsin's wildlife and natural resources takes a cutting edge when students use GIS, GPS, and RS data to explore original research questions about ecology. The Wildlands Science Research School near Augusta works closely with state and county agencies and has been able to track, map, and predict ecological patterns in several plant and animal species. Among the results, student efforts have assisted in re-evaluating and further extending the implementation of the state's natural resource management plan.

### *Students' Home Ranges*

As an introductory study in biology, students establish their personal home ranges by carrying a GPS receiver on their person after school and on weekends for a week. Each student's GPS receiver automatically logs their position every 10 minutes, data that is periodically downloaded to disk and brought to class. The student-collected data is displayed in a GIS at point locations, which are then converted into density maps, with the darkest areas of the map indicating geographic areas most popular with the student. Small groups, classes, or multiple classes can then share and/or combine their data to establish aggregated maps. Street networks, zoning and parcel data, and high-resolution aerial photography can be incorporated to provide greater meaning to the data. In effect, the exercise establishes a student's (or group's) home-range boundary. Concepts such as carrying capacity, habitat, and migratory studies in a biology or health class are then linked into the students' home range studies.

### *A Local Natural Heritage Inventory*

In Vermont, students began recording the location of vegetation plots and species with a GIS and GPS receiver, establishing a map of the surrounding environment on land owned (or under agreement) by the high school. Essentially creating a local natural heritage inventory, students were able to document the location (or presence and absence) of several animal species, taking careful field notes and digital photos. The data were then placed into a GIS, including photos and notes that were hyper-

linked to web pages on the school's server. Moreover, the students were able to incorporate color aerial photography into the GIS, to better understand how the school property and the surrounding land have changed over the past several years.

### *Relative Air Quality*

Earth science students studying atmospheric conditions began using lichens as bioindicators of relative air quality, where the density and diversity of lichen species (and even morphology) is correlated to quantity of atmospheric sulphur dioxide (SO<sub>2</sub>). Using a GPS receiver, students locate a tree of prespecified species and standardized measurement grid to calculate a lichen index. The latitude, longitude, tree species, and lichen index are uploaded into an internet database. Students can then retrieve spreadsheets and maps of their data and their peers' data, as they look for mathematical and spatial patterns in lichen density and diversity. Through text and spatial queries, students work directly with the map data, creating maps filtered on several variables and overlaid with other relevant thematic data (e.g., land use, vegetation indices, and urbanization). The internet-based GIS technology allows a level of exploration, analysis, and peer collaboration typically out of reach for introductory students.

## **Conclusion**

Geotechnologies are a spatial data collection, analysis, and visualization tool kit. For most, the implementation of one or more of these technologies will be implemented progressively, catering the use of technology to your comfort level and increasing the technology integration and shifting instructional practices as your needs change. To help ease the way into advanced uses of geotechnologies, consider a *Presentation*→*Exploration*→*Analysis*→*Synthesis*→*Visualization* approach. In the early stages of your work with geotechnology, find local collaborators, GIS analysts, and other teachers using GIS to call on for support. Join some of the GIS educator networks on the web, such as KanGIS (<http://kangis.org>) or EdGIS (<https://list.terc.edu/mailman/listinfo/edgis>) to keep abreast of new data sources, training workshops, and software.

If you prefer using prepared materials in the classroom, conduct searches for GIS lessons on the web. Many of these resources are high quality and provide data and a teacher guide in a single downloadable package. Although a variety of suitable materials for teaching about GIS exist, there are relatively few materials for inquiry-based teaching of secondary science with GIS. When deciding whether to use GIS, allow your instructional and content needs to instigate and direct your use of geotechnology, rather than using these technologies to dictate your instructional and content needs. After all, as science educators, we teach *with* geotechnology and not necessarily *about* geotechnology.

**Suggested Readings**

- Audet, R. H., and G. Ludwig, eds. 2000. *GIS in schools*. Redlands, CA: ESRI Press.
- Downs, R., and A. deSouza, eds. 2006. *Learning to think spatially: GIS as a support system in the K–12 curriculum*. Washington, DC: National Academy Press.
- Green, D. R., Ed. 2001. *GIS: A sourcebook for schools*. London: Taylor and Francis.
- Malone, L., A. M. Palmer, and C. L. Voigt. 2002. *Mapping our world: GIS lessons for educators*. Redlands, CA: ESRI Press.
- Mitchell, A. 1999. *The ESRI guide to spatial analysis volume 1: Geographic patterns and relationships*. Redlands, CA: ESRI Press.