

## **Web-based Interactive Mapping Applications for Use in Science Methods Courses**

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### **Introduction**

Geospatial thinking, a subset of spatial thinking, is a skill that necessitates knowledge about space, the ability to use tools of representation properly, and reasoning skills (National Research Council [NRC] 2006). Geospatial reasoning involves problem solving that is connected to data referenced to the Earth's surface or to the Earth's representation through maps (Huynh & Sharpe, 2013). One effective method for teaching geospatial thinking and reasoning (GTR) is through geospatially-enabled learning technologies, such as geographic information systems (GIS) or other tools that have the capacity to display dynamic maps, globes, and other representations of the Earth (Bodzin, 2011). Geospatially-enabled learning technologies may enhance science curriculum learning by adding an emphasis on geographic space, visualization, scale, and representation. While these technologies show promise to support the development of GTR, the NRC (2006) report *Learning to Think Spatially: GIS as a Support System in the K-12 curriculum*, pointed out that we still lack specific knowledge of what kinds of geospatial learning experiences lead to student improvement, how to infuse geospatial thinking in the science curriculum, and how best to use geospatially-enabled learning technologies with classroom learners.

To address these issues, our Environmental Literacy and Inquiry group at Lehigh University has worked in partnership with a local area urban school district, and has developed (1) an 8-week geospatial technologies-integrated energy resources middle level curriculum unit

rich in Web GIS investigations and (2) a series of Web GIS tectonics investigations designed to enhance a typical Earth science curriculum. In this paper, Web GIS as a visual instructional technology to support GTR is described. I present a Web GIS curriculum approach for promoting GTR and highlight our Web GIS energy resources and tectonics curriculum materials and illustrate how they are designed to enhance both Earth science understandings and GTR skills.

### **Web GIS as a Technology to Support Geospatial Thinking and Reasoning**

Geospatial thinking is inherent to the Earth and environmental sciences where there is a heavy reliance on cognitive thinking skills that include knowledge about space, the ability to use tools of representation properly, and reasoning skills (NRC 2006). According to Golledge (2002), knowledge about space consists of the recognition and elaboration of the relations among geographic spatial primitives, such as place-specific identity, location, or magnitude, and the advanced concepts derived from these primitives such as arrangement, organization, distribution, pattern, and geographic association. Geospatial thinking involves using tools of representation for making inferences about space, geospatial patterns and geospatial relationships related to the Earth's surface. These representations include map and globe visualizations that are used as tools to organize and understand data that is georeferenced to the Earth's surface. The NRC (2006) report *Learning to Think Spatially* pointed out that GTR enables knowledge about space and representations to be combined for problem solving and decision-making.

Thinking geospatially requires knowing, understanding, and remembering geospatial information and concepts. It provides a way of examining data and information that reveals properties or relations about the Earth's surface that may or may not be readily apparent. GTR involves cognitive processing of georeferenced data that has been encoded and stored in memory,

or that is, represented externally to the mind by map visualizations (Uttal, 2000). In the geosciences, the capacity to visualize data patterns and relationships on the Earth's surface is integral to the process of GTR and involves geospatial abilities such as geospatial visualization, orientation and geospatial relations which can be facilitated by GIS (Albert and Golledge, 1999).

GIS is a class of software applications that organizes Earth's features into thematic layers and then uses computer-based tools to aid one with examining their patterns, linkages, and relationships. The GIS tool set enables learners to view, manipulate, and analyze rich data sets from local to global scales, including for example, such data as geology, population, seismic hazards, energy resources, climate, land cover, and elevation using two- and three- dimensional visualization and analytical software. GIS visualizations and its interactive visual interfaces can effectively provide material for analysis and reasoning in geospatial contexts (Andrienko et al., 2007). Web-based GIS (referred to as Web GIS) is a form of GIS that is deployed using an Internet Web browser. Web GIS offers some of the same functions as a desktop GIS, but does not require the full suite of (often expensive) specialized software or tools that need to be mastered before one may effectively use the software. It provides a scale-independent tool that allows users to manipulate and analyze very large data sets to discover geospatial patterns related to the earth's surface. Recent Web GIS development capabilities that include the use of Javascript application programming interfaces (APIs) can provide for the customization of both the Web GIS interface and tools to reduce the cognitive load that learners may experience when compared to typical desktop GIS software applications that are designed for industry and not for use in school settings. The capability to manipulate structural relations in data dynamically in a Web browser to produce new graphical data representations make Web GIS a valuable tool to support GTR in a school setting.

Some studies have investigated the effectiveness of using GIS integrated into the science curriculum. Edelson et al. (2002) reported that a geospatial middle curriculum unit that used the Learning-for-Use design approach addressed student misconceptions pertaining to the influence of physical geography on temperature over long timescales. Baker and White (2003) found the use of GIS in a two-week problem-based learning module improved middle students' data analysis skills. Bodzin (2011) reported that the use of virtual globes, a more simplified geospatial technology platform was associated with students' improved spatial thinking skills involved with aerial and remotely-sensed image interpretation to identify objects and investigate ground cover features with appropriately designed curriculum learning experiences. Bodzin, Fu, Peffer, and Kulo (2013) found that students using the geospatial curriculum approach with a desktop GIS version of the energy resources curriculum described below had better performance on an energy literacy measure compared to a group of students using their business-as-usual curriculum.

### **Curriculum Approach with Web GIS**

Our curriculum approach for geospatial thinking and reasoning builds on our design work for teaching and learning with geospatial technologies (Bodzin, 2011; Bodzin, Anastasio, & Kulo, 2014) and the Geotech Center's Geospatial Technology Competency Model (U.S. Department of Labor, 2010). The curriculum approach incorporates design principles in each investigation to promote geospatial thinking and reasoning skills (Figure 1). These include:

1. Use motivating contexts and personally relevant and meaningful examples to engage learners.
2. Design image representations that illustrate visual aspects of Earth and environmental scientific knowledge.

3. Design Web GIS data to make geospatial relations readily apparent.
4. Scaffold students (Jonassen, 1999; Quitana et al., 2004) to analyze geospatial relations.
5. Develop curriculum materials to better accommodate the learning needs of diverse students, while also expanding the geospatial science pedagogical content knowledge of science teachers.

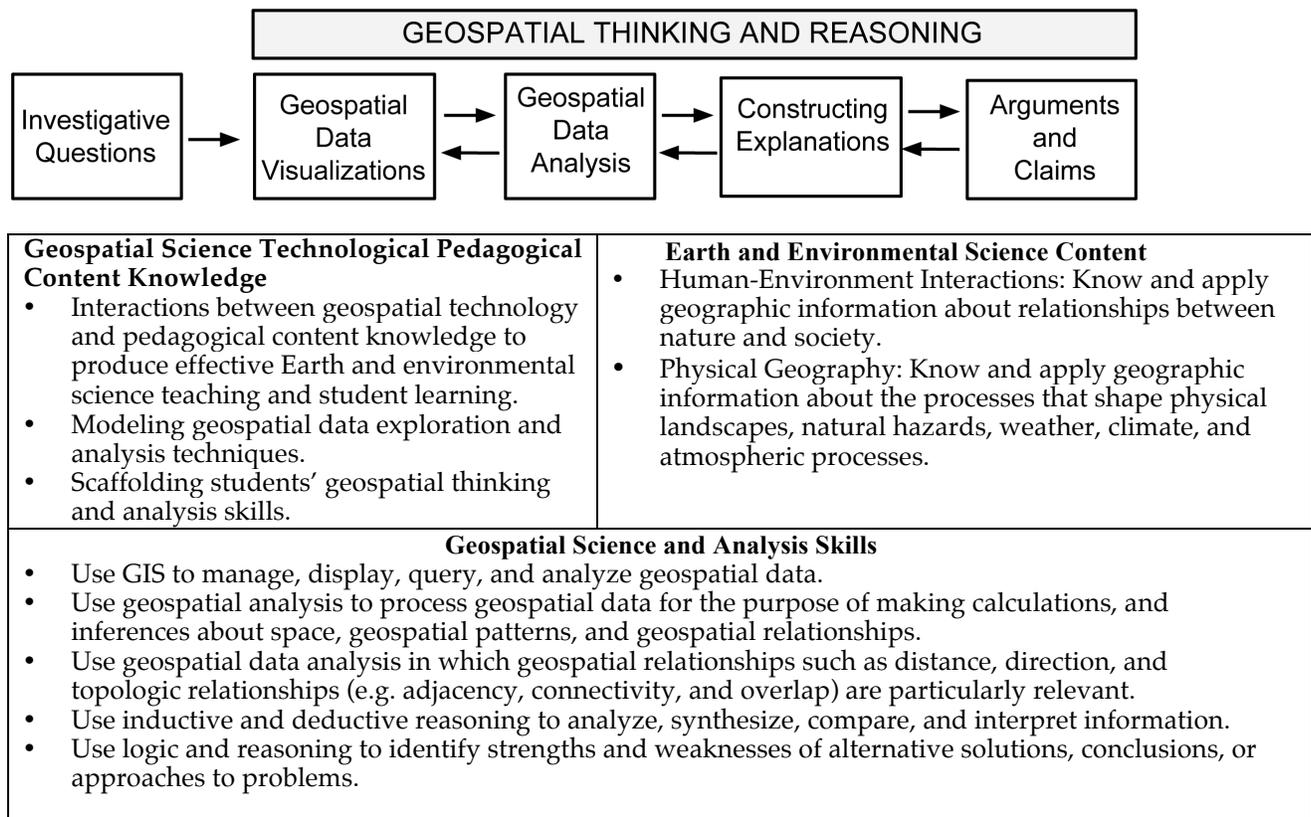


Figure 1. Key components of the geospatial curriculum approach.

A primary goal of the curriculum approach is to develop geospatial learning activities in such a way that the software and hardware become invisible to the user. Therefore, the initial geospatial data visualizations for each investigation are designed to be quick and intuitive for both students and teachers to use, thus decreasing interface issues that were reported by users of other GIS platforms (Baker & Bednarz, 2003; Bednarz, 2004). The learning activities include educative materials (Davis & Krajcik, 2005) that use Web-based videos, text, and graphics to

promote and support teachers' learning of important Earth and environmental science subject matter and geospatial science pedagogical content knowledge that instructors may be lacking. Each learning activity includes baseline instructional guidance for teachers and provides implementation and adaptation guidance for teaching a variety of learners, including reluctant readers, English language learners and students with disabilities.

### **Web GIS Learning Activities for Energy Resources**

The energy resources curriculum (<http://www.ei.lehigh.edu/eli/energy>) is a middle level 8-week curriculum that includes fourteen days of geospatial learning activities and a week-long culminating GIS project. The curriculum has 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. The curriculum also includes inquiry-based laboratories, demonstrations, readings, a multi-day energy audit activity, and other learning activities aligned to the curriculum learning goals. The geospatial learning activities are designed to promote GTR skills as students examine, categorize, analyze, infer, and evaluate energy resources using georeferenced data in Web GIS. In these learning activities, students use geospatial analysis for the purpose of making inferences about space, geospatial patterns, and geospatial relationships. The investigations involve geospatial reasoning skills as students identify strengths and weaknesses of different energy resources. Other learning activities in the curriculum include personal exploration of energy consumption practices, laboratory investigations, demonstrations, and content readings.

In the first geospatial learning activity, students are presented with the investigative question: *Where is the best place to locate a new solar power plant?* In this activity, students first use Google Earth to explore solar power plants around the world to examine landcover,

topography, and the space needs of the power plant area. They then use Web GIS to analyze annual average sunshine data to determine the feasibility of existing solar power plants and to determine optimal locations to build new very large solar power plants. We designed the Web GIS for students to visualize geospatial patterns of average annual sunshine quickly in the Web GIS map viewer (see Figure 2). We also developed a customized top-menu bar solar icon widget for this specific learning activity that enables students to view data for specific solar power plants locations. Clicking on the solar icon widget displays a drop-down list of the solar power plant locations in the Web GIS map viewer. When the student places his or her cursor over a location, a corresponding data pop-up window shows the specific location in the Web GIS map viewer (see Figure 2). When the student clicks on the displayed location, the map viewer zooms into the actual location enabling the students to quickly analyze the ground cover and topography at that location.

In the next geospatial learning activity, students investigate, *Where is the best place to locate a new wind farm?* They first 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 use Web GIS to examine wind speed and land use patterns in Pennsylvania to determine the optimal places to locate new wind farms in different geographical areas. We designed the Web GIS for students to visualize geospatial patterns of wind speed to quickly assess wind potential (see Figure 3). When the Pennsylvania Wind layer is selected, the Web GIS map viewer initially displays the wind speed layer, illustrating the best wind potential in the northwest corner of the state adjacent to Lake Erie. We also developed a customized top-menu bar Pennsylvania wind farm widget for this learning activity that enables students to navigate

quickly to a zoomed-in view from one location to another to analyze the land use at different proposed wind farm locations.



Figure 2. Web GIS displaying average annual sunshine with solar power plant locations displayed for the investigation.



Figure 3. Web GIS displaying wind potential with wind farm locations displayed for the investigation.

The Web GIS includes a specific query and analysis tool set that is used to investigate hydroelectric power dams in the continental United States and global fossil fuel consumption and production. In the *Investigating Hydroelectric Dams with GIS* activity, students use Web GIS to examine and query features of hydroelectric dams including their widths, height, capacity, surrounding area, shape and size of the reservoir, and the distances of each dam to nearby population centers. We developed a customized top-menu bar hydrology widget that enables students to query and analyze specific data subsets including the ten most powerful US hydroelectric power dams and Pennsylvania hydroelectric power dams. We also designed a series of three Web GIS investigations in which students investigate global coal, petroleum, and natural gas production and consumption patterns. During these investigations, students analyze the relationships among countries' coal, petroleum, and natural gas consumption and their populations. The initial Web GIS data allows students to first observe global patterns of a

particular fossil fuel reserve when that particular map layer is selected. We included a dynamic querying feature to permit students to analyze the relationships with these data layers. When performing such a query, the results produce a new map visualization displaying the per capita consumption of a selected fossil fuel for each country.

In the culminating Web GIS project, *Isle of Navitas* (Latin for "energy"), student groups are assigned one of three provinces on the island and take on the role of "Chief Energy Officers" for their province. The Web GIS for the Isle of Navitas includes geospatially referenced data layers that display infrastructure, natural resources, weather variables (wind, solar exposure, and precipitation), topography and bathymetry, land use, and culturally significant areas among other information (Figures 4 and 5).

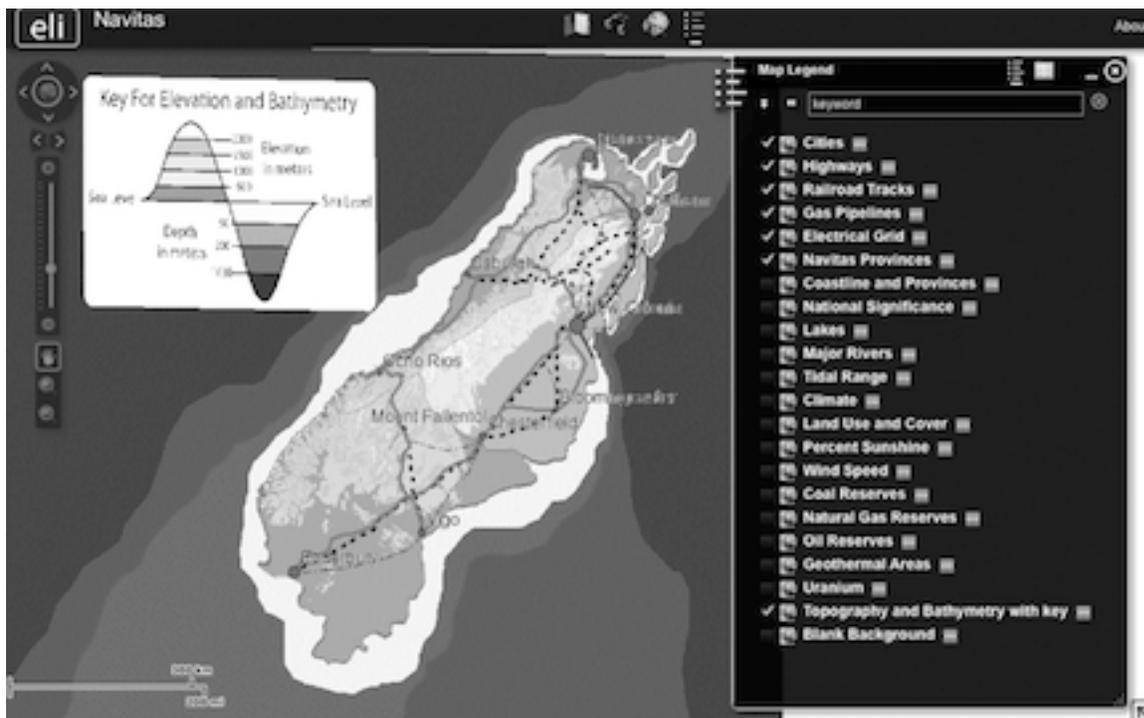


Figure 4. Isle of Navitas showing population, energy distribution, and transportation infrastructure.

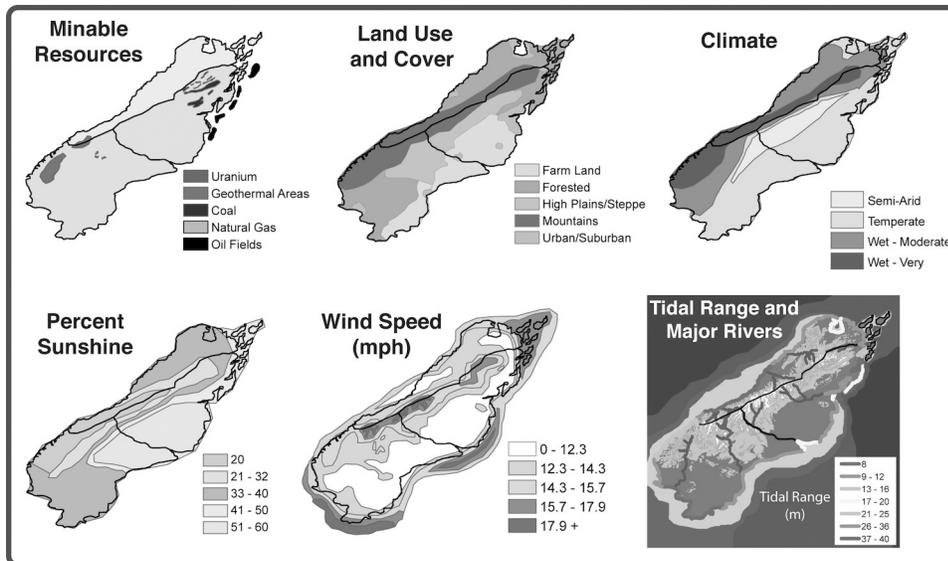


Figure 5. Data layers for the Isle of Navitas.

Students begin the Isle of Navitas project with the following scenario and tasks:

You are the chief energy officer (CEO) of one of three provinces on the Isle of Navitas, an island about 120,000 km<sup>2</sup> (46,000 mi<sup>2</sup>, approximate size of the Commonwealth of Pennsylvania). It has a population of about 7,000,000 people. Your task is to explore the energy resources for your province using Web GIS to recommend an efficient combination of energy sources that will satisfy energy demands while minimizing the impact on the environment. You will:

1. Explore energy resources for the Isle of Navitas.
2. Analyze the benefits and costs of each energy source.
3. Analyze the environmental impacts of each energy source.
4. Recommend an efficient combination of energy sources for your province.

During the activity, students use Web GIS to explore the energy resources in their assigned province. For each energy resource (hydroelectric, tidal, biomass, solar, wind, coal,

petroleum, natural gas, geothermal, and nuclear), students respond to a series of questions that apply their energy resource explorations to facets of environmental decision-making. They use Web GIS to analyze the energy resources 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. 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.

### **Tectonics Web GIS Learning Activities**

Tectonics (<http://www.ei.lehigh.edu/eli/tectonics>) is a series of geospatial investigations designed to augment a typical middle school Earth science curriculum. Students use Web GIS to investigate important tectonics concepts that are more difficult to understand using a traditional text and worksheet-based medium. The geospatial investigations are designed to promote GTR skills as students analyze, infer, and evaluate georeferenced earthquakes, volcanoes, plate boundaries, heat flow, age of the ocean floor, and other georeferenced data in the Web GIS to understand important concepts related to heat flow, plate movements and tectonic effects related

to natural hazards. In these learning activities, students use geospatial analysis to examine geospatial patterns and geospatial relationships within the data.

The Web-based visualization and analysis tools were developed with Javascript APIs to enhance the Web GIS interface. The Web GIS interface integrates graphics, multimedia, and animations that allow users to explore and discover geospatial patterns that are not easily visible as static single maps. The Web GIS features include a swipe tool that enables users to see underneath layers, query tools useful in exploration of earthquake and volcano data layers, a subduction profile tool and an elevation profile tool that facilitate visualization between map and cross-sectional views, a suite of draw and label tools, a geolocation function, and interactive image dragging functionality. The Web GIS tool set enables learners to view and dynamically manipulate, and analyze rich data sets to make informed decisions about living in areas containing seismic hazards and fault zones.

*Geohazards and Me: What geologic hazards exist near me? Which plate boundary is closest to me?*

In these investigations, students locate the most recent earthquake and volcano that has occurred nearest to their location and investigate how geologic hazards are distributed on the Earth's surface and infer how this distribution is related to plate tectonics. A three year period of recent earthquakes data with moment magnitudes greater than 4.0 is incorporated in the Web GIS to enable the data layer to load quickly into the map viewer even over modest network speeds. The displayed color of the earthquake map locations (epicenters) indicate the source (focal) depth of the earthquakes. Students use the geolocator tool to place their current location on their map. The map viewer is set to provide a view of Western United States or Eastern United States depending upon the user's location. This enables the Web GIS image to focus the

map viewer to help students visualize the earthquakes that have occurred near their location, immediately making the learning activity relevant and meaningful to the learner. The size of the symbols and the number of earthquakes that are displayed in the Web GIS are dependent upon the extent of the navigational zoom. Fewer events are shown with broader navigational extents so the map is not too cluttered with overlapping data points. With their location on the map, students then display a series of data layers including historic earthquakes with magnitudes greater than 8.0, volcanoes, and plate boundaries. They observe and measure the hazards and plate boundary locations that are closest to where they live with a *distance measure* tool. Students can learn more about each earthquake and volcano by clicking on them to display a pop-up data box that includes a hypertext Web link to the USGS, NOAA, or Smithsonian Web site. They then learn that geologists determine seismic hazards by studying the timing, location, and magnitude of past earthquake events and use this information to develop risk assessment maps that communicate the potential for seismic hazards to occur in a particular area. Figure 6 shows the seismic hazard layer displayed on the Web GIS. The yellow, orange, and red colors displayed in the seismic hazard layer, such as those on the west coast, are associated with a higher seismic hazard risk. The darker green color in the seismic hazard layer on the U.S. east coast is associated with a lower seismic hazard risk. Using the Web GIS, students are able to easily observe an important geospatial pattern; the highest risk areas correspond to the locations of more volcanoes and earthquakes.

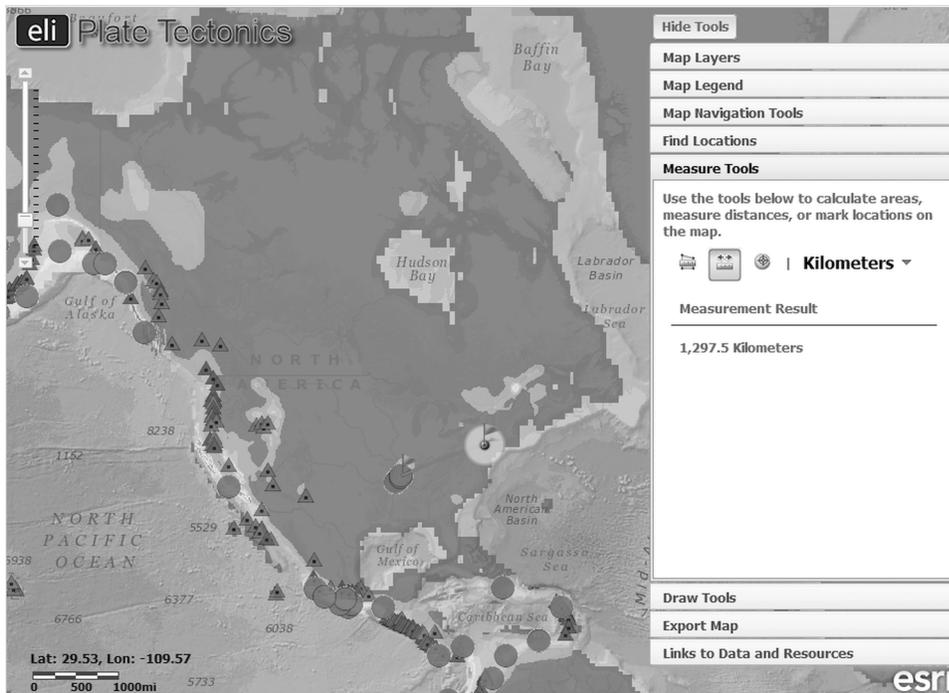


Figure 6. The Web GIS displaying the seismic hazards, volcanoes, historic earthquakes (large circles), and plate boundaries layers. The distance measurement result displays the distance between Bethlehem, Pennsylvania (geolocator circle with flag) and the location of the nearest historic earthquake with a magnitude greater than 8.0 (large circle with flag).

### *How do we recognize plate boundaries?*

In this investigation, students analyze earthquake epicenter and volcano data to determine the eastern and western boundaries of the North American Plate. In addition, they analyze the movement of the surrounding plates to determine plate boundary types (divergent, convergent, or transform). During the learning activity, the Web GIS enables students to better understand that physiological features such as volcanoes can convey to us information about the the locus of plate boundaries.

The initial visualization is customized for a North American audience and is set to display a blue-boxed study area around North America. Students display the locations of earthquakes and use the Web GIS *draw* tool to outline the location of the North American plate boundaries. They then use the Web GIS to identify the adjacent plates next to the North

American plate. The Web GIS is designed in such a way that all the user needs to do is click on a location in the map viewer to display the plate name at a particular location. Students then activate the volcanoes layer and outline the Juan de Fuca plate by drawing a line to the west of the volcanoes located in the northwestern U.S and western Canada. Students next use the Web GIS to examine the relative plate motion across the plate boundaries they have drawn to identify divergent, convergent, and transform boundary areas. We developed a map layer that includes a series of red arrows that illustrate the boundary type: arrows perpendicular to the boundary and pointing towards each other illustrate convergent boundaries, arrows perpendicular to the boundary and pointing away from each other are located at divergent boundaries, and arrows parallel to the boundary and pointing in opposite directions are located at transform boundaries. This layer of arrows is a visualization feature designed to help students associate a plate boundary's map color with the actual plate motions that occur at a specific location. In the last part of this investigation, students use the Web GIS to identify different types of lithosphere. We developed the Web GIS to display an oceans base map that enables the user to easily observe that plates are made-up of oceanic and continental lithosphere, and makes apparent that plate boundaries occur in both oceanic and continental lithosphere and helps students appreciate how topography and bathymetry is related to the underlying lithosphere.

*How does thermal energy move around the Earth?*

In this investigation, students locate areas where heat most escapes from the Earth's interior. They investigate how surface heat flow is distributed around the Earth and examine its geospatial relation to plate boundaries. Students also discover which geologic features on the Earth's surface are associated with heat transfer from the Earth's interior. Using the Web GIS,

students can dynamically visualize how the distribution of hot spots on the Earth surface are geospatially related to lithosphere thickness, plate motion, and heat flow.

Students begin this investigation by discovering the relationship between heat flow and plate boundaries. The initial Web GIS visualization in the map viewer displays the surface heat flow layer. Students are able to quickly overlay the plate boundary layer and readily observe a geospatial pattern that the highest surface heat flow is located along the divergent plate boundaries and is related to the age and elevation of the ocean bottom.

The Web GIS incorporates a swipe tool that enables learners to swipe one data layer over another to help analyze the geospatial patterns displayed in the Web GIS. In this investigation, students use the swipe tool to discover the geospatial relationship between surface heat flow and the age of the ocean floor by dynamically swipe the surface heat flow layer over the age of the ocean floor layer (see Figure 7). This produces a new visualization that enables students to readily observe the geospatial pattern that the hottest crust is the youngest crust on the ocean floor.

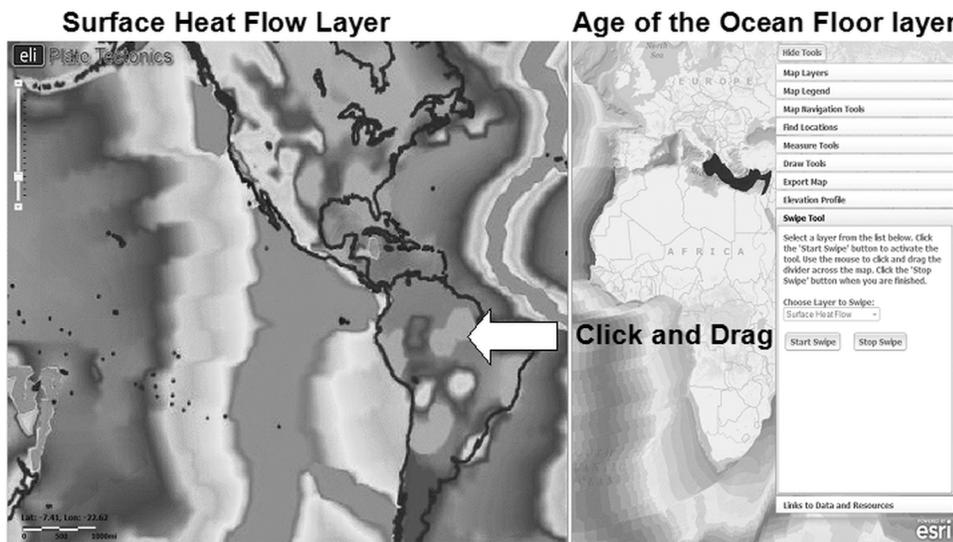


Figure 7. An example of the swipe tool in *How does thermal energy move around the Earth?*

where the surface heat flow layer (left portion of figure) is being swiped over the age of the ocean floor layer (right portion of figure).

The Web GIS also includes an elevation profile tool that allows students to create an elevation profile of an area in the map viewer by drawing a line across that area (Figure 8). The elevation profile tool simultaneously displays the elevation of a specific point on the map that corresponds to the displayed map profile. When an elevation profile line is drawn across the Mid-Atlantic Ridge, the resulting profile permits the user to readily observe the symmetry in age and bathymetry across the plate boundary that lies along the mid-ocean ridge (see Figure 8). In the investigation, students use the elevation profile tool to discover a geospatial relationship that ocean bathymetry is related to both surface heat flow and the age of the ocean floor. Students learn that younger ocean floor is warmer and therefore more buoyant, resulting in higher elevations. As the ocean floor cools and spreads away from the divergent boundary, it sinks and decreases in elevation. In the last part of this investigation, students learn about surface heat flow near hot spots. They identify which plates have the most hotspots and learn how lithosphere thickness and plate speed affect hotspot abundance by examining the distribution of hot spot locations and plate movement vectors.

### *What happens when plates diverge?*

In this investigation, students locate and study different divergent boundaries using the Web GIS. They investigate how tectonic stresses are accommodated at the plate boundary by examining earthquake and fault data and calculating the half-spreading rate of a plate boundary. In addition, they use the Web GIS to investigate features of passive margins and compare it to the lithospheric structure near an active spreading ridge from which all passive margins originated.

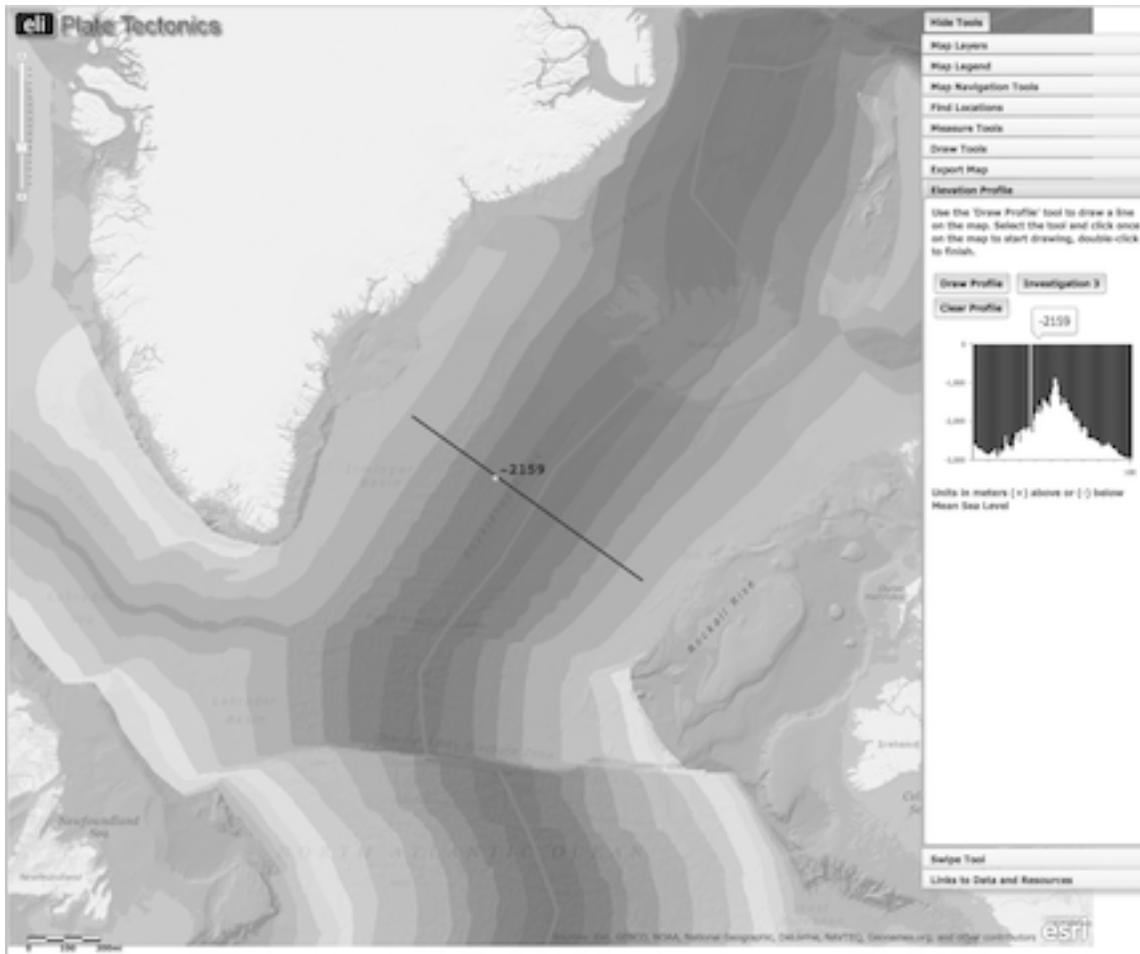


Figure 8. An elevation profile drawn using the elevation profile tool. The light dot on the profile line corresponds to the vertical light line on the elevation profile graph.

Students begin this investigation by exploring geospatial patterns of ocean bathymetry surrounding divergent boundaries on the ocean floor at the Mid-Atlantic Ridge (divergent plate boundary opening the Atlantic Ocean) and the East Pacific Rise (divergent plate boundary opening the Pacific Ocean). Students display the *Enhanced Bathymetry/Topography* layer on the Web GIS to help them visualize bathymetric changes away from the ridge. On the map viewer, darker shades of blue represent lower elevations (deeper water) and lighter shades of blue represent higher elevations (shallower water). The shades of blue are lightest along the divergent boundaries and become darker towards the continents. This helps students visualize a geospatial

pattern that the divergent boundaries - the Mid-Atlantic Ridge and East Pacific Rise – are located at a high elevation and the elevation of the ocean floor decreases as it moves towards the continents.

In the next section of the investigation, students discover the relationship between earthquakes and divergent boundaries. Students perform a series of data queries to discover patterns of earthquakes along the divergent plate boundaries. The query results display a pattern of extensional earthquake epicenters located on divergent plate boundaries. Further queries using different earthquake epicenter depths helps students visualize that most earthquakes occur at shallower depths (less than 10 km) along divergent boundaries and do not occur at greater depths. Using the Web GIS, students display the *Lithosphere Thickness* and *Surface Heat Flow* layers to discover that earthquakes do not occur at great depths because the lithosphere is too thin and too hot for earthquakes to occur at those locations. Next, students use the *distance measure* tool to calculate the half-spreading rate of the Mid-Atlantic Ridge and East Pacific Rise divergent plate boundaries. They learn that the East Pacific Rise is spreading 4.6 times faster than the Mid-Atlantic Ridge. Students can thus determine that spreading centers in oceans bounded by passive margins have slower spreading rates than those bounded by subduction zones.

The investigation continues as students discover how passive continental margins form. Students first view an embedded graphical image of a passive continental margin located off the east coast of North America. Students then activate the *marine gravity anomaly* layer. This layer displays changes in gravity and provides a geospatial visualization to help learners understand how continental crust transitions to oceanic crust at a passive continental margin. Stronger gravitational forces are represented by the red-yellow color in the Web GIS. Weaker

gravitational forces are represented by blue-green color. Differences in gravitational forces occur because continental crust and oceanic crust have different compositions and different densities. Oceanic crust is more dense than continental crust. A change in gravity occurs across the continental margin because the density changes at the transition boundary between continental crust and oceanic crust. This is indicated by locations on the map viewer where red/yellow colors appear next to blue/green colors when the marine gravity anomaly layer is displayed. To help students clearly see this boundary, we developed a *continental boundaries* tool that outlines the continental margins of North America and Africa as a thick black line. Students then use the swipe tool to help them visualize the transition from continent to oceanic lithosphere (see Figure 9).

To conclude the investigation, students use the continent boundaries tool to reconstruct the paleogeography of the North American and African continents to 90 million years ago to further understand how ocean floor spreading produces plate motion and leads to the formation of passive margins along the coasts of these two continents. Students first place the continents at the Mid-Atlantic Ridge, and then, using the map legend for the *age of the ocean floor* layer, determine and place the continents at the location where they were positioned approximately 90 million years ago. Students then click on the outline of each continent to drag and rotate it to simulate its ancient location.

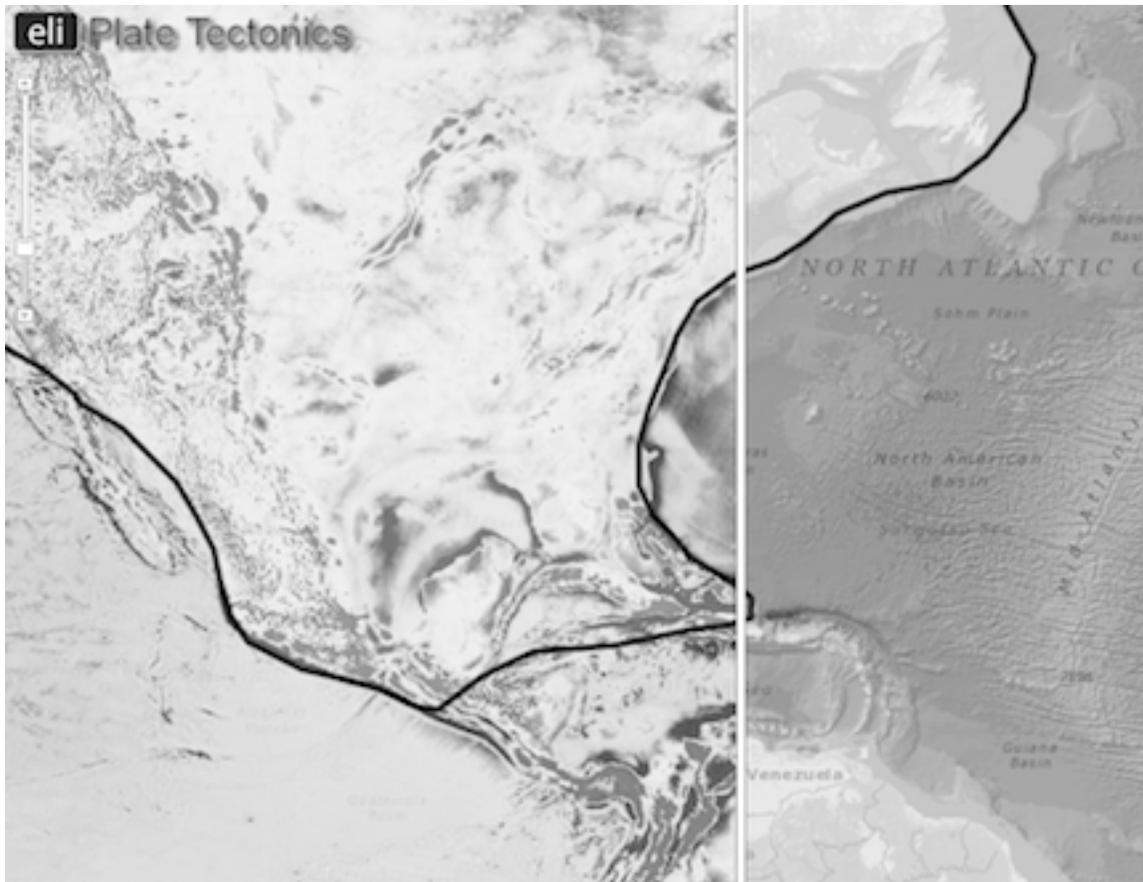


Figure 9. Web GIS displaying the marine gravity anomaly layer and the continental margin boundary (thick black line) with the swipe tool (thick white line) activated.

*What happens when plates move sideways past each other?*

In this investigation, students study an oceanic transform boundary, the Charlie-Gibbs Fracture zone, using earthquake and age of the ocean floor data. They then investigate a continental transform boundary at the San Andreas Fault zone and view historical photographs embedded in the Web GIS and earthquake data to learn about the seismic hazards associated with living on a continental transform boundary.

Students begin this investigation by exploring an oceanic transform boundary at the Charlie-Gibbs fracture zone. They use the *query earthquakes* tool to determine the geospatial relationships between earthquakes and different plate boundaries. The *query earthquakes* tool allows students to specify an earthquake depth (all depths, greater than 100 km, between 10 and

100 km, or less than 10 km) and type (extensional, contractional, or transform) and then display the results in the map viewer. The resulting visualizations show a geospatial pattern that transform earthquakes occur on transform faults and are typically greater than 100 km deep and extensional earthquakes are found on divergent boundaries and are shallow (less than 10 km deep). Students can learn more about each earthquake by clicking on them in the Web GIS; a pop-up data box display appears with additional information including the date the earthquake occurred, its magnitude, and focal depth. The Web GIS also includes embedded videos to help students visualize the different plate motions that occur at divergent and transform boundaries.

Students then explore the lithosphere on both sides of the Charlie-Gibbs Fracture zone to distinguish the active transform plate boundary from the rest of the fracture zone. The *age of the ocean floor* layer is displayed. The color bands that represent the age are “offset”, and do not line up on opposite sides of the fracture zone (see Figure 10). The students view an embedded video in the GIS to observe different plate movement patterns at the active transform fault and at the inactive fracture. Students then use the *polyline* tool to draw the plate motions they observed in the video onto their GIS map. They first draw arrowheads on each of the four bold line segments that point in the direction that the crust is spreading away from the divergent boundaries (Figure 10). Next, students draw arrowheads on each of the six thin line segments that point in the direction that the crust is spreading away from the divergent boundaries on each side of the Charlie Gibbs Fracture Zone. Students then identify more fracture zones in the Atlantic Ocean by looking for patterns of offset ocean floor ages.

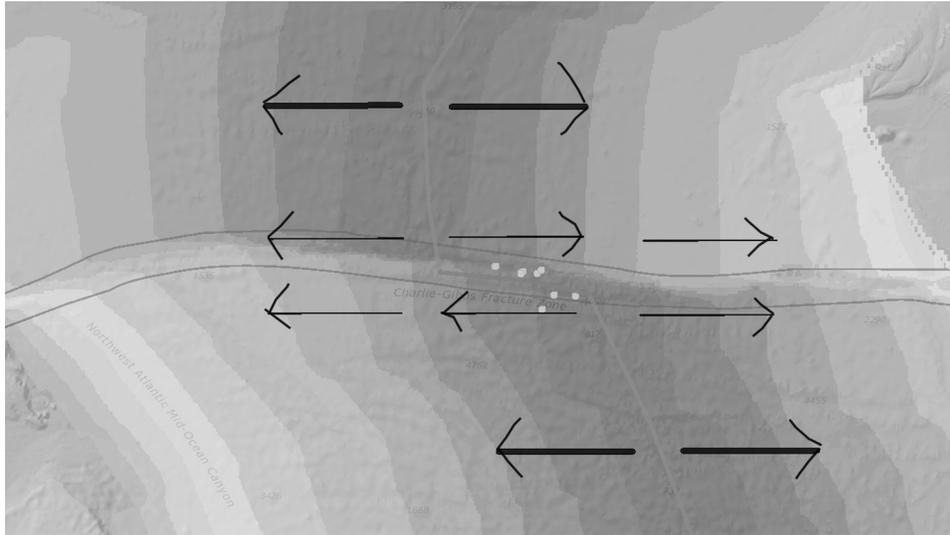


Figure 10. The Charlie-Gibbs fracture zone with student-drawn arrows showing the direction the plates are moving. Deep transform earthquake epicenters (yellow circles), plate boundaries, and the age of the ocean floor data layers are displayed.

To conclude the investigation, students examine a continental transform boundary at the San Andreas Fault zone. We included a specific *GPS plate vector data* layer and embedded videos to help students understand the dynamic plate motion that occurs in this fault zone. Next, students examine population density, seismic hazard data, historic earthquake epicenters and historical images to understand the risks involved with living in this area.

*What happens when plates collide?*

In this investigation, students analyze the distribution of earthquakes and volcanoes using the Web GIS to learn about plate collision at an ocean-ocean subduction zone and at an ocean-continent subduction zone. They discover the relationship between the subduction zones and volcanoes, and determine the slope of a subducting slab along a convergent plate boundary. Students also learn about the types of landforms created by continents colliding at convergent zones.

Students begin this investigation by navigating to a preset study area of the Aleutian Islands in the Web GIS with the *enhanced bathymetry/topography* layer activated. Next, they analyze a pre-drawn elevation profile that crosses the Aleutian Trench off the coast of Alaska. The elevation profile displays a sharp contrast in elevation of the subducting plate (6,921 m below sea level) and the overriding plate (2,517 meters in elevation). Students then identify the subducting and overriding plate names by clicking on the Web GIS map viewer.

Students continue the investigation by using the *polyline* tool to outline the subduction zone boundary by tracing the path of the deepest water, which is displayed as dark blue in the map viewer. They then activate the *Global Plate Vectors* and *Volcanoes (Composite Only)* layers to determine what types of plate boundaries lie on the line they just drew. They then view an embedded video in the map viewer that shows a subduction zone where ocean crust is subducting underneath lithospheric crust to help visualize the tectonic processes that occur at that location.

Next, students use the *Subduction Profile* tool to compare two subduction zone profiles that display the depth to slab location, earthquakes, and volcanoes layers at two locations: one where ocean crust is subducting underneath continental crust at Kodiak Island (see Figure 11) and one where ocean crust is subducting underneath ocean crust at Atka Island. This tool provides students with an interactive geospatial visualization in the Web GIS. When students place their cursor over the profile line on the map viewer, they see the corresponding point on the subduction zone profile display. Using the subduction zone profile tool, students can identify the downgoing plate as the locus of deep earthquakes, and the overriding plate as the location of volcanoes at the surface. In the investigation, students analyze these two profiles and observe

that the angle of the subducting slab is steeper where ocean is subducting underneath continent than where ocean is subducting underneath ocean.

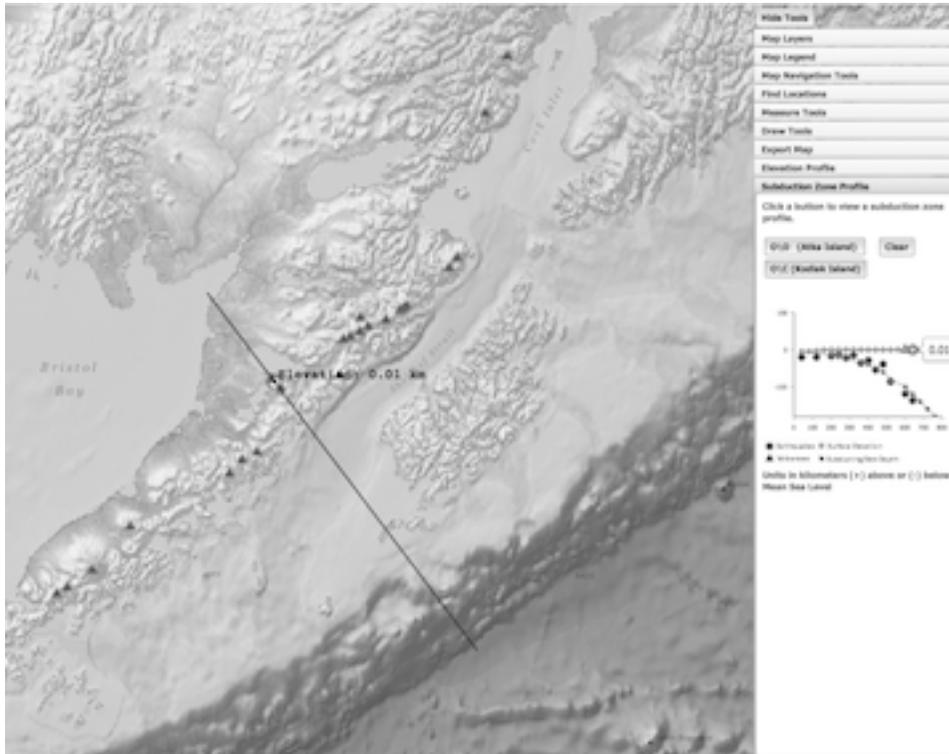


Figure 11. Subduction zone profile at Kodiak Island, an ocean/continent subduction zone. The subduction zone profile tool displays surface elevation above sea level (light blue circles), earthquakes (red circles), volcanoes (purple triangles) and subducting slab depth (gray circles). Note that the volcano elevation on the map viewer is also displayed in the subduction zone profile.

To conclude the investigation, students recreate a continent collision between North America and Africa to learn about convergent zones and how the Appalachian Mountains were formed. In the Web GIS, students highlight the continental boundaries of North America and Africa and then drag and rotate Africa to collide with North America, thus simulating how these plates collided resulting in the formation of the Appalachian Mountains.

## Conclusion

Web GIS, when appropriately designed, is a powerful visual instructional technology that can be used to promote GTR for middle level students. In a recent curriculum implementation study of the Web GIS Tectonics investigations, urban middle level students significantly increased both their tectonics content knowledge and GTR (see Bodzin, Fu, Bresser, & Vallera, 2014).

A GIS consists of map information, a database, and a computer interface that ties them together to create a visualization tool for geospatial analysis. A GIS allows users to select different layers of information to construct a map. Most of the information we have about our world contains a location reference, placing that information at some point on the globe. A GIS uses a framework of location to generate and display georeferenced data from many sources and display it on a computer screen with data-defined color schemes. The data layers in a GIS is analagous to using a series of color transparent overlay maps, drawn at the same scale, that are placed on top of a hard copy map or diagram. GIS offers teachers and their students enhanced learning opportunities to quickly examine how attributes shown in one layer may be spatially related to data in another layer. GIS also permits learners to easily query, analyze, and display geographical information and produce new data-defined color visualizations in the process. In addition, GIS permits users to adjust the scale representation of the map, thus, aiding learners with making inferences about geospatial patterns and geospatial realtionships.

The curriculum examples presented in this chapter illustrate how freely available Web GIS can enable students to visualize geospatial data patterns and relationships on the Earth's surface that are much more difficult to reveal using more traditional paper-based materials. Design and development groups have created interactive Web GIS interfaces that are designed to

be user-friendly for middle level students. Classroom teachers and developers can take advantage of robust Web platforms such as ESRI's Explorer for ArcGIS (see <http://www.esri.com/software/explorer-for-arcgis>) to create their own interactive Web maps to provide geospatial learning experiences for learning science. The learning activities highlighted in this chapter illustrate how Web GIS can be used to promote GTR using geospatial visualizations for important Earth and environmental science content.

Web GIS is a rapidly growing technology and has great potential for transforming science education with novel and interactive visualizations. The Web GIS interface integrates graphics, multimedia, and animations that allow users to explore and discover geospatial patterns that are not easily recognized. The GIS tool set enables learners to view, manipulate, and analyze rich data sets from local to global scales and to dynamically explore multiple large data sets simultaneously. The ability to experiment interactively with the data sets facilitates student self-discovery through data exploration promoting student engagement. The Web GIS allows students to work at their own pace and to develop their scientific intuition using authentic science practices. The Web GIS also eases classroom management by maximizing time on task allowing faster assignment dissemination, making rich background content available, and allowing for real-time student feedback.

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