The Hidden Earth Curriculum Project: Spatial Visualization in Undergraduate Geoscience Courses

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Spatial visualization abilities are an essential component to undergraduate geology courses. In such courses, students learn to visualize three-dimensional topography from two-dimensional topographic maps by building mental representations from wavy contour lines. Students learn to observe landscapes and extract clues about how that landscape formed. They also learn about the three-dimensional geometries of geologic structures and how these are expressed on the earth's surface or on geologic maps. From such data, students reconstruct the geologic history of areas, trying to visualize the sequence of ancient events that formed our modern landscape.

The Hidden Earth Curriculum Project, funded by the NSF CCLI program, was conceived to develop interactive animations to help students learn the various types of visualization abilities, to assess these abilities and how they improve as a result of instruction, and to design modules based on modern pedagogy and best practice. The materials developed have been extensively researched at our university, where over 2,500 students a year take introductory geology courses. The materials are also widely used in universities, colleges, and high schools across the U.S. and as far away as Papua, New Guinea. In this chapter, we highlight some of the material we have developed as well as some of the research results.

Hidden Earth Curriculum Project

As part of the Hidden Earth Curriculum Project, and our earlier NSF-funded Hidden Earth Project, we developed interactive animations and modules to improve and assess college students' visualization abilities. Most animations are QuickTime Virtual Reality (QTVR) movies with which students interact by clicking and dragging the mouse. QTVR movies have the advantage that they require student involvement: if the student does not click and drag with the mouse, nothing happens in the movie. We have developed two types of QTVR movies. QTVR panorama movies are single images, perhaps stitched together from several images, that students can scroll and zoom to gain different perspectives. QTVR object movies contain a matrix of images (Figure 1), where clicking and dragging horizontally in the movie moves from one image to another along a row, whereas clicking and dragging vertically moves up or down a column from one row to another. QTVR object movies allow us to create movies in which students can rotate, cut into, erode, or make partially transparent any objects or terrains. Such movies

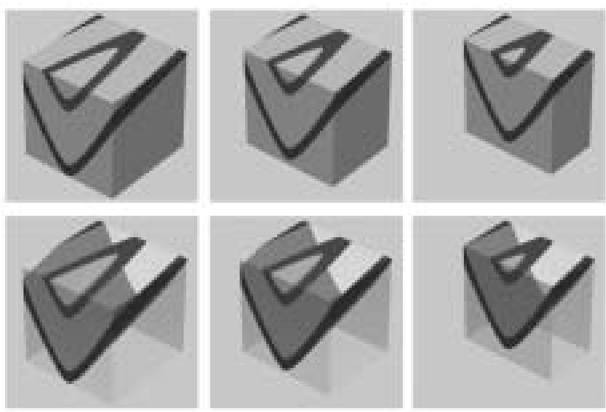

Figure 1. Matrix of images in a QTVR object movie. Clicking and dragging horizontally moves from one image to another within a row, whereas clicking and dragging vertically moves from one row to the next.

have huge advantages over traditional materials, such as those printed on paper, because they allow actions that are otherwise not possible, such as changing the shading on a terrain or the transparency of a geologic block.

One of the most important abilities for students in undergraduate geology courses is the ability to visualize topography from topographic maps, which are used as base maps for many types of geologic problems. To support the improvement of such abilities, we developed a large array of interactive animations about topography. Using QTVR object movies, students can change a two-dimensional topographic map into a three-dimensional–appearing shaded land surface (Figure 2). Students can rotate and tilt a geologic terrain, upon which topographic contours have been draped, to gain different perspectives and to observe how the shape of the land surface corresponds to the shape and spacing of contours. They can flood a contour-draped terrain with virtual water to observe the correspondence of elevations and contours. Students can progressively slice into topographic terrains to observe a series of topographic profiles of that terrain. They can practice how to locate themselves on a topographic map by using virtual topographic terrains upon which topographic features have been numbered. The Visualizing Topography module is used in a number of other colleges across the U.S. and internationally.

Another important spatial ability is for students to be able to visualize the three-dimensional geometry of geologic structures, such as horizontal and tilted layers, folds, and faults. To help students gain such abilities, we created over 250 interactive QTVR object movies of geologic blocks in which students could rotate, slice into, and erode blocks, as well as displace faults, progressively uncover buried geologic structures, and make the blocks partially transparent to reveal their internal structure (Figure 1). These movies are imbedded into the Interactive 3D Geologic Blocks module, which has versions for a general studies geology course and an upper-level structural geology course. In this module, students are asked to sketch and predict how geologic structures would be exposed on the sides or the interior of the blocks. Such sketches and predictions require the students to use and improve their overall spatial visualization abilities.

After students are able to visualize geologic structures in the relatively simple confines of geologic blocks, they investigate how geologic structures interact with topography and how they are represented on geologic maps. Using our "Interaction of Layers and Topography" QTVR movies, students can adjust the tilt of a plane to investigate how it intersects simple topographic features, such as a hill or valley (Figure 3). Using the knowledge they gain from this experience, students can observe the expression of layers on natural landscapes and, at a glance, determine the orientation of the layer at depth. Similar intersections of layers and topography are expressed on geologic maps, which show boundaries between geologic formations as lines that zigzag

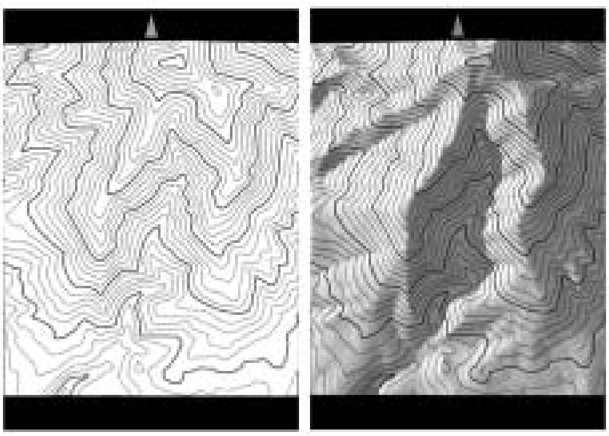

Figure 2. Frames in a QTVR movie from the Visualizing Topography module. The left image shows an unshaded contour map, which the student can progressively turn into the shaded relief map on the right.

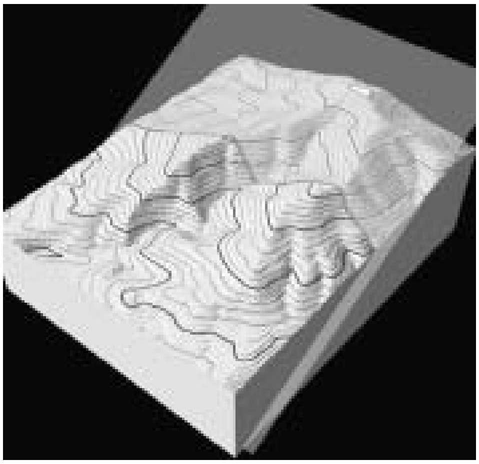

Figure 3. One image from a QTVR movie showing the interaction of layers and topography. The partially transparent plane, representing a tilted geologic layer, intersects the contour-draped terrain along the thicker gray line.

across a topographic base map. Students investigate these interactions using QTVR panorama and object movies of geologic maps draped over digital topography (Figure 4). These movies permit students to zoom in and out and spin the map-draped terrain to gain the best perspective to understand the orientation of the layers and to reconstruct the geologic history (sequence of events) as recorded on the map. Such movies have been successfully used in the general studies geology course and several upper-division courses.

The Visualizing Topography and Interactive 3D Geologic Blocks modules were used in a research experiment, in which two introductory geology lab sections used the modules and two lab sections were a control group taught without the modules (Piburn et al., 2002, in press). Students were pre- and posttested with a content-related geospatial test and with several standard tests of spatial visualization. The students who used the materials had higher gains, compared with the control group, in their scores on the geospatial test and in their general spatial abilities as measured by a standard test of spatial visualization. Also, although males scored higher on all pretests, using the modules resulted in higher gains for females and identical scores for the two genders as a result of instruction (Piburn et al., 2002, in press).

One of the main goals of general studies geology courses across the country is to teach students how to observe and interpret the geologic scenery around them. Professional geologists use several strategies, perhaps automatically, when they observe and interpret such scenes. For example, geologists are trained to observe the important geologic features among all the "visual noise" present in all natural scenes. Also, geologists commonly mentally explore a landscape by focusing their attention on one geologic aspect at a time (layers versus fractures, bedrock versus loose pieces of rock). To help undergraduate students gain similar strategies, we developed the Visualizing Landscapes web-based module. In this module, photographs of landscapes are annotated in a graphic program to highlight the different geologic features, one at a time. Through such annotated images, students can learn to recognize the same attributes that professional geologists do, such as the difference between layers and fractures.

Another aspect of natural landscapes with which students commonly have difficulty is understanding how geologic scenes are constructed by a series of events that formed the sequence of rocks, followed by erosion that sculpted the landscape. We assessed student preconceptions about how changing geologic environments can deposit a sequence of different kinds of geologic rocks, such as occurs when seas move in and out across the land. After identifying these misconceptions through surveys and interviews, we developed a Sedimentary Environments module built around interactive QTVR movies. Using these movies, students can move seas in and out and see how this results in a sequence of sandstones, limestones, and other rocks (Figure 5). Then, students can uplift and erode these rock layers to learn how this sequence might appear in a landscape. Using control and experimental groups, we demonstrated that the modules were better than traditional methods at helping students

Figure 4. A geologic map draped over digital topography and shaded for a folded area in the Appalachian Mountains.

Figure 5. One image from a QTVR movie showing sand dunes encroaching over beach deposits along a shoreline.

Figure 6. Images from two Biosphere 3D QTVR movies. The image on the left shows annual total precipitation for Africa and adjacent regions. Higher amounts of precipitation are shaded darker. The image on the right shows the location of earthquakes colored by magnitude and plotted on a shaded relief globe showing the Indonesia-Australia region.

understand changing environments and sequences of geologic events.

On a larger scale, geology and climate control the environments in which plants, animals, and humans can survive. To help students investigate environmental factors, we developed the "Biosphere 3D" website, http://www-glg.la.asu.edu/~sreynolds/biosphere3d. This site has several hundred interactive QTVR movies showing the distribution of geologic, climatic, and ecologic factors draped on virtual globes of the earth (Figure 6). Among the geologic factors shown are the distribution of earthquakes, volcanoes, plate boundaries, tsunamis, and loss of life from these. Climatic factors shown include average annual precipitation, land temperatures, sea temperatures, wind directions, atmospheric pressure, and ocean currents. Ecologic aspects include growing days, the distribution of croplands, and world vegetation zones. QTVR object movies permit students to spin a virtual globe to the region of interest and then compare different factors, such as earthquakes versus volcanoes or ocean currents versus average annual precipitation. This website enables students to explore the earth using real scientific data and to better understand the environment around them.

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