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## Lessons Learned While Teaching Earth Science With GIS

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The SAGUARO (Science and GIS: Unleashing Analysis and Research Opportunities) project has developed GIS-based earth science curriculum materials for introductory-level undergraduate and secondary school students (Hall-Wallace et al., 2003, 2004). The activities use the "teach with GIS" model and incorporate many of the design considerations of previous GIS-based teaching modules (Carstensen et al., 1993; Thompson et al., 1997; Lloyd, 2001). This chapter reviews the evolution of GIS teaching methods, presents our perspectives on the challenges to developing and distributing GIS-based teaching materials, and discusses the techniques we used to overcome these obstacles. Our experience comes from the frontlines of the push to incorporate spatial technology into the general educational experience of all students at the undergraduate and secondary school levels, not just those majoring in the disciplines typically associated with GIS.

### Teaching About GIS, Teaching With GIS

Traditional approaches to teaching GIS have been tool-centric, focusing on the theoretical and computational underpinnings of spatial data representation and analysis and the use of specific software packages in upper-division college courses (Sui, 1995). Jenkins (1991) offered an early and scathing appraisal of a "narrowly vocational" technology-centered GIS education, a criticism echoed by Sui (1995). Others have noted that undergraduate GIS programs typically emphasize software skills over conceptual depth, a practice that reduces students' ability to cope with the technological change that characterizes GIS and their ability to distinguish and propose solutions to the spatial elements of

problems (University Consortium for Geographic Information Science, 1997, 2002).

In response to this criticism, an alternative approach emphasizing the use of GIS as a teaching tool began to emerge in the early 1990s (Jenkins, 1991; Thompson, 1991; Kemp et al., 1992; Carstensen et al., 1993). Sui (1995) articulated the "teach with GIS" and "teach about GIS" philosophies, stating that the "teach with GIS" method stresses the use of GIS as a teaching tool, moving software-specific procedural steps as well as the underlying GIS theory into the background of the educational process. Making GIS use transparent to the student shifts the focus to learning science and geography concepts and spatial problem-solving and moves GIS education from "mere technical training to more stimulating education" (Thompson et al., 1997; Sui, 1995). There are several important education advantages to teaching with GIS. First, this approach allows GIS to be introduced to students earlier in their education. Sufficient pre-processing or automation mitigates the need to have a full understanding of spatial and statistical analytical techniques typically reserved for the upper-level undergraduate student (Kemp et al., 1992; Carstensen et al., 1993; Thompson et al., 1997). Second, teaching with GIS presents an opportunity to establish GIS as a tool for problem-solving, which is lost when GIS education focuses solely on the technology (Pattison, 1964; Sui, 1995). Third, instructors less proficient with GIS can better incorporate the technology into their courses, thereby introducing a broader student audience to GIS (Lloyd, 2001). This is accomplished by minimizing student interaction with the GIS while maximizing their time learning the science or geography content.

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The use of GIS in lower-level courses is supported by research that shows students prefer a combination of traditional and computer-based instruction (Wentz et al., 1999). It also provides an important opportunity to expose non-GIS majors and pre-service K-12 teachers to GIS, because these students often take these courses to fulfill science electives. With an estimated 50% turnover of the nation's K-12 teachers expected in the first decade of this century (Bettis, 2001), incorporating GIS-based learning into introductory courses represents an opportunity to introduce GIS and strategies for teaching with a GIS to the next generation of teachers.

### Lessons From the SAGUARO Project

The primary obstacle to implementing the "teach with GIS" strategy remains the relative scarcity of GIS-based teaching materials, a scarcity directly related to the time-consuming nature of creating these materials (Sui, 1995; Meyer et al., 1999; Lloyd, 2001). To address this problem and promote the use of GIS in the earth sciences, the SAGUARO project team developed GIS-based activities to examine earth processes at multiple scales and investigate the relationship between these processes and society. Below, we outline our approach to building curriculum modules that use GIS as a learning instrument. We found that simplifying the experience for both the student and the instructor was critical to successful use of the modules.

#### Lesson 1: Simplify the user's experience

Traditionally, GIS-based teaching curricula have extensively modified the ArcView user interface and removed tools to create a pedagogically simple interface to the user (Thompson et al., 1997; Keiper, 1999; Lloyd, 2001; Lo et al., 2002). The SAGUARO project took a different approach and made only slight modifications to the basic interface and, in fact, added utilities to the interface rather than removing them. From our perspective, the key to a successful educational experience with GIS lies not in the elimination of menus and icons that the students don't use, but in the simplification of the menus that they use and the procedures that they follow. Like most software, ArcView's functionality is accessed through menus and submenus. Instructions that lead students through the steps to perform even basic procedures can become quite complex and often frustrate

students unnecessarily. We have found that by streamlining, automating, or even eliminating multiple-step command sequences, students' frustration is minimized, and their attention remains focused on the scientific problem rather than on the software. Thompson et al. (1997) had similar experiences. The SAGUARO activities use a variety of strategies to minimize student distraction during an activity. These include providing preconstructed views to avoid having students negotiate directory structures to insert cryptically named themes into a view and having students load precreated legends (to ensure relationships are clearly visible) rather than have them symbolize themes.

To enhance the learning experience, we added three icons to ArcView's graphical user interface. We added a toolbar button that allows students to rapidly switch between geographic and orthographic projections and to rotate the orthographic projection when visible. Student frustration with the sequence of commands required to change the projection of an ArcView view window prompted us to implement the icon to switch projections. We added a Quick Load button that allows easy loading of complex queries in dialog boxes, changing of views, or zooming to a preset view extent to resolve a pattern or relationship. The latter feature helps students who are geographically challenged to find specific regions of the world. We also added a Media Viewer button that provides access to multimedia data that aren't tied to a particular location (i.e., they are not quite suitable for ArcView's location-dependent hot linking function but are still relevant to the particular topic being investigated).

The Media Viewer provides access to movies, images, websites, and other visuals that are tied to a concept rather than a geographic location. Thus, students can investigate the 1993 Hokkaido earthquake, for example, using both the GIS and supporting multimedia. Using ArcView's measuring tools, students determine the distance from the earthquake's epicenter to Okushiri Island and calculate the advance warning the residents of coastal communities had of an impending tsunami. Their chilling answer, that residents had only 5 minutes to evacuate, is buttressed when students use the Media Viewer to launch computer simulations of the tsunami wave sweeping over the resort community Aonae and view photos that illustrate the tremendous devastation inflicted on the town.

When teaching with GIS, it is tempting to try to teach about GIS at the same time. For example, in an early proto-

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type of the SAGUARO module on tropical cyclones, we wanted to have students create graphics that enclosed different portions of the Atlantic Ocean. Students would then select sections of the Atlantic hurricane tracks contained within the graphics (i.e., perform a select by graphic spatial overlay operation) and calculate statistics to learn about the relationship between hurricane wind speeds and their location. They would also learn how to add graphical elements into an ArcView view window. Unfortunately, through classroom testing and direct observation by the development team, we found that students were frustrated by the mechanics of creating the boxes. Questions abounded: "Where exactly was the Caribbean Sea? Where is the dividing line between the north and South Atlantic Ocean?" Even with explicit written directions, the activity was simply too free-form. We tried many approaches to improve the instructions, but students still had problems and were frustrated because they spent too much time on the tool and not enough time thinking about the science. Our solution was to give the students the graphic boxes and have them use the precreated boxes to perform the select by graphic operation, calculate the statistics, and obtain the critical information. The lesson we learned—to forget about trying to teach about the tool and stick to teaching science—is one whose importance is hammered home every time we field-test our activities.

#### Lesson 2: Simplify the data

In addition to simplifying functional procedures, it is important to simplify both spatial and nonspatial components of the GIS data to focus students' attention on the critical information. This is particularly important when the activity calls for an operation that involves opening the theme table or performing a query. In the SAGUARO activity investigating U.S. water use, the tabular data distributed by the U.S. Geological Survey include over 150 attribute fields labeled in a cryptic coding scheme. To make these data more understandable to students, most of the attributes are stripped away, leaving only the fields the students need to investigate the major water use patterns. Spatial data are typically simplified in two basic ways. Raster data sets are aggregated (if the grid resolution is high) and converted into the ArcView shape file format. This eliminates the need for ArcView's Spatial Analyst extension, which adds complexity to the lesson and increases the software and hardware costs of teaching with GIS. For example, the U.S. annual precipitation

data (raster format) were obtained as an American Standard Code for Information Interchange (ASCII) grid with a grid cell resolution of 2 square miles. To facilitate processing in an exclusively vector environment, the grids were aggregated by a factor of 10 and converted into a shape file, allowing students to qualitatively and quantitatively explore precipitation patterns nationwide.

The second data simplification process involves generalizing the vector data sets into manageable (i.e., smaller than 5 MB and often less than 1.5 MB) sizes. This reduces screen redraw times on the older, slower machines that typify the computer teaching resources at both the collegiate and secondary school environments. Through classroom testing, we have discovered that minimizing screen refresh times is critical, because students become frustrated and distracted from the learning experience while waiting for a screen to redraw.

#### Lesson 3: Structure activities to address science and geography standards

The national science and geography standards (National Research Council, 1996; National Council for Geographic Education, 1994) provide useful frameworks around which to design GIS-based teaching modules. Both sets of standards emphasize inquiry as a way of learning, use of science, technology and geography to address societal problems, understanding the nature and history of science and geography, and using unifying concepts and processes to understand earth as a system. The SAGUARO project modules investigate plate tectonics and geologic hazards, tropical cyclones, water resources, and ocean systems, using the science and geography standards and a progressive increase in geographic scale to thoroughly explore each topic.

Each module begins at the global scale to explore fundamental spatial and scientific properties of the earth's physical systems, to review pertinent geography and scientific nomenclature, and to set the stage for large-scale investigations. For example, in the tropical cyclones module, students examine the global distribution of locations where tropical cyclones first formed over the last 50 years. Students next load a legend that classifies these formation points by the season in which they formed. This illuminates a pronounced relationship between the hemisphere in which the cyclones form and the season of the year.

After using the Media Viewer to watch a movie showing

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how sea surface temperatures change during a year, students use a precreated legend to classify the formation points by the sea surface temperature at which the cyclones formed. They graph the number of cyclones in each temperature category, which reveals the fundamental concept that tropical cyclones typically form at sea surface temperatures of 80°F or higher. This discovery process has exposed students to GIS data classification procedures and creating and interpreting graphs, all in the context of investigating the relationship between the earth's seasons, the dynamics of sea surface temperatures, and the formation of tropical cyclones. A global-scale investigation in the Exploring Water Resources module examines the impact of future sea-level rise scenarios on coastal cities and critical cropland, whereas one in the Exploring the Dynamic Earth module investigates historic patterns of major deadly earthquakes from 186 BC to present and links the temporal distribution to the diffusion of written historical record keeping. These global-scale activities emphasize inquiry, the importance of science and technology to society, and the fundamental science and geography concepts behind these processes.

After the global scale investigations, the activities progress to larger scales. This telescoping of scales is important for engaging student interest (Klein, 1993; Thompson et al., 1997; Keiper, 1999). After all, the global patterns of tropical cyclone formation points are interesting but may not have any real meaning to the student. Have students look at the people and places affected by a devastating hurricane that occurred in a place physically and emotionally close to home and the event assumes a human dimension that reinforces the importance of understanding science. Progressing to larger scales also exposes students to basic aspects of spatial data representation and provides opportunities for spatial analysis of human and natural resource data sets.

The regional and local investigations explore the societal connections to the natural world to a greater degree than the global-scale activities. For example, the case study in the tropical cyclones module explores the impact of a major hurricane on New York City. Students use hurricane storm-surge data to determine the extent of flooding likely from a category 4 hurricane. They then use census block data to identify areas with high concentrations of elderly, low-income, and non-English-speaking people in the greater New York City

area. Students then perform a spatial overlay operation to determine which of the identified census blocks are subject to inundation by the storm surge and use this information to develop evacuation strategies for emergency management personnel.

#### Lesson 4: Facilitate distribution

The eclectic hardware and software environments that characterize both university teaching labs and secondary school computer resources have also served to dictate the final makeup of the SAGUARO project modules. Small file sizes and purely vector data were concessions to older machines and limited budgets. Scripts are run to adjust the windows to fit any monitor resolution and position the window in the upper left corner of the computer screen. The continued importance of Apple Macintosh computers in the education market prompts us to design our materials for use with ArcView 3.0a for the Macintosh. All the SAGUARO scripts verify the computer platform and respond accordingly. Finally, the project files, multimedia, and scripts will run from either the CD-ROM or from the hard drive when extracted from the CD.

#### Lessons 5: Classroom implementation and testing

One challenge of introducing GIS-based instruction can be providing access to the hardware and software, especially for classes with large enrollments (100–1,000 students). The modules were extensively tested at the University of Arizona, which, like many colleges and universities, has a site license for Environmental Systems Research Institute (ESRI) products that allows the use of the software for teaching purposes at little or no cost. Thus, we were able to install ArcView and the data needed to complete the assignments in university computer labs and in our library. The workbooks and data sets we have created also come with a 120-day ArcView license, which allows any student with a computer to complete the assignments at home.

Our materials have been used successfully as homework and as extra credit in several large lecture courses for non-science majors, with enrollments ranging from 175 to 350 students. None of the professors teaching these courses use GIS in any research capacity. Providing adequate technical support is important, because computer skills and con-

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confidence learning with technology varies greatly among students. In our experience, this is addressed by providing students the option of attending a help session offered when the homework is assigned. Typically, a 5-minute introduction to ArcView was given at the beginning of the session, after which the instructor and one or two teaching assistants helped students as needed. After the first help session, questions were minimal, and generally only one person was needed to staff a lab serving 50 students.

In 2002, 99% of the students using the final published version of the materials completed all the assignments on their own as homework, with an average score of 86%. Thus, we conclude that students can achieve a high level of success in learning with GIS with minimal intervention. Students expressed in interviews and course evaluations that they enjoyed the dynamic nature of the maps and the excitement of exploring real data.

## Conclusions

While teaching with technology has its challenges, we have found that it is both feasible and worthwhile to integrate GIS-based activities in large introductory-level lecture courses. The SAGUARO modules have been incorporated into introductory courses, including geology, geologic hazards, atmospheric science, hydrology, and computer applications, and into high school earth science and environmental studies courses. Designed using the national science and geography standards as a framework, the activities introduce a broad range of science and societal topics at different geographic and temporal scales and explore fundamental spatial relationships using basic and advanced visualization and analysis tools. The integration of multimedia educational resources in the SAGUARO modules enhances the learning experience, whereas attention to hardware and software technical details eliminates many potential sticking points for both the instructors and the students. More information on the curriculum is found at <http://www.scieds.com/saguaro/index.html>.

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