Integrating GIS into the Undergraduate Learning Environment[1]

William J. Lloyd

Abstract

Despite the promise of GIS, substantial barriers have prevented its widespread use in geographic education. Among the key factors are technical impediments stemming from software complexity, pedagogic issues related to the lack of experienced faculty and the shortage of curriculum materials, and systemic issues associated with faculty motivation. This case study describes strategies that were employed for addressing each of these barriers in a large enrollment, multi-section world geography course. Successful implementation of those strategies has enabled large numbers of students in classes taught by instructors with no formal GIS experience to spend a substantial amount of time learning geography with the help of simple, easy-to-use GIS software applications.

Key Words: *GIS, geographic education, undergraduate curriculum*

William J. Lloyd is professor and chair of geography at California State University, Fullerton. His major interests include G.I.S. and the applications of technology to geographic education. He received his Ph.D. in geography from U.C.L.A. in 1977.

Journal of Geography 100:158-163

In recent years we have heard repeated calls to bring GIS into the mainstream of geographic education (Bednarz 1995, Fitzpatrick 1999). Because GIS has unique advantages for organizing and accessing spatial information, we have been urged to extend its use beyond courses in technical geography (Nellis 1994). Yet the pace of efforts to integrate GIS into the broader curriculum remains slow (Thompson et al. 1998, Bednarz et al. forthcoming). Even faculty who are comfortable teaching courses in GIS often fail to incorporate the technology into their systematic and regional geography courses. Instead, they tend to view GIS as a complex, advanced geographic technique to be taught to upper division and graduate students with a serious career interest in GIS geography (Carstensen et al. 1993). They understand how highly trained specialists can apply GIS to the mapping and spatial information needs of business and government, but reject it as too complex to put into the hands of untrained students. This leads to a dichotomy between "how to teach about GIS and how to teach with GIS" (Sui 1995, 579). What is needed are ways to empower students to learn geography through the use of GIS without the need for a heavy investment of time and energy in learning GIS (Svingen 1994, Fitzpatrick 1993, Meyer et al. 1999). This paper looks at the major impediments that serve to restrict the wider use of GIS in geographic education and describes a case study involving a set of interrelated strategies designed to help overcome those barriers.

GIS as a Tool for Active Learning

When we make GIS mapping and querying tools available to our students, we empower them to become active users of spatial data and active learners of geography. GIS and related information technologies can play an important role in constructivist approaches to education with their emphasis hands-on active learning and inquiry (Hill and Solem 1999, Bednarz et al. forthcoming). When we employ GIS to improve student access to geographic information and relationships, we are empowering students as active learners of geography (Bishop et al. 1995). GIS provides more than simply a convenient technique for organizing and retrieving spatial information; it also facilitates the kind of spatial reasoning that supports higher levels of learning among our students. An argument can be made in support of employing GIS as a facilitating technology for helping students gain geographic knowledge and intelligence. Sui (1995), for example, argues that GIS provides students of geography with a digital model of the world that can support a broad range of most if not all of the analytical methods employed by geographers.

Barriers to the Wider Integration of GIS

Three broad sets of obstacles have contributed to the lack of widespread integration of GIS into geographic education (Bednarz et al. forthcoming). The first of these revolves around technical factors such as the availability of hardware, software and data. The second has more to do with the lack of teacher training and curriculum materials. The third consists of broad systemic issues that encourage or discourage innovation in education. Any successful attempt to extend GIS across the geography curriculum will have to find ways to overcome each of these barriers. This paper describes recent efforts at California State University, Fullerton, to incorporate GIS as a geographic learning tool into a large, multi-section, world geography course. A substantial portion of student learning time was reassigned away from a traditional lecture format to a self-paced active-learning approach focusing on the use of GIS technology and a series of curriculum materials were developed that took advantage of the strengths of GIS as a tool for the interactive visualization and analysis of spatial information. This paper provides a detailed look at the strategies that were employed to overcome the technical, curriculum and systemic barriers to the use of GIS in this project.

Strategies for Incorporating GIS into Geographic Education

Beginning with the fall 1998 semester, a substantial GIS component was incorporated into the pedagogy of several sections of our introductory world geography course. World Geography (now renamed Global Geography) is a freshman-level general education course where the students, for the most part, are not strongly motivated to learn geography and are unlikely to have any prior knowledge of GIS. By the spring 2000 semester, six sections of the course containing a total of 247 students were actively using GIS as a substantial component of their learning environment. In each section, approximately one-third of the total pedagogy focused on student access to GIS, with the remaining two-thirds devoted primarily to a combination of lecture and discussion.

Overcoming Hardware and Software Barriers

At the onset of the project, two major sets of technical barriers stood in the way: a lack of adequate computer resources and the overly complex nature of GIS software. The existing department computer teaching laboratory contained computers with insufficient memory and power to drive the latest GIS software, while the number of machines was too small to handle the targeted number of students. At the same time, even supposedly user-friendly GIS software such as ESRI's *ArcView GIS* relied on a user interface whose complexity worked against the goal of having students spend their time learning geography rather than learning GIS.

The process of upgrading the computer facility began with a search for funds to replace obsolete hardware. In the early stages of the project, equipment grants totaling $94,000 were obtained from a combination of sources, including the National Science Foundation, the university's School of Humanities and Social Sciences, and the faculty senate's General Education Committee. Nearly all of those funds were spent on developing a 25-station teaching lab with supporting servers, networking, and peripherals. Once the equipment was purchased, however, it was not simply inserted into a traditional laboratory space. The goal of achieving a large-scale integration of GIS into a high-enrollment, freshman general education course required a broader rearranging of time and space that included flexible scheduling and the physical juxtaposition of class discussion space with computer space. An important goal was to create a "learning space" that would serve both non-technical as well as technical classes, a space that would encourage interaction among student as well as between students and the computer.

Along with hardware issues, the complexity of GIS software represented yet another set of technical barriers that needed to be addressed. The nature of the project and the intended audience necessitated an environment where energy would be focused on learning geography through the use of technology and not on learning the technology as an end in itself. This ruled out the direct use of even relatively simple GIS software such as ESRI's ArcView GIS since mastering the native ArcView GIS interface would require a disproportionate amount of student learning time (Figure 1).

The approach taken in this project was to customize ArcView GIS into a series of mini-applications tied to specific course learning goals. This approach is similar to previous efforts described by Carstensen et al. (1993) and Proctor and Richardson (1997) with one important exception: Today we have a new generation of software tools that make it much easier to customize and automate the GIS environment. Software tools such as the Avenue programming language that are an integral part of the ArcView GIS software package support a high degree of automation linked to simple, highly customized interfaces. The large arrays of generic buttons, menus, and tools can be eliminated in favor of a small handful of labeled buttons that are keyed directly in to the learning activity (Figure 2).

Those buttons are linked to automation scripts that allow students to apply GIS querying and mapping principles without the need to first learn about database design or GIS methods. The scripts provide students with access to GIS data layers derived from widely available datasets including ESRI's ArcAtlas: Our Earth and the five-CD dataset ESRI Data and Maps distributed with ArcView. By combining content narrowly tailored to specific geographic topics with a high degree of automation, the mini-applications permit students to spend their time using GIS to learn geography rather than wrestling with the complexities of GIS itself.

Developing GIS-Based Curriculum Materials

In all, programmed mini-applications were developed for eight distinct topics in world geography:

- Global overview of major world regions
- Global overview of climate patterns and climate controls
- Environmental opportunities and constraints in Africa

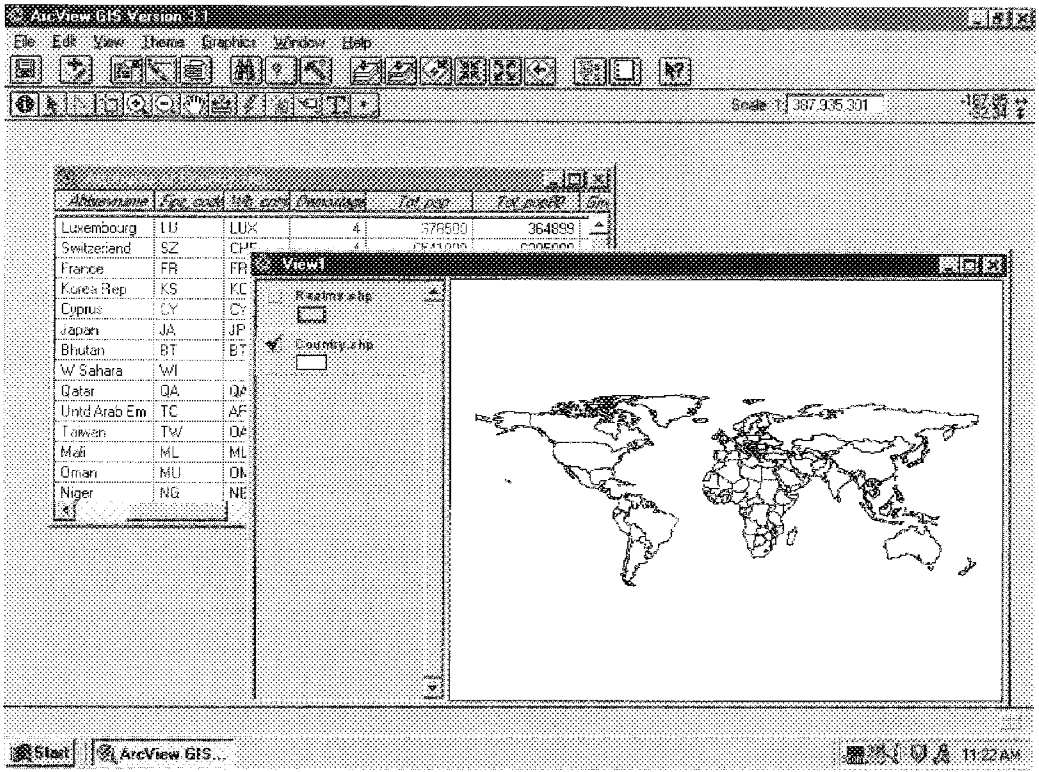

Figure 1. The native ArcView GIS interface.

and Southwest Asia

- Population geography and the demographic transition
- Uneven development in the global economy
- European imperialism and colonial empires
- Language and nationality in Europe
- Cities and suburbs in North America

Each of the eight mini-applications is linked to a detailed learning activity designed to be completed by small groups of two or three students sitting together at a computer workstation over the course of a 50-minute class period. The activities provide students with an explanation of key concepts and processes along with a sequence of prompts that structure student interaction with the GIS software and databases. Although the content of each of the activities was designed to approximate the material that would be covered in a standard 50-minute lecture/discussion, their tight focus and careful scripting did require some sacrifice of the breadth of material that would traditionally be included in a classroom lecture.

Throughout the course of each activity, students were directed to create customized maps and data queries and then were asked a series of questions about the information that appeared on the screen. The maps and queries employed a range of common GIS techniques and concepts such as point-and-click map queries, selection and mapping of individual attributes, proximity searches, overlays, and zoom in/zoom out. The manner in which GIS functionality enhanced geographic learning is illustrated through the following specific examples drawn from each of the activities:

Global overview of major world regions

Students created customized map views in two adjacent windows and then use point-in-polygon clicks, database queries, and scale changes to compare map patterns and summary statistics for countries and regions.

Global overview of climate patterns and climate controls

Students identified climate patterns through a series of world map overlays involving climate regions, latitude zones, ocean currents, wind patterns and political boundaries.

Environmental opportunities and constraints in Africa and Southwest Asia

Students selected specific features such as desert climate or savanna vegetation from physical geography layers and mapped the resulting patterns. Students then clicked on individual sites to bring up photographs that illustrated the interaction between human activities and the physical environment.

Population geography and the demographic transition

Database queries for individual countries provided three distinct views of the underlying data: a statistical table containing demographic statistics, a graph illustrating the country's relative position within the demographic transition model, and a map showing the location of the country.

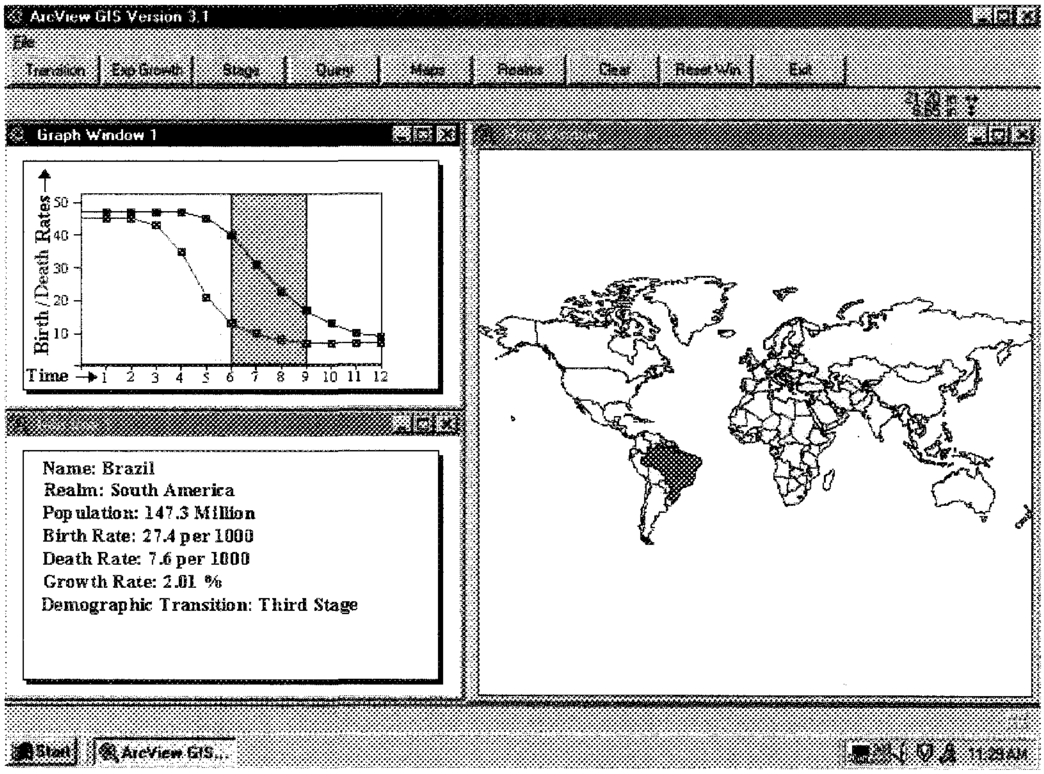

Figure 2. Example of a Customized ArcView Avenue mini-application interface

Uneven development in the global economy
Patterns of uneven development were identified by searching the database for contiguous countries with sharply differing levels of per capita income.

European imperialism and colonial empires
Changes in map projections were used to illustrate the global reach of European colonialism.

Language and nationality in Europe
A proximity search measured the degree of similarity or difference between the major language spoken in each country and the range of languages spoken in neighboring countries.

Cities and suburbs in North America
Students queried the database to identify general demographic patterns and then refined the search by introducing a second variable. For example, an initial map would show that high proportions of children are found in both inner city and outer suburban locations. Reselecting for low income would show that most areas that combine a high proportion of children with lower incomes are located in the inner city and not in the suburbs.

In each case, the use of GIS techniques, concepts, and software provided students with an interactive environment for uncovering important geographic patterns and relationships. That interaction extended beyond the student-computer link to include a continuous discussion among students of the results that appear on screen. This ability of technology to redefine the social context of learning by acting as a stimulus for student discussion was one of the unexpected bonuses arising from the use of the mini-applications.

The applications were developed using ESRI's *ArcView Avenue* programming language, the type of application-specific scripting language that is already familiar to most geographers specializing in GIS. I was the author of both the programmed mini-applications and the learning activities that accompanied them. By using this approach, I could simplify the development of the mini-applications and avoid the miscommunication and missed opportunities that can arise when an educational software developer lacks a detailed familiarity with the subject being taught (Krygier et al. 1997, Thompson et al. 1998). One disadvantage of this approach, though, was the amount of time required to complete the mini-applications, which averaged about twenty to twenty-five hours of development time per application.[2]

Overcoming Systemic Issues

The main systemic barrier to the wider integration of GIS into geographic education is the lack of faculty motivation (Bednarz et al. forthcoming). It is tempting to conclude that the problem would be solved if all geography instructors achieved a minimum competence in GIS, but that is an unrealistic expectation when dealing with a large, multi-section general-education course. Instead, the approach I took was to try to insulate the instructors from the complexity of the GIS applications. In other words, an important goal of the mini-applications was to create a learning environment that would be simple for both the faculty and students to use.

Table 1. Student Rating of Mode of Instruction

Mode of Instruction	Mean Rank
Computer-Based Instruction	3.59
Lectures Supported by Slides	3.54
Videos	3.38
Discussing Current Events	3.09
Lectures without Slides	3.02
Reading Text Book	2.93

Simplified software by itself, however, was not a sufficient faculty motivator. It was also necessary to identify individual instructors who were open to innovation. The approach I took was to work with a small number of junior faculty members who were less set in their approach to teaching. No one was compelled to incorporate GIS into their classes. Instead, those who were interested in participating were brought in as partners in a process that resembled a team-teaching approach. I encouraged them to think of the project as an experiment where multiple strategies would be tested and evaluated. Prior to the beginning of each semester, we would meet to discuss the results from the previous semester and to make any needed changes. Several graduate teaching assistants were also involved in the project. They provided instructional support for students working on the mini-applications, and equally important, they helped bolster the confidence of those instructors who were unfamiliar with GIS technology.

Student Reactions

Student response to the mini-applications has been generally favorable. At the end of the spring 1999 semester a brief survey was given to the students in which they were asked to rate the six learning environments as a use of the time they spent learning geography. They ranked each activity on a scale ranging from 1 (poor use of their time) to 5 (excellent use of their time). The survey was administered to students from several sections, all taught by the same instructor. A total of 81 students completed the survey. The results of the survey showed that students in general believed that their learning time was best spent working at the computer, viewing slide lectures, and watching and discussing videos, and not as well spent discussing current events, listening to lectures without slides, or reading the textbook (Table 1). Looking beyond student attitudes toward using GIS to learn geography, evidence from a formal assessment of student learning largely confirmed earlier work indicating that students learn at least as well using computer-based instructional materials as they do with traditional approaches to learning (Rutherford 2000, Linn 1997, Proctor and Richardson 1997). One recurring criticism did come from a small minority of students who believed that the activities were not challenging enough. Such criticism is not surprising, as the written activities do not encourage open exploration but instead are carefully scripted to keep students from getting lost or confused.

Looking Toward the Future

At this point in the project, each of the major barriers to the wider adoption of GIS has been successfully addressed. Hardware and technical barriers were overcome by a combination of new funding sources and careful attention to the design of a new computer classroom. The shortage of curriculum materials was overcome by writing a series of computer mini-applications and accompanying learning activities. Faculty resistance to innovation was dealt with largely by working with part-time and junior faculty members and graduate teaching assistants.

As a result, large numbers of students in classes taught by instructors with little or no formal GIS experience are now learning geography using simple, easy-to-use GIS software. The concerns raised by Meyer et al. (1999) that students might spend too much time learning GIS and too little time learning geography have largely been circumvented by the use of the programmed GIS mini-applications. Because the operation of each mini-application is directly linked to a scripted learning exercise, students are able to employ GIS concepts such as buffers, overlays, and spatial database queries to help them learn geography without the need to learn the intricacies of GIS software. The major advantages to this approach are the ease of use and the tight integration of GIS with geographic learning. The main drawback is the amount of time needed to develop and program each of the applications, a point that echoes the concerns of Hurley et al. (1999).

Where do we go from here? One promising approach would be to extend the concept of the GIS mini-applications to the World Wide Web. Each of the world geography mini-applications has now been converted from the *ArcView/Avenue* language to new programs written with the *Java* programming language and ESRI's *Map Objects Web Server* technology that can be accessed across the Internet. Reaching out to students across the Web, empowering them to discover new ways to learn geography at a distance, is certainly an attractive idea. At the same time, however, use of the Web raises the risk of losing the rich social context of learning that takes place in the computer classroom environment. Hurley et al. (1999) argue that there is no inherent conflict between constructivist theory and distance learning, though others suggest that a cautious approach should be taken (Taylor 2000).

Notes

1. Partial support for this work was provided by the National Science Foundation's Division of Undergraduate Education through grant DUE #9751362.
2. Anyone interested in obtaining additional information about the individual mini-applications and the underlying scripts should contact the author at blloyd@fullerton.edu..

References

Bednarz, S. W. 1995. National geography education standards. In *First National Conference on the Educational Application of Geographic Information Systems (EdGIS)*, ed., D. Barstow, M.D. Gerrard, P.M. Kapisovsky, R.F. Tinker and V. Wojtkiewicz. Cambridge, MA: TERC Communications, pp. 40–41.

Bednarz, S. W., R. M.Downs, and J. C.Vender. Forthcoming. Geography education in America. In *Geography in America at the Dawn of the 21st Century*, ed. C. Willmott and G. Gaile.

Bishop, M.P., J. F. Shroder, Jr., and T. K. Moore. 1995. Integration of computer technology and interactive learning in geographic education, *Journal of Geography in Higher Education* 19(1):97–110.

Carstensen, L., C. Shaffer, R. Morrill, and E. Fox. 1993. GEOSim: A GIS-based simulation laboratory for introductory geography, *Journal of Geography* 92(5):217–222.

Fitzpatrick, C. 1993. Teaching geography with computers, *Journal of Geography* 92(4):156–159.

Fitzpatrick, C. 1999. GIS in K–12 classrooms: Real applications and real learning, National Council for Geographic Education *Perspective* 27(4):4, 6.

Hill, A. D., and M. N. Solem. 1999. Geography on the Web: Changing the learning paradigm? *Journal of Geography* 98(3):100–107.

Hurley, J. M., J. D. Proctor, and R. E. Ford. 1999. Collaborative inquiry at a distance: Using the Internet in geography education, *Journal of Geography* 98(3):128–140.

Krygier, J.B., C. Reeves, D. DiBiase, and J. Cupp, J. 1997. Design, implementation and evaluation of multimedia resources for geography and earth science education, *Journal of Geography in Higher Education* 21(1):17–39.

Linn, S. E. 1997. The effectiveness of interactive maps in the classroom: A selected example in studying Africa, *Journal of Geography* 96(3):164–170.

Meyer, J. W., J. Butterick, M. Olkin, and G. Zack. 1999. GIS in the K–12 curriculum: A cautionary note, *Professional Geographer* 51(4):571–578.

Nellis, M. D. 1994. Technology in geographic education: Reflections and future directions, *Journal of Geography* 93(1):36–39.

Proctor, J.D. and Richardson, A.E. 1997. Evaluating the effectiveness of multimedia computer modules as enrichment exercises for introductory human geography, *Journal of Geography in Higher Education,* 21(1):41-55.

Rutherford, D. 2000. Assessing a computer aided instructional strategy in geographic education. Unpublished master's thesis, California State University, Fullerton.

Sui, D. Z. 1995. A pedagogic framework to link GIS to the intellectual core of geography, *Journal of Geography* 94(6):578–591.

Svingen, B. E. 1994. New technologies in the geography classroom, *Journal of Geography* 93(4):180–192.

Taylor, J. 2000. Using the World Wide Web in undergraduate geographic education: Potentials and pitfalls, *Journal of Geography* 99(1):11–22.

Thompson, D., B. Tucker, T. Clark, and T. Poston. 1998. Learning with geographic information systems – a candid look at ArcView ™, Proceedings, ESRI User Conference, San Diego, California.