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Enhancing education through research in the environmental science laboratory: integrating GIS and project-based learning at Colby College

Enhancing Education through Research in the Environmental Science Laboratory: Integrating GIS and Project-Based Learning at Colby College

Philip J. Nyhus
F. Russell Cole
David H. Firmage
Phoebe S. Lehmann
Department of Biology and Environmental Studies Program
Colby College

Introduction

Colby College has a long history of integrating research and education, particularly in the Division of Natural Sciences. In 1998, the college's commitment to undergraduate research was acknowledged when Colby was chosen as one of ten undergraduate institutions across the nation to receive a National Science Foundation (NSF) Award for the Integration of Research and Education (AIRE). Over the last three years, this award has enabled the college to strengthen existing courses and programs and to develop new ways to involve undergraduate students at all levels in the process of discovery. Colby was one of only two AIRE schools to use these funds to hire postdoctoral fellows to strengthen opportunities for undergraduate research and to increase exposure to new technology inside and outside the classroom.

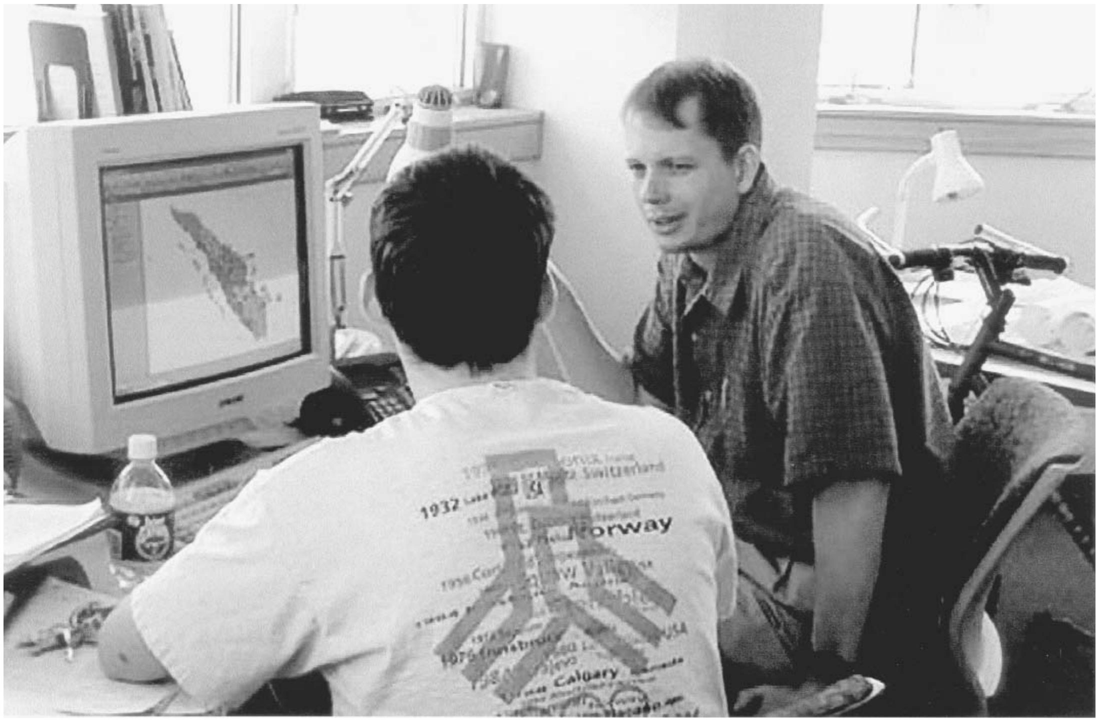
The outcome of this experience was very successful and enabled us to address two central challenges of our grant that are faced by many similar institutions as well. These were how to increase and enhance undergraduate research opportunities and how to increase access to new technology in the classroom. In this paper we describe one component of our AIRE activities, an enhancement of an established problem-based, capstone environmental science course for senior biology/environmental science majors achieved by combining a high-end geographic information system (GIS) with the unique benefits of a service learning and inquiry-based perspective. A collaboration among two senior faculty members and an NSF-AIRE Fellow gave students an opportunity to complete a significant research project that resulted in a comprehensive written report and presentations at local, regional, and national meetings; to work with cutting-edge technology that could be applied to other campus research projects; to develop multi-faceted research and presentation skills to enhance their competitiveness for employment or graduate school; and to enhance their appreciation for the process of research and discovery.

Integrating research and education and the NSF-AIRE award

Colby College is a small, highly selective liberal arts college in central Maine with a student body of approximately 1,800. Over the last decade, the school has conducted several college-wide strategic planning efforts to develop and institutionalize a vision that integrates teaching through research. One of the more visible impacts of the most recent strategic planning effort was the successful competition for a NSF-AIRE grant. The award was viewed as an opportunity to build on the college's strengths and to address several outstanding needs identified by earlier campus-wide and Division of Natural Sciences planning efforts.

A major goal of this three-year grant was to strengthen and enhance student research opportunities at all levels in the science curriculum. Curricular changes were targeted at majors and non-majors by enhancing introductory and advanced science laboratory content and adding course-based projects that offered solid research training. With this award we also tried to expose all students to state-of-the-art technology and to enhance collaboration across departments and programs.

To help meet these goals, and to overcome curricular, technological, and faculty time constraints identified in earlier division planning efforts, a significant proportion of Colby's NSF-AIRE funds were devoted to hiring five 12- or 24-month postdoctoral teaching fellows. Fellows were hired in the Departments of Biology, Chemistry, Geology, and Physics and



Philip Nyhus, NSF-AIRE Fellow in Environmental Science at Colby College, working with student Aaron Megquire on a GIS project.

Astronomy as well as the Environmental Studies Program. These fellows had expertise in specific, previously identified needs within each of the disciplines. In addition, their teaching and research interests overlapped with those of their faculty mentors. Several significant distinctions differentiated these NSF-AIRE Fellows from typical sabbatical replacement positions or research postdoctoral fellows. The NSF-AIRE fellows had faculty mentors to guide their teaching and research program. They were given restricted teaching duties to facilitate curriculum development that included enhancing existing courses and designing new ones. Also, they team-taught courses with their faculty mentors in addition to teaching their own courses. The fellows were encouraged to develop training workshops for students, faculty, and staff; to work closely with students on independent research projects; and to participate in disseminating the results of these activities.

Why GIS?

Geographic Information Systems (GIS) are used to collect, integrate, analyze, model, and display digital information related to the surface of the earth. These software and hardware systems are widely used in both the public and private sectors (Clarke 2001). Recent improvements in software functionality, computing power, and the availability of digital data are rapidly facilitating the adoption of GIS in environmental science curricula nationally and internationally. An estimated 1,500 two- and four-year colleges and universities use some form of GIS for teaching and/or research in the United States and more than double that again internationally. More than 50,000 students annually are exposed to GIS in colleges and universities in the United States alone (Johnson 2000)

GIS can be a powerful teaching and research tool because of its multi-purpose functionality. Students can learn and apply basic GIS concepts within one semester. They can use GIS as a data management, analysis, and presentation tool. Additionally, this technology is well suited to serve as a focal point for interdisciplinary collaboration and discussions, an important element in a course in which students are working on different components of a larger project. Finally, GIS is increasingly being applied to many different problems in business, government, and academia, giving students a valuable introduction to cutting edge skills in high demand.

Before the NSF-AIRE grant, some faculty at Colby had used a limited GIS for teaching, but overall, few appropriately configured computers were available for GIS, the campus did not use industry-standard GIS software, and existing faculty had limited time to develop necessary new skills or the time to incorporate the use of GIS into existing courses. More sophisticated spatial analyses by student researchers were limited by not having a powerful GIS available. Importantly, campus awareness about the potential for GIS as a tool to integrate research and education was limited.

As a result, some faculty felt that upgrading GIS capabilities would offer a unique opportunity to enhance teaching and research in biology/environmental science and environmental studies. Given the significant time commitment necessary to develop this capacity on campus, an NSF-AIRE Fellow with GIS experience and interests in environmental studies was hired and assigned a lead role in spearheading a campaign to address these limitations.

The first step was to develop a plan to integrate GIS into environmental science/studies teaching and research. The fellow spent the first year reviewing Colby's environmental science/studies curricula, existing GIS capacity and needs, and investigating different GIS software systems. Following this review, a small GIS laboratory was established.

The second step was to build Colby's GIS capacity by combining on- and off-campus resources. The school contributed appropriate computer hardware, dedicated space, software and support, and funding for student research assistants. The NSF-AIRE award provided teaching Fellow salary and support. This initial support enabled the school to leverage these resources toward several major software, hardware, and data acquisition grants that resulted in the college obtaining high-end hardware and some of the most advanced GIS software available on the market, including ArcView, ArcInfo, and ArcGIS.

ArcView GIS was eventually chosen as the primary software system because it provides sophisticated data creation, editing, manipulation, and presentation capabilities but does not require the same user sophistication as the more advanced ArcInfo. ArcView offers several important advantages to students. It runs on standard Windows-based PC platforms or even Macintosh computers with PC-terminal emulation software and it has a relatively short learning curve for basic data entry, manipulation, and presentation tasks. Virtually all data available from state, federal, and many commercial vendors are in a format ArcView can use. Finally, students gain experience with name-brand software that is widely used inside and outside academia.

Integrating Project-based Learning and GIS

We believe it is widely recognized that project-based learning, when carried out effectively, can encourage better understanding of course content and appreciation of the discipline. Students benefit from development of problem-solving skills, the experience of tackling open-ended research problems, and working with a range of research and presentation tools. When matched with a service-learning component, such courses can also enhance civic responsibility among students, help to meet community needs, involve the community, encourage citizen participation, and offer an opportunity for the college and students to give back to the community (Firmage and Cole 1999).

One important benefit of a project-based course is that more students can be exposed to an intensive, mentored research experience than students carrying out different individual research projects. This course format has been very important to integrating research and education successfully in the Department of Biology at Colby, in particular, because it is a large department with many majors. Offering independent research experiences to each major would be logistically impossible. Students have the added experience of learning how to work collaboratively as well as learning how to design and implement a research project from start to finish.

The semester-long research course that we focus on here, Problems in Environmental Science, has been taught annually since 1981. The class is treated as a consulting firm and the students engage in real world experiences by undertaking a detailed analysis of a local environmental problem. This course is designed to provide a common research experience for all senior biology/environmental science majors and builds on previous coursework in ecology and environmental science (Firmage and Cole 1999). It entails intensive independent and group research, small discussion groups, considerable writing and speaking, and collaborative problem solving. Students become familiar with research methods commonly used in the field of environmental science and develop an understanding of relevant state and local regulations and their application. A major emphasis of this capstone course is to strengthen skill development important for graduate study or postgraduate employment, including writing and presentation skills, literature searching strategies, teamwork, project design, and advanced computing techniques.

As the Problems in Environmental Science course evolved over the last decade, a variety of research and presentation tools were added to the laboratory section of the course. For example, students used relatively sophisticated water quality testing and monitoring equipment, global positioning systems (GPS), and even a rudimentary GIS. Computer presentation techniques were also taught.

Each year, approximately twenty senior environmental science students tackle a different environmental problem. For the last thirteen years, students have been engaged in studying problems associated with watershed land use patterns and their effects on lake water quality. Students are divided into field teams at the beginning of the semester to focus on different aspects of water quality and land use analysis. The entire class conducts some of the data gathering and some is done by individual teams. Acting as consultants, these teams carry out independent and integrated research throughout the semester. As the fieldwork winds down, students are divided into separate editorial teams to tackle the considerable task of compiling and analyzing the data, writing results and interpreting them, drawing conclusions, and formulating recommendations. This phase of the course culminates in a major research report and public presentation of class findings. The

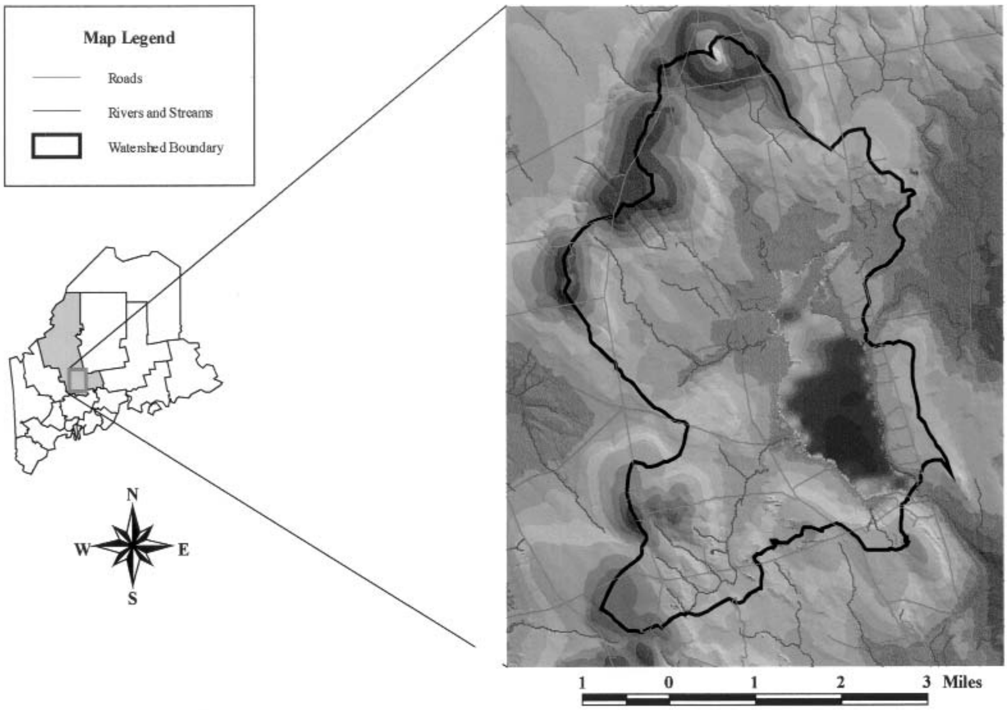


Figure 1. GIS base map developed by students showing Lake Wesserunsett and its surrounding watershed, including roads, rivers, streams, watershed boundary, topography, and bathymetry of Lake Wesserunsett. Digital data from Maine Office of GIS.

results obtained by these studies have been used by local lake associations to guide management decisions. The data are also used by the Maine Department of Environmental Protection. Multiple requests are received annually from citizens and local lake associations requesting class assistance in studying specific lake water quality problems.

As their research progresses, students develop a broad understanding of the health of the lake under study and potential impacts from the adjacent watershed. Students are asked to identify and assess possible factors affecting water quality, and to suggest possible remediation options. Some of the questions the class investigates include:

❍ What are the physical and chemical characteristics of a lake that may have a significant impact on water quality?

❍ What effects do current and historic land use patterns have on water quality?

❍ Based on historic population and land use changes, what future projections can be made that may influence land use and lake management decisions?

❍ If problems occur, what remediation options are available that could realistically be applied to this situation?

To answer these questions about lake and watershed characteristics, data are collected from a variety of sources, including water samples from the lake during and prior to the semester, shoreline development surveys, road surveys, and analysis of existing maps and publicly available information. Students also collaborate with Maine Department of Environmental Protection and local government officials to obtain information.

Incorporation of the new GIS capability into the Problems in Environmental Science class was very successful. Students in the class working on land use issues were divided into two teams, the GIS group and the Land Use group. Prior to starting their research, the teams were introduced to basic GIS principles and given an overview of ArcView GIS software. The GIS group developed a base map of the study area used by all students (Figure 1). Digital data were obtained from the Maine Office of GIS and the US Geologic Survey. This group developed maps showing watershed boundaries, major roads, waterways, topography, and soil types. The first four themes were developed from data downloaded from state offices. A three-dimensional triangulated irregular network (TIN) map was also derived from the downloaded contour data to develop the topography map. Soil maps were scanned and digitized to create polygons of the soil types found within the watershed Information about the soil types, such as permeability, was then added to the associated polygons.

The Land Use group developed land cover classifications and land use change analyses using aerial photographs. Photographs several decades old were obtained from a local

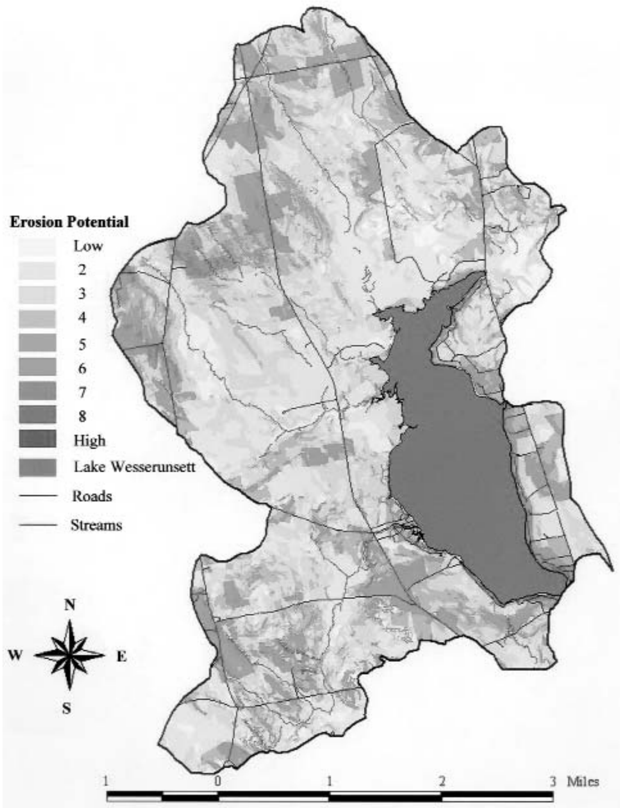


Figure 2. Example of GIS analysis carried out by students showing erosion potential of the Lake Wesserunsett watershed with roads and streams for geographic reference. Darker shades show higher erosion potential. Original data from USDA Soil Survey Maps for Somerset County, Maine Office of GIS, and aerial photographs digitized by students.

Soil and Water Conservation Service office. These photographs were compared to ones the class obtained by contracting to have the watershed flown to determine current land use patterns. The photographs were scanned and rectified using digital orthophotos of the area available from USGS. Land cover classes for both sets of photographs were then digitized and maps were produced showing those conditions and comparing the changes that had occurred over time. Tax maps were also added, which, when combined with shoreline and road surveys, allowed the students to determine potential sites of further development.

The two groups were able to combine their data sets to create maps showing levels of suitability for septic systems and erosion potential in the watershed. Using ArcView's ModelBuilder utility, contour, land use, and soils data were transformed from vector-based themes (point, lines, polygons) to grid-based themes (pixels with associated values). These themes were merged within a weighted overlay process to define erosion hazard within the watershed basin (Figure 2). In this overlay, each theme is given a proportion (out of 100%) of the total estimated impact and within each theme classes are given scalar values representing low to high values. In our case, areas with little slope are given low values while steep slopes were given high values; land use with low erosion potential, like forested areas, were given low values while those with high erosive potential, like bare ground, were given high values; and soils types with different erosive potential were similarly ordered. Our scaled values were based on estimates taken from the published literature. This model outputs a map showing the erosion potential (i.e., the result of combining slope, land use, and soil type) across the watershed. A similar model was used to derive septic suitability.

The ability to look at and analyze GIS data enabled the students to ask and to answer questions that were previously difficult. For example, students could explore the implications of logging on erosion potential and use their model to simulate the impact of modifying different parameters. By using rectified data with real world coordinates and guided by global positioning system units, students could evaluate their land use classifications in the field. Being able to interlace soil information with slope and land use types for the entire watershed opened many new avenues of discovery. Additionally, ArcView allowed a model to be constructed for phosphorus transport to the lake, based on slope, precipitation, and land use information. We are currently adding modeling capability for a number of components through BASINS 3.0 (available from EPA), which interfaces with ArcView.

Students developed a comprehensive report over 200 pages in length that summarized methods, data, results, and specific recommendations for land and water conservation. They also presented the results to the public in a town meeting, to their peers at the College's undergraduate research symposium, and to other scholars at a regional and national meeting. As one indicator of the student's success, a research poster from this course shared first prize among all poster presentations at the 2001 Maine Water Conference.

After the course was completed, some of the students used GIS for further independent research and received interviews for GIS-related positions because of this academic training. The data were made available to a local watershed association, the Maine Department of Environmental Protection, and the public. Adding the use of ArcView to the course, through the expertise of the NSF Fellow, dramatically improved the final product the students were able to create and gave them training in an area that will be quite useful when entering the job market or graduate school. The use of GIS as a research tool not only enhanced the course, but also made this technology available in other courses within the Department of Biology and the Environmental Studies Program. We are continuing to expand use of this research tool through workshops for interested faculty members making curricular enhancement sustainable into the future.

Lessons Learned

A broader and more formal assessment of the entire AIRE program at Colby, which included the development of multiple courses and initiatives across the entire Science Division, will be carried out after the fourth year of the grant. Nevertheless, preliminary feedback from students and faculty already indicate several ways in which the expanded GIS initiative in this individual course has had a positive impact.

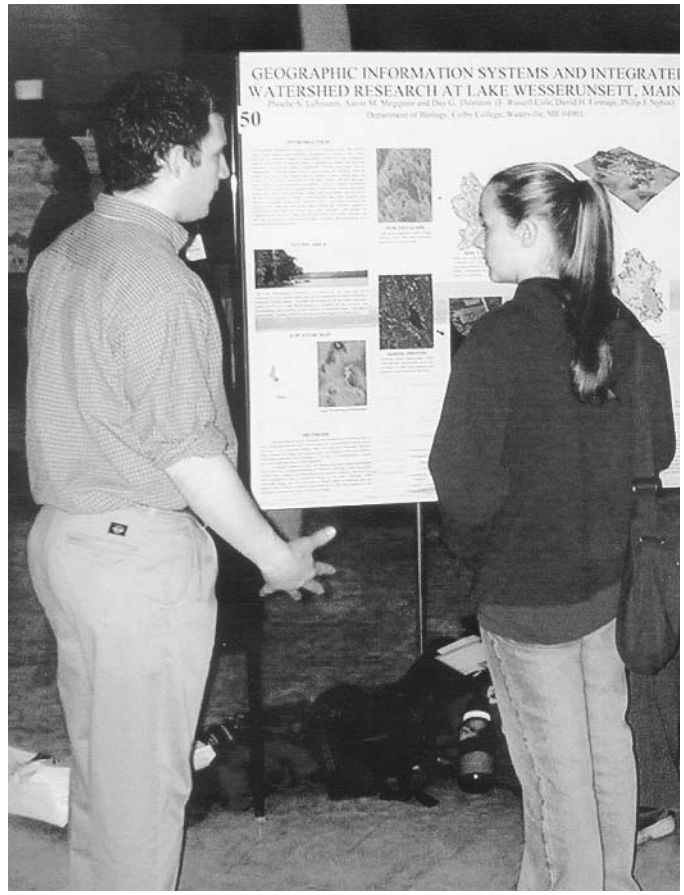
A number of students within the GIS groups have continued to use GIS in their own research projects after completing the course. With no formal GIS course available on campus, this course has become a *de facto* introductory GIS course and training opportunity. Other students have expressed interest in joining the course to learn GIS after seeing what their colleagues are able to accomplish.

The application of GIS tools and concepts is driven in part by student initiatives. In the first year, the entire methodology was developed by a summer research student working with the AIRE Fellow and then modified and updated by the GIS groups during the course. This year the same process is occurring as students refine existing methods and generate new ones as the study progresses. This iterative process has generated considerable enthusiasm among students and faculty members because, along with staff members and external collaborators, they are involved in a real-world problem solving exercise.

Because students were exposed to sophisticated, cutting-edge technology that gave them a valuable skill, they were more motivated than students in earlier years who used a less advanced, free-ware GIS package. Students were exposed to problems similar to those they would encounter as professionals, including data collection, analysis, presentation, and integration of their results with data from other groups.

We believe this experience shows how the activation energy and synergy generated by the unique interactions of a postdoctoral teaching fellow and senior faculty mentors can be used to rapidly integrate new technologies into the laboratory. With the rapid pace of technological innovation today, developing effective inquiry-based courses and ensuring that students are exposed to the latest technology can be a significant challenge for time-strapped college educators. Faculty members need the time to learn enough about new technology to decide whether and how to adopt it. They must learn how to use these tools, develop exercises or manuals for students to follow, and test the technology and methods before students use them. For the average faculty member at a liberal arts college, this can be a daunting task.

The teaching fellow was able to contribute new skills and the time to investigate and acquire the GIS hardware, software, and to develop the new laboratory modules. For example, the fellow was able to work during the summer to develop and complete a trial run of GIS exercises with a research student who could then share her expertise with other students when the course was taught in the fall. The senior faculty mentors provided the mature course, decades of combined experience with innovative teaching strategies, and the guidance to bring this project to completion. In just two years, the GIS component of the course was completely overhauled and dozens of students were exposed to industry-standard GIS techniques who otherwise would not have had that opportunity. GIS was also integrated into other courses, and a training workshop was held for over a dozen interested faculty to encourage further integration of this research tool into the science curriculum. Interest generated by this project resulted in substantial support from the college to enhance further the hardware available for GIS activities, approval of the hiring of a permanent laboratory teaching assistant with GIS experience, and funds for additional training for this person.



Aaron Megquire, a student who participated in the senior capstone research course, presented a poster describing the GIS component of the study at the National Conference of Undergraduate Research, University of Kentucky, March 2001.

This experience suggests that GIS can be a powerful tool to enhance interdisciplinary research collaborations among departments and improve individual research-based courses. Enhanced functionality of modern GIS software enables students to complete sophisticated projects within a single semester. While an introductory course in GIS theory and methods would increase the ability of students to tackle complex GIS projects, our experience suggests that this is not a pre-requisite for completing major projects within the time constraint of a semester.

Finally, given the high student-to-faculty ratio in departments like Colby's Department of Biology, we believe that senior capstone courses, particularly those with tools like GIS that can enhance the research experience, are a way to insure that each student has a significant research experience.

Acknowledgements

We acknowledge the efforts and contributions of senior biology students who have participated in the Problems in Environmental Science course. We are particularly grateful to those students in the years 2000 and 2001 who helped to develop the methods and tools described in this paper. Bernadette Graham and Dan Tierney, teaching assistants in biology, contributed considerably to the course and its GIS component. We recognize Colby's National Science Foundation Award for the Integration of Research and Education for providing postdoctoral funding for P. Nyhus. We also thank Dean of Faculty Edward Yeterian for his encouragement throughout the project and for the financial resources to establish our GIS laboratory.

References

Clarke, K. 2001. *Getting Started with Geographic Information Systems*. Saddle River, N.J.: Prentice Hall.

Firmage, D. H. and F. R. Cole. 1999. Service Learning in Environmental Science at Colby College. Harold Ward, Editor. Pages 25-37 in *Acting Locally: Concepts and Models for Service-Learning in Environmental Studies*. Washington, D.C.: American Association of Higher Education.

Johnson, A. 2000. Community College GIS Programs are Expanding. *GIS Educator*, Summer 2000.

Philip Nyhus recently completed two years as a National Science Foundation Award for the Integration of Research and Education (NSF-AIRE) postdoctoral fellow in Environmental Science at Colby College. He will be applying his experiences to his new position as assistant professor in the Department of Geosciences and the Environmental Studies Program at Franklin and Marshall College in Lancaster, Pennsylvania.

F. Russell Cole, Oak Professor of Biological Sciences, is a member of the Department of Biology and the Advisory Committee for the Environmental Studies Program at Colby College. He has served as chair of the Department of Biology and the Division of Natural Sciences. He is currently the Project Director for Colby's NSF-AIRE grant.

David Firmage, Clara C. Piper Professor of Environmental Studies, is a member of the Department of Biology and is affiliated with the Environmental Studies Program at Colby College. He has served as the chair of the Department of Biology, as the Director of the Environmental Studies Program, as the chair of the Interdisciplinary Studies and Natural Science Divisions.

Phoebe Lehmann is a recent graduate of the Department of Biology and the Environmental Studies Program at Colby College. She was instrumental in helping to develop the GIS methodology described in this paper.