Paper # EDUC1764
Title: **Embedding GIS in Diverse College Courses: Case studies & learning theory**
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Abstract:
A GIS map provides a powerful learning environment for higher education. The interactive nature of GIS invites students' deep engagement with the course material. The visual user interface transforms quantitative data into accessible images that appeal to a broad cross-section of the student body, from musicians to science majors. This session describes how GIS has been used to teach *critical thinking* skills, *spatial thinking* skills and *quantitative reasoning* skills. It reviews examples of how students learn to use *visual evidence* as a tool for reasoning, in the context of their studies. It describes how instructors are teaching with GIS and how students are learning with GIS. Drawing on theories from a wide range of sources, this session describes how GIS supports the educational process at the perceptual, logical and applied levels of learning. The presentation provides a précis of a book of case studies published by ESRI Press in 2006.

Each of here at the ESRI EduConference certainly understands the importance of geography. In our presentation we take for granted that spatial thinking is a critical skill; a skill that should take its place in the common academic curriculum along with logical analysis, critical thinking and quantitative reasoning. With a few dozen colleagues from colleges and universities, we have gathered accounts of how faculty members have incorporated maps and GIS into their classrooms, to teach these important skills:

- Spatial analysis
- Quantitative reasoning
- Critical thinking
- Using visual evidence to reason and communicate.

Their accounts are being published by ESRI Press as *Understanding Place: GIS and Mapping Across the Curriculum*. Before we began this project, we were both highly enthusiastic about using GIS as a learning environment. After working with these innovative teachers and learning about their challenges and successes, we are even more passionate about the teaching potential of GIS.

In this paper we will share highlights from this anthology of case studies, which ranges from geology to music. Our immediate purpose is to sow seeds of inspiration for educators rather than to describe implementation details, but we both welcome the opportunity to talk more about any of these stories, and 386 pages of context will be available in print next month. The book is organized by discipline, but today we'd like to group the examples by thinking skill, beginning with spatial thinking.

Spatial Thinking
In 2005, the National Academy reported on the potential of GIS to support spatial thinking, to help students develop a "cognitive spatial toolkit" to code, categorize and organize information, then to manipulate and utilize that information to structure problems, find answers, and express

solutions to these problems.[i] An example of simple spatial thinking is noticing that two things often happen in the same location and asking “why?” Complex spatial tasks address the interplay among multiple phenomena, or among cunningly calculated phenomena.

Simple spatial thinking can yield fascinating results, just by observing patterns of proximity and connectivity. Proximity and connectivity often flag interesting relationships, signaling the need for a second look. David J. Staley at the Ohio State University describes a course in which he encourages students to read and to create maps as narratives. Introducing the maps in Figure 1, he writes,

> One of my favorite map exercises introduces students to this idea of identifying a meaningful pattern within a spatial narrative. I begin with two map transparencies, one showing the network of roads and waterways that traversed the Roman Empire, the second showing the spread of Christianity from its early concentration in urban areas to its slow diffusion over time into the hinterlands. Then, I superimpose one map onto the other and ask the students to tell me what they see. Overlaying the two maps, the relationship between the roads and waterways and the spread of Christianity are made very clear: that Christianity spread along the trade routes that connected cities in the Roman Empire. Students then light upon the historical irony: that one cause of the fall of Rome—the spread of Christianity—was itself facilitated by the very infrastructure of the Roman Empire. I could, of course, attempt to describe this irony to them in words, but until the students see the story unfold via the spatial narrative of the map this historical irony does not register.”[ii]

Figure 1a Roads and waterways of Roman Empire, ca. 200 CE.
John P. McKay, Bennett D. Hill, and John Buckler. 1948. *A History of Western Society,*
3rd edition. Houghton Mifflin. 148.

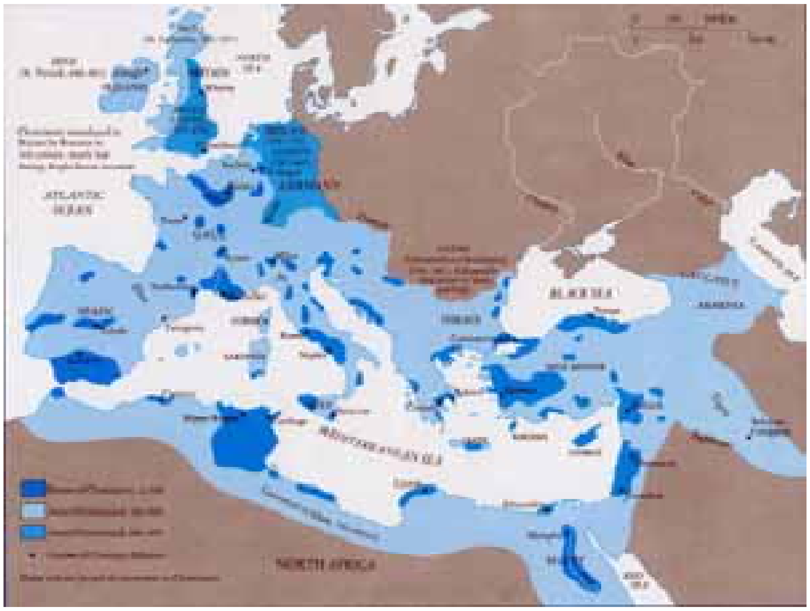

Figure 1b Spread of Christianity, ca. 300–800 CE.
John P. McKay, Bennett D. Hill, and John Buckler. 1987. *A History of Western Society,* 3rd edition. Houghton Mifflin. 201.

Figure 1c Overlay of figures 1a and 1b showing relationship between Roman trade routes and spread of Christianity.

At Fairfield University in Connecticut, Joel Goldfield and Kurt Schlichting use population density maps of France to enrich their students' experience with authentic data about real individuals. They realize this goal via collaboration between a French class and a Sociology class. The French students help the Sociology students navigate the web to find the French census data, and then the Sociology students generate population density maps of Paris. Figure 2 displays the concentric rings of decreasing density. Several language and cultural courses use these population density maps as the launching point for classroom conversation. The authors write,

> Using numerical data, geographical data, and various related images to study the French language supports pedagogical theories of simultaneous left-brain and right-brain

> activities and multiple connections for improving foreign language acquisition.[iii] We discovered that fruitful discussions of deeper topics can occur when students are able to visualize the statistics and geography as people and places.[iv]

The concentric zone maps initiate student discussions of historical centralization in France. Classes discuss the centralization of institutions such as the nationalized school system, the army, governmental policy, and taxation. Students speculate on the behaviors and settlement patterns of starving peasants of yore seeking work and lodging near jobs in the city.

> [The class] reflected that when Louis XIV declared, "*L'état, c'est moi*," he foretold a migration that would put one quarter of the nation's population inside a 71-km (44-mile) radius. These discussions teach students to look at quantitative information like map legends and converse about density and proportion.[v]

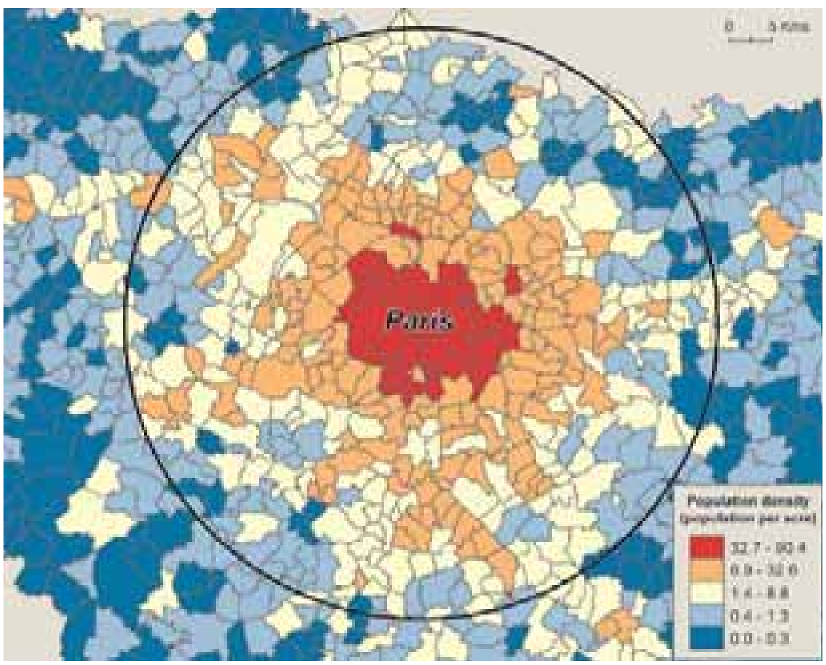

Figure 2. Map of the Paris metropolitan area showing rings of decreasing population density

Quantitative Reasoning

Several of our contributing authors mentioned the benefits of using GIS as a learning environment for quantitative reasoning skills. The French students at Fairfield were motivated to discuss population density and proportion, albeit using relative differences as depicted by colors. Religious Studies students at Connecticut College also looked at census data and ethnicities and examined how those factors related to the rich plurality of religions in their campus town.

Patrice C. Brodeur noted, "Often religious research focuses on interpersonal dialogue and humanist methodologies, yet data-oriented methodologies also have a place in our curricula."[vi] To provide his students with a data-oriented research experience, he and Beverly A. Chomiak introduced ArcMap in a seminar described as "an ethnographic exploration of contemporary religious life in New London as a means to map its new religious diversity and explore the relationship between faith and American citizenship." Students' research project included field work and data collection. Data was entered, organized and presented with GIS. Figure 3 replicates a map created by a team of students in the course suggesting a correlation between new immigrants and geographic mobility. "The map shows that more Spanish-speaking parishioners travel a shorter distance to church than most English-speaking parishioners. This was consistent with what the students had observed on the census maps, indicating that there was a high density of Hispanic residents living in the center of New London where [their study site] was located."[vii]

Figure 3. Comparison of Hispanic- and English-speaking groups within one Roman Catholic community in terms of distance of travel between home and church.
ESRI Data & Maps. ESRI Business Industry Solutions.

All reasoning, including quantitative reasoning, is a product of imagination, insight, and intuition — not computation and calculation alone.[viii] GIS users understand the power of a single image to convey large quantities of multivariate data at a single glance, accessible as gestalt knowing as well as sequential reasoning. Christina Drennon asked her students to measure spatial, social and demographic factors to report on the impact of a non-profit agency in their city. Both insight and statistical analysis played a role.

Habitat for Humanity in San Antonio, Texas commissioned Christine Drennon and her Urban Studies course to conduct an evaluation of the efficacy of their 30-year-old program, comparing key indicators in neighborhoods with Habitat homes and for the city overall. They began by mapping a set of standard socioeconomic variables from the US Census Bureau, like the ones in Figure 4, showing spatial relationships from which the students extrapolated theories. Over the course of the project, students were challenged to identify key indicators, create more maps, and perform statistical assessments.[ix] An example of a resulting map is shown in Figure 5.

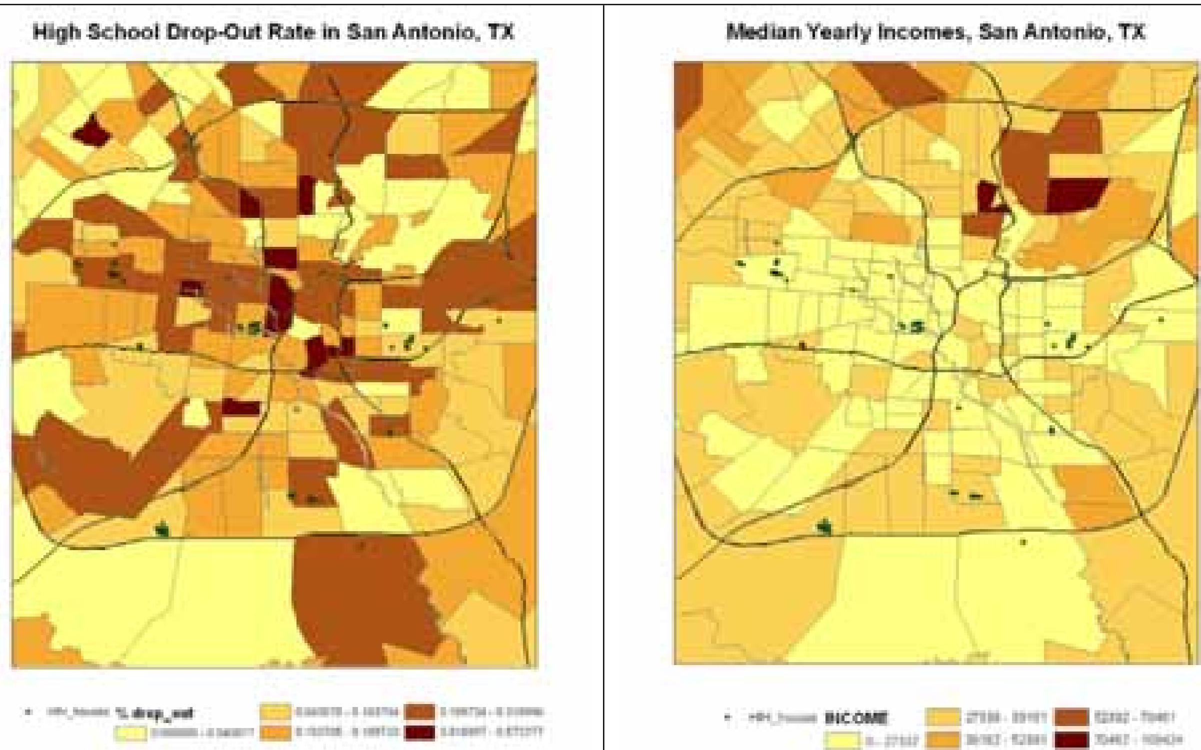

Figure 4. Examples of the maps that students used to explore the spatial relationships between locations of Habitat for Humanity houses and social and demographic variables. ESRI Business Information Solutions.

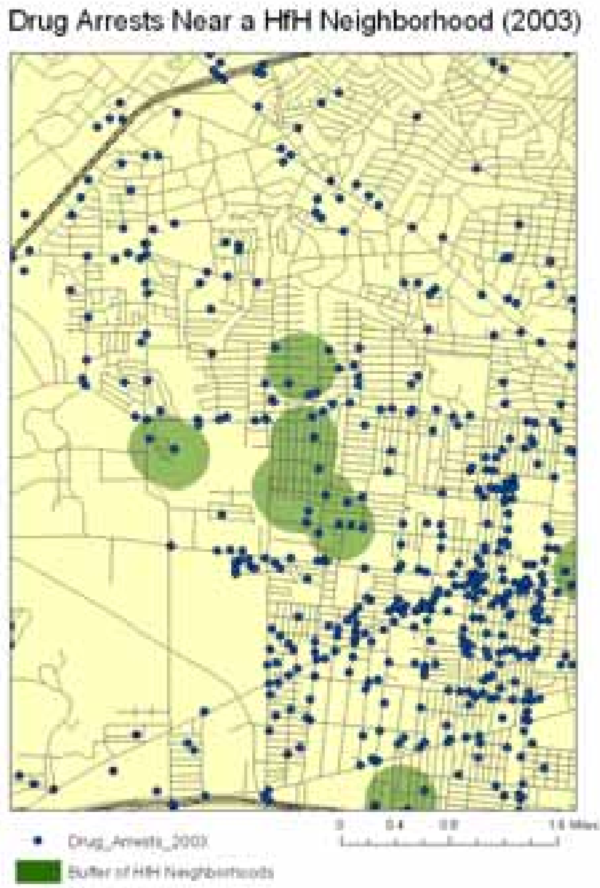

Figure 5
Example of map produced when students were analyzing and validating spatial relationships between data layers.
ESRI Business Information Solutions.

Drennon's preferred teaching method is problem-based instruction. Students used GIS as a tool for organizing, analyzing and communicating to each other and to their client. Drennon presented students with an authentic problem and relied on the community context to motivate their learning and to structure their investigation. Her students worked in teams to identify salient research questions, to determine what data was needed to answer the questions, and to acquire the skills necessary to analyze the data in this interdisciplinary course.

Critical Thinking

Drennon writes, "Problems encountered in an interdisciplinary studies class mirror problems encountered in the world: they are multifaceted, they involve data gathered from disparate and inconsistent sources, and they may require complex spatial statistical analysis."[x] This ability to work with multiple dimensions is an essential aspect of critical thinking. GIS provides a rich environment for students learning to think with multiple variables, providing the opportunity to look at data layers individually or in myriad combinations. The software allows students' analytical skills to mature, to start with visual inspection of data layers and then evolve to quantitative analysis of spatial relationships.

In their Politics course at Washington and Lee University, Mark Rush and John Blackburn posed a puzzle for their students: to redistrict the state of Virginia and improve on the status quo. After studying the history, politics and legal constraints of gerrymandering, and inspired by the "one-person, one-vote" principle, students engage whole-heartedly with this multidimensional challenge. The authors write,

> The results have been remarkable demonstrations of creativity and political acumen. Each time we've taught the course, our students have produced highly original maps that meet or surpass the requirements posed by state and federal law. The students' district plans have all resulted in more opportunities for minority representation, the division of fewer municipal boundaries, more geographically compact and less bizarre district boundaries, and close adherence to the requirement of equal district population.[xi]

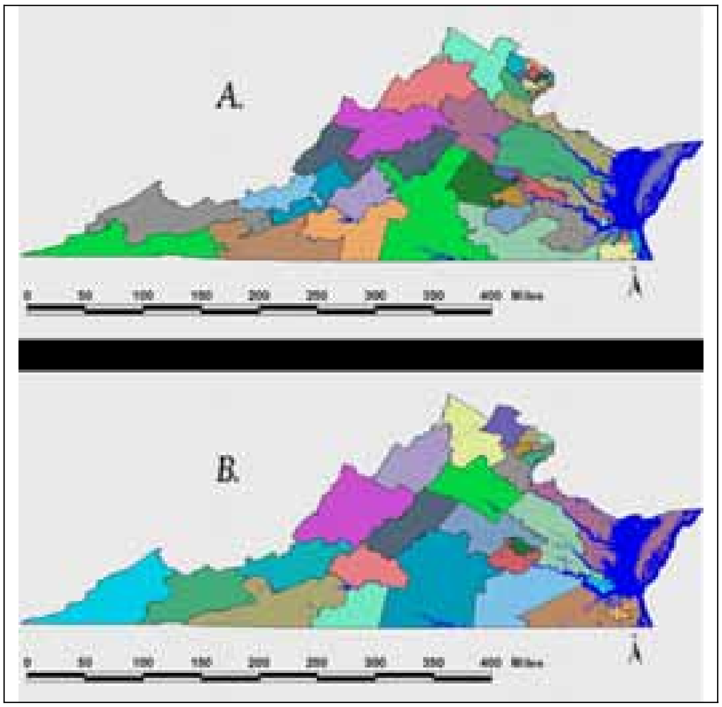

Figure 6. A Microsoft PowerPoint slide from Karl Kursteiner's (WLU '04) presentation demonstrating the differences between the adopted districting plan for the state senate and his own, multimember solution.
U. S. Census Bureau and ESRI Data & Maps.

Although these instructors acknowledge that GIS demands a great deal from themselves and from their students, they are enthusiastic about the course and their students' achievement of higher-order, synthesis-level knowledge. The ability to absorb, digest, evaluate, interpret and synthesize information "liberates" students from the limitations of always believing what they are told, what they hear, and what they see, the essence of critical thinking.[xii]

Using visual evidence to reason and communicate

In another case study, A. Endre Nyerges and his students challenged the prevailing assumptions about small forest patches in the Republic of Guinea. They tested a hypothesis that, rather than disappearing remnants of larger forests, these patches could be new forests springing up as a result of human activities. In one of their assignments, students mapped and examined various topographical features known to influence vegetation such as water and human settlement. They found no evidence that settlements led to the eradication of forest. Examining their maps, some of which are shown in Figure 7, they observed that the availability of water is the most important factor influencing the presence or absence of both trees and settlement.[xiii]

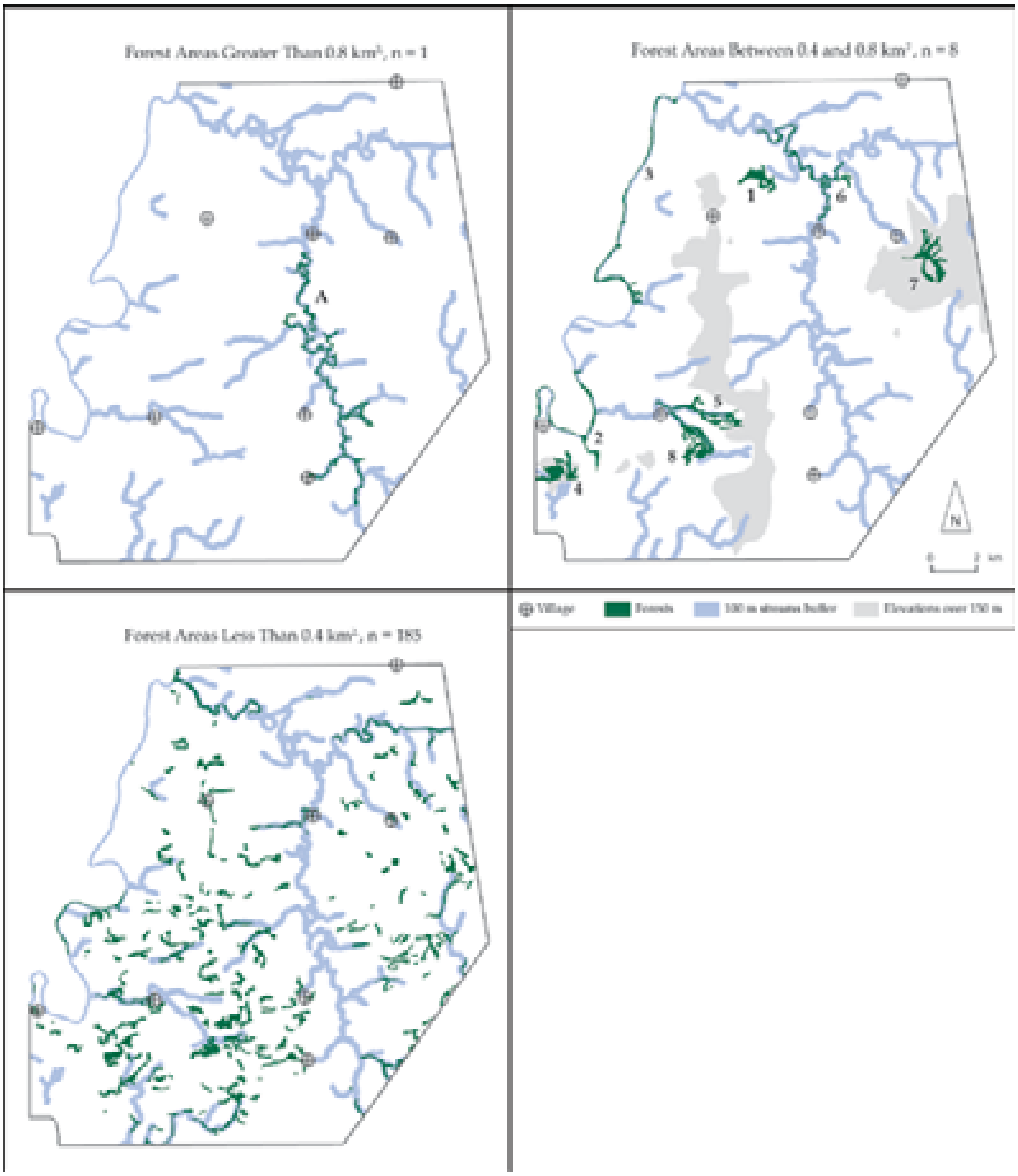

Figure 7. Three maps portraying Kilimi forests organized according to size. (1) Forest areas greater than 0.8 sq. km—This view shows the largest forest in Kilimi, accounting for 8 percent of the total forest cover of Kilimi). (2) Forest areas between 0.4 and 0.8 sq. km—These eight forests in the mid-size range contain 25.8 percent of the total forest cover of Kilimi. Forests are numbered 1–8 in order of increasing area. (3) Forest areas less than 0.4 km sq.—The remaining 185 forest patches contain 66.2 percent of the total forest cover of Kilimi.

U.S. Geological Survey.

Edward Tufte and Jacques Bertin have written powerfully about the value of using images as tools for reasoning. Nyerges' students used topographical images as data to determine patterns in forest growth. At Denison University, student and faculty researchers transformed field measurements into maps, creating images that illustrated the effect of time and sedimentation across three decades.

Karl Korfmacher, Brigitte Ramos, and Shelie Miller collaborated on a project that mapped the change in pond depth over time. They began the project by measuring and mapping the current depth of a pond, at certain locations. This map is seen in Figure 8a. They also collected core soil samples from the pond bottom at those locations. Just as the growth rings of a tree carry the marks of drought or fire for individual years, sediment layers of a pond similarly carry information about the local air and water quality around the pond. Because leaded gasoline was phased out in the 1970's, the lead concentration in the sediment soil core varied, with the highest concentrations dating to 1972. Using the measurement of the current pond depth, and the depth of the 1972 lead layer, they calculated the change in pond depth across three decades. Figure 8b shows the calculated depth of the pond in the 1970's. Having transformed numeric data into images, the researchers could make better use of the information. Miller, the student researcher, applied her knowledge of soil, earth science and chemistry to explain the patterns of change that emerged.

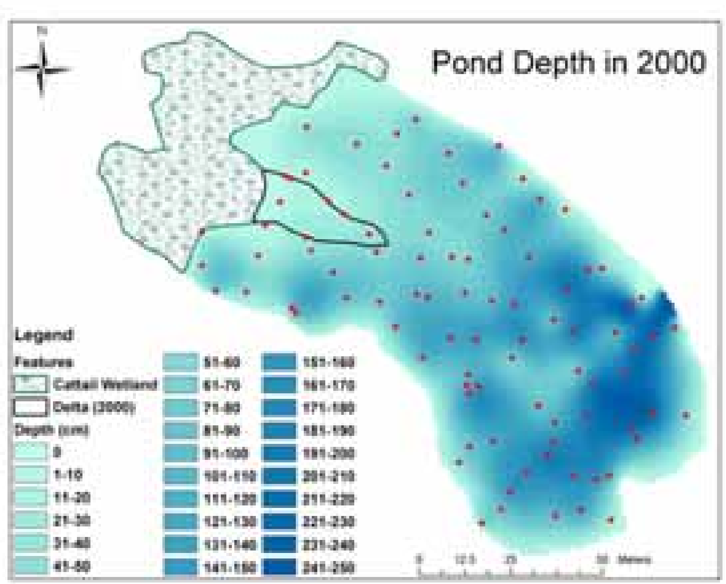

Figure 8a. 2000 bathymetry image showing current pond depth. Red points indicate GPS locations of depth only measurements. Not pictured are additional points showing depth data at the sediment sampling sites and points of zero depth along the pond shore. Image was generated using the spline interpolation algorithm with tension for all depth data. Notice the general trend of deposition continuing beyond the end of the delta feature, in the direction of the dam outlet.

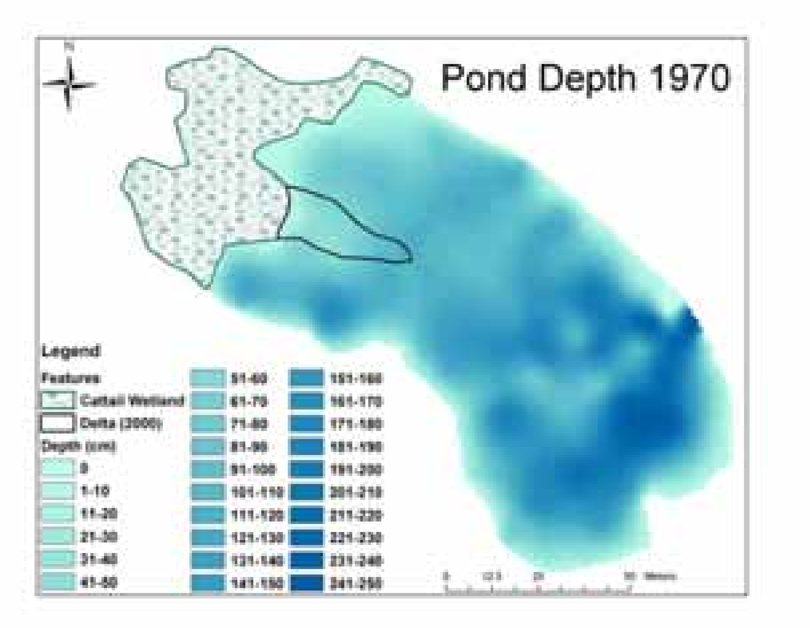

Figure 8b. 1970 bathymetry image, created by adding depth to peak lead concentration to the 2000 bathymetry image. Notice the minimal delta development, compared to figure 8a, and the relatively deep areas on either side of the current delta region. As the analysis of additional samples is completed, this image is expected to change to better represent the pond bottom in the early 1970s.

Students' capacity for visual complexity can often outpace their cognitive capacity; they can see and remember a complex image long before they achieve an analytical understanding of its meaning. When teaching a subsequent course in Environmental Chemistry, Ramos utilized these bathymetric maps to provide context for student field work. The maps, in contrast to the raw data, provided visual evidence of how the pond had changed, providing a realistic context for discussions of erosion, flow across the watershed, and how sediment comes to be deposited on the pond bottom.

Summary:
The case studies above are drawn from the sciences, the social sciences, and the humanities. We include examples of how maps provide evidence for reasoning and discovery, like the maps showing the advance of Christianity, or the map of New Guinea forest parcels. We include stories of maps as tools for thinking about, and communicating about, multidimensional situations, like modifying voting districts in Virginia. Some stories illustrate fairly simple cognitive processes, like perceiving the concentric rings of population density around metropolitan Paris. Other examples demanded more cognitive engagement, like synthesizing and reporting on various socioeconomic indicators in urban San Antonio.

We have focused on just a few curricular benefits that the academy acknowledges as common learning goals of a sound education: spatial analysis, quantitative reasoning, critical thinking, and the use of visual evidence to reason and communicate. These thinking skills are learned in the context of specific disciplines, but their usefulness transcends those boundaries. Other curricular goals, such as community collaboration and community service, are addressed elsewhere in the anthology. Each case study illustrates how GIS applies when students are "doing the work" of that discipline, from archeology students inventorying Mediterranean artifacts to biology students monitoring bird nests. To learn more about any of these examples, please contact us, or take a look at the anthology due out in September.

Notes

[i] The National Academies Press. 2005. *Learning to think spatially: GIS as a support system in the K-12 curriculum.* Washington, DC: National Research Council.

[ii] Staley, David J. 2006. Finding narratives of time and space. In *Understanding Place: GIS and Mapping Across the Curriculum*, ed. Sinton and Lund, Redlands, CA: ESRI Press, 58-60.

[iii] See Hadley, Alice Omaggio. 2001. *Teaching Language in Context.* Boston: Heinle & Heinle. 90–99; also see Met, Myriam. 1999. "Making Connections," in June K. Phillips and Robert M. Terry, eds., *Foreign Language Standards: Linking Research, Theories, and Practices.* Lincolnwood, Illinois: National Textbook Co., 137–64.

[iv] Goldfield, Joel and Kurt Schlichting 2006. Foreign language and sociology: Exploring French society and culture. In *Understanding Place: GIS and Mapping Across the Curriculum*, ed. Sinton and Lund, Redlands, CA: ESRI Press, 233.

[v] Ibid.

[vi] Brodeur, Patrice and Beverly A. Chomiak 2006. Religious studies: Exploring pluralism and diversity. In *Understanding Place: GIS and Mapping Across the Curriculum*, ed. Sinton and Lund, Redlands, CA: ESRI Press, 249.

[vii] Ibid, p 253.

[viii] Karl Popper (1902–1994).

[ix] Drennon, Christine 2006. Urban studies: Assessing neighborhood change with GIS. In *Understanding Place: GIS and Mapping Across the Curriculum*, ed. Sinton and Lund, Redlands, CA: ESRI Press, 146-8.

[x] Ibid, p. 151.

[xi] Mark Rush and John Blackburn. 2006, Political science: Redistricting for justice and power. In *Understanding Place: GIS and Mapping Across the Curriculum*, ed. Sinton and Lund, Redlands, CA: ESRI Press, 134-5.

[xii] Faccione, Peter A. 2004. Critical thinking: What it is and why it counts. Insight Assessment. Millbrae, California: California Academic Press.

[xiii] Nyerges, A. Endre 2006, Anthropology: Mapping Guinea savanna ecology in Sierra Leone. In *Understanding Place: GIS and Mapping Across the Curriculum*, ed. Sinton and Lund, Redlands, CA: ESRI Press, 120-1