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Geographic information systems: A tool to support geography and environmental education?

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Abstract

Geographic information systems (GIS) education is at a crossroads in the United States. Since its inception in the early 1990s, GIS has diffused slowly into select groups of K-12 classrooms through the efforts of geography and environmental educators. However, many of the assumptions underpinning the initial period of enthusiasm for the technology are now being questioned. This paper reviews issues identified as barriers to dissemination in order to help shape and inform the next phase of GIS implementation. First, the existing arguments for GIS in elementary and secondary education in the United States are reviewed and evaluated. Second, considerations related to developing an improved pedagogical foundation for GIS are explored. Finally, implications and suggestions for guidelines for the next decade of dissemination and implementation of GIS are discussed.

Introduction

Geographic information systems (GIS) education is at a crossroads in the United States. Since its inception in the early 1990s, GIS has diffused slowly into select groups of K-12 classrooms through the efforts of geography and environmental educators. These committed individuals, supported by key organizations and GIS vendors, have worked under the assumption that GIS offer the potential to support classroom learning through student driven inquiries in many aspects of the natural and social domains. In particular, the use of innovative teaching strategies such as Project- or Problem-Based Learning (PBL) requires a rich suite of tools to foster and drive learning. These tools include media and technical applications for information access, analysis, and reporting. Researchers have concluded that technical tools, when used appropriately as instructional supports, have the potential to enhance student learning and teacher instructional success (Dede, 1998; Cognition and Technology Group at Vanderbilt, 1996). Based on this research, GIS proponents have worked under the belief that GIS holds the promise to assist with many of the elements necessary to support classroom inquiry and PBL. Their vision has been that GIS encourage the collection and display of spatial data (or data that can be spatialized). After data are mapped, pattern-seeking and analysis inquiries (collectively known as *spatial thinking*) can help students draw conclusions, solve problems, make decisions, and consider areas of further research.

However, many of the assumptions underpinning the initial period of enthusiasm for the technology are now being questioned. GIS education is struggling to win a wider audience among those educators who serve as role models and opinion formers for the majority of teachers, characterized as *respectable early adopters* (Longley *et al.*, 2001). Several recent research studies have made it clear that little is known about the actual benefits and learning outcomes of GIS (see for example Keiper, 1996; Kerski, 2000; Baker, 2002). The geography and environmental education research community do not know the exact contribution of GIS to substantive geographic and environmental learning. Nor are we able to state unequivocally that GIS in elementary and secondary education has a clear, positive effect on the development of spatial thinking, reasoning, or environmental understanding, the central goals of geography and environmental education. In fact, a growing number of researchers in this field are examining GIS critically in order to plan software systems designed to better support student learning. There is a growing understanding that the programs available for school use in the United States, essentially the same powerful, full-capacity software used by professionals in the field, are a barrier to implementation, despite protestations that it is not. The most prevalent model for GIS use in classrooms, students using such GIS software on personal computers (with the ensuing high learning curve to learn the software), is being reexamined in the light of the proliferation of Internet-based GIS such as Geography Network (http://geographynetwork.com). Research in how people think about and reason with spatial concepts, and how the design of GIS can be made more consistent with these principles, is making educators aware of some of the inherent difficulties associated with human mind/computer interactions and using such devices to solve problems that have geographic dimensions. In a related area, researchers are also beginning to rethink the pedagogy associated with GIS by incorporating advances in learning theory to instructional approaches. To use the language suggested by Dede and others, the *appropriate uses for GIS to enhance and support student achievement* are ambiguous. Some feel that the technology, so attractive and appealing, may have blinded practitioners from considering a number of significant issues associated with implementing GIS in educational settings.

All of these ideas and issues are causing a reconsideration of GIS in education. There appears to be a need to develop a new rationale for GIS in K-12 education, one based in educational research as well as the long term needs of society. When the first United States conference on the educational application of GIS sponsored by the National Science Foundation (NSF) was held in 1994, an official focused discussion by asking these questions, '*We need ... recommendations about where GIS is now, and where it is going to go as a research tool. What is the learning that produces understanding of concepts and processes students should know and be able to apply? What insights does GIS allow that the other ways of learning do not? What is GIS going to allow in education that we cannot do in other ways?*' (Salinger, 1995, p. 24). These questions remain unanswered in 2003, nearly a decade later. In addition, many more exist. GIS adherents need to take a step back to reexamine the appropriate role for GIS and to search for new rationales in order to launch and sustain the next ten years of efforts.

The purpose of this paper is to review these and associated issues in order to help shape and inform the next phase of GIS implementation. First, the existing arguments for GIS in elementary and secondary education in the United States are reviewed and evaluated. Second, considerations related to developing an improved pedagogical foundation for GIS are explored. Finally, implications and suggestions for guidelines for the next decade of dissemination and implementation of GIS are discussed.

This is a call for geography and environmental educators to think critically about the value of GIS, to study its uses in geography and environmental education carefully, and to consider the most effective pedagogies to implement it. New educational technology is seductive. Radio, television, computers, multimedia, and now hand-held computing devices have, in turn, been offered as solutions to educational problems. Claims were made that each would enhance learning and transform the educational system, yet, in some cases, the system absorbed each without the intended change (Cuban, 1986). In this case, it is argued that we must carefully evaluate the value of GIS to geography and environmental education and encourage only that which promotes and supports spatial thinking and environmental understanding. We do not wish to fall prey to *technocentrism*, the justification for the use of technology because of the so called Mount Everest rationale – we use it '*because it is there*' (Salomon and Perkins, 1996).

The rationale for GIS

There are three competing and yet complementary justifications for incorporating GIS in K-12 education: (1) the educative justification: GIS and its theoretical superstructure, GIScience, supports the teaching and learning of geography and environmental education; (2) the workplace justification: GIS is an essential tool for knowledge workers in the 21st century; and (3) the place-based justification: GIS is the ideal tool to use to study the environment of a local community.

The educative justification: GIS and teaching/learning geography

For geographic educators the most important and powerful argument for incorporating GIS into the curriculum is its purported ability to enhance spatial thinking skills. In the United States, the National Geography Standards (1994) specifically encouraged the inclusion of GIS in precollegiate education, noting that GIS could be used to enhance students' geographic skills and ability to think spatially. There are three dimensions of spatial thinking: spatial visualization, spatial orientation, and spatial relations (Golledge and Stimson, 1997, p. 158). Spatial relations, listed in the left hand column of Table 1, are the aspects of spatial thinking most often developed in geography classrooms.

These parallel closely the processes used by individuals to develop their cognitive maps, shown in the right hand column of Table 1. Cognitive maps are the store of knowledge an individual has about environments organized as internal models of the world. Cognitive maps are the basis of both spatial and non-spatial decision-making. They are produced by the interaction of spatial relational data, spatial thinking processes, and environmental attributes as filtered through perceptions, beliefs, values, and attitudes. It has been suggested that cognitive maps are an internalized geographic information system. *It is difficult to think of a single functionality embedded in the GIS that does not have a parallel in human information processing capability* (Golledge and Bell, 1995, cited in Golledge and Stimson 1997, p. 236).

The educative argument for GIS is that it helps students to learn geography by practicing spatial thinking. The argument goes like this: GIS models the processes of spatial thinking. By mirroring these processes, doing GIS (following its procedures and steps to produce maps) demonstrates for students the cognitive strategies used in spatial thinking. Student ability to engage in spatial thinking is then enhanced. Students benefit from using a GIS to produce maps, it is argued, because it practices and sharpens their cognitive mapping skills, such as assessing similarity and proximity, and their spatial thinking skills, such as associating and correlating spatially distributed phenomena. A publication showcasing examples of GIS in US and Canadian schools states, *GIS is a powerful analytic tool that helps people understand the significance of spatial distribution patterns, whether the issues involve the siting of a new professional sports stadium, animal migratory patterns, or designs for*

Table 1. Spatial thinking skills

Spatial relations	Processes used in cognitive mapping and GIS
Abilities (skills) that recognize spatial distribution and spatial patterns	Constructing gradients and surfaces
Identifying shapes	Layering
Recalling and representing layouts	Regionalizing
Connecting locations	Decomposing
Associating and correlating spatially distributed phenomena	Aggregating
Comprehending and using spatial hierarchies	Correlating
Regionalizing	Evaluating regularity or randomness
Comprehending distance decay and nearest neighbor effects in distributions (buffering)	Associating
Wayfinding in real world frames of reference	Assessing similarity
Imagining maps from verbal descriptions	Forming hierarchies
Sketch mapping	Assessing proximity (requires knowing location)
Comparing maps	Measuring distance
Overlaying and dissolving maps (windowing)	Measuring directions
	Defining shapes
	Defining patterns
	Determining cluster
	Determining dispersion

cost-effective school bus routes (Audet and Ludwig, 2000, p. 4).

The workplace justification: GIS as an essential skill

Many of the arguments for teaching GIS in elementary and secondary schools use workplace skills (employment opportunities) as the most important justification. The position paper written to establish a committee to study the incorporation of GIS across the K-12 curriculum by the prestigious US National Academies cites first and foremost, *. . . concerns about the capacity of the American workforce to compete successfully in a context defined by intense international competition in global markets and rapid technological change in the nature of the work process.* The paper presents GIS as a decision support system able to manipulate an increasingly important commodity, spatial data, and links GIS to the need for 'knowledge workers' able to collect data, calculate and analyze data, and communicate knowledge, stating, *A GIS can both support and help implement the critical thinking skills that are central to creating smarter workers* (Committee on Geography, 2000). In the influential document, *NCGIA Core Curriculum*, Goodchild and Kemp (1990) rationalized incorporating GIS into pre-collegiate education because (1) it is a key tool to analyze the environment and solve problems, particularly at the local scale, (2) it enhances student interest in geography and related subjects, and (3) GIS is an attractive technology capable of motivating students to careers in science and engineering. At the post secondary level, the growth and proliferation of GIS certificate programs, on-line, Web-based distance learning GIS modules such as ESRI's Virtual Campus, and related self-teaching opportunities for 'busy professionals' further illustrate the workplace value of GIS. The inclusion of GIS in pre and post secondary geography education is thus justified to meet workplace needs and to smooth the school-to-work transition.

The place-based justification: GIS to study the environment of a local community

In the United States most classroom-based GIS involves a study of the local community. This fact reflects one of the perceived strengths of GIS as a key tool to explore and study the local environment. It also reflects more mundane factors such as the greater availability of local data, and the development of programs to link classroom educators with local government and business GIS users. Perhaps the most important reason for the emphasis on community-based study focuses on the deeply-held beliefs of many teachers about the value and wisdom of grounding learning in the local environment and students' experiences. GIS is a key feature in some environmental education programs because it is perceived as an ideal tool to create a learning environment in which students can learn by doing.

Starting with Dewey in the 19^{th} century, American educators have experimented with and promoted place-based education, nature studies (the precursor to environmental education), problem-situated education, and other 'alternative geographies' (Bednarz and Bednarz, 2003; Smith, 2002). Studying the local community fits well with current education theories, particularly those related to constructivism, as well as calls for 'authentic' education rooted in real world problems. In the most recent resurgence of place-based education in the United States, central aspects of the learning/teaching process are all community based. Content has a local focus and is relevant to the lives of students. The processes of learning are localized and the local context for learning is central to the development of student experiences. The community is the textbook, the teacher, and the classroom (Tolman, 2002). GIS fits well with this framework.

Environmental education-type GIS projects dominate in the US context. *GIS in Schools*, an influential book, one of the few for educators on GIS available in the US, (Audet and Ludwig, 2000), now published in Japanese, features numerous examples of teacher-led, community-based GIS.

The Community Atlas project started by ESRI in 1999, with the intent that classrooms describe their community through student-authored maps and narratives, simply reflects this interest in place-based education. Throughout the school year, classes work on their project which can focus on one of three areas: community history, solving a significant community problem, or a general description of the community, culminating in a nation-wide competition between schools and classrooms. Currently, there are over 40 publicly-viewable projects submitted to the Community Atlas from the first three years of activity (ESRI, 2003). Most of these involve some aspect of environmental education; many are science-based.

The Community Mapping Program (CMP), a program created in 1999 by The Orton Family Foundation, is a place-based, project-based educational program that brings students, teachers and community mentors together to address local needs and issues and build enduring connections to place. Mapping and decision-making technologies, including GIS and GPS, are introduced to enhance the discovery process. The CMP integrates community-based projects into existing curricula in primary and secondary schools, alternative-learning centers and other educational organizations and then asks, 'How can GIS enhance the project?'

In sum, GIS is used frequently in the US as a key technology, one of a toolbox, that enables students to study the local environment. In some cases students collect data themselves; in others, students use existing datasets as well as other data gathering and analysis tools, both technology-based and not. Often these learning endeavors are organized in case-based, problem-based or project-based formats. Students are encouraged to 'construct' their own learning, to 'explore', and to learn through their experiences.

Evaluating the cases

In the previous section three justifications for incorporating GIS in K-12 education were discussed. None seem to be particularly persuasive given the slow growth of GIS in US classrooms. How does each stand to evaluation? The answer appears to be that each appeals to a different constituency and each may need strengthening to be more effective and attractive.

For geography educators, it seems that the educative justification is more appropriately within the realm of geography. While providing students with key technological skills is a worthwhile and legitimate concern of education, geography (and environmental educators) should be cautious about serving a merely utilitarian role providing trained knowledge workers for the Information Economy as opposed to preparing educated, spatially-skilled individuals. A review of a partial list of skills mastered by students using GIS shown in Table 2 indicates that a large number are related to the *technology* of GIS and not to anything inherently geographic.

Two questions need to be considered. The first relates to time. Given the limited amount of time in the curriculum for geography, is it worthwhile to spend it mastering GIS? The second relates to long-term educational goals. In what ways do GIS contribute to and support geographic teaching and learning?

Research has not confirmed a connection between spatial relational skills and GIS instruction. A review of research in the US on measures of effectiveness of GIS concludes, '*much of the potential is garnered from intuition or related more broadly to the combination of technology and constructivist learning environments*' (Keiper, 1999, p. 49). Research comparing the efficacy of hands-on mapping activities with comparable GIS-based learning experiences for students found no significant difference between groups (Kerski, 2000). While it seems intuitive that GIS will complement the development of key geographic skills, it is not yet proven.

There appears to be a disconnect in the educative argument for GIS in geography, and that lies with the spatial thinking-GIS connection. There is no piece of a GIS that guides or directs students to analyze GIS produced maps using spatial relational procedures. For example, in the publication *Mapping Our World* (Malone *et al.*, 2002), students are led step-by-step to create a series of maps using a modified version of ArcView3.x. Students are directed to hypothesize, investigate, analyze, and so on through the procedure of creating a series of maps. But there is no explicit help for either teachers or students to complete the analysis of the maps and data. There is no direct link to the concepts and spatial processes listed in Table 1. It is obvious that modeling map production may not necessarily assist in developing cognitive processes.

The case for environmental educators may be different. When GIS is used as an instructional support in place-based, environmental settings, significant affective and cognitive gains are realized (Audet, 1993; Baker, 2002; Crabb, 2001; Kerski, 2000). Anecdotes of successful environmental education projects facilitated by GIS abound. However without prior explicit instruction related to the mechanics of GIS, data representation, or spatial thinking and reasoning, GIS may have a negative effect on student learning (Baker, 2002; Doerring, 2002). The positive outcomes of such projects may be largely affective, related to the development of ancillary skills such as learning to work in groups and improved attitudes toward technology and science.

Another consideration is the issue of *transfer* which will be discussed in detail later. Research in how students move from school settings to real world contexts indicates that both settings value different skills and proficiencies. In school, abstract reasoning, mental work, and individual achievement are emphasized. In contrast, real world settings are more tool-based and require people to work in groups. Problem solving is highly contextualized, not abstract. While community based studies in theory may help students to transition to the workplace by providing them practice in key real-world skills, the transfer literature indicates that the experiences need to be structured in ways that allow students to see connections between the local and the global, between the specific case and generalized settings in order to maximize education value.

Table 2. Skills addressed by the use of GIS

General computer skills	Learning skills
file management downloading and uploading Internet-based data data manipulation (unzipping, saving, printing, formatting data)	working in teams to tackle real world problems creating reports and presentations communication with peers
Database skills	**Geographic, cartographic and visualization skills**
classifying data differently observing the results on maps sorting, querying, creating and populating new fields	image & network analysis clipping, unioning, dissolving reprojecting data symbolizing points, lines, areas creating a map layout three-dimensional analysis skills

Depending upon the understood goals and expectations, then, GIS can be rationalized in environmental education, in technical programs, and possibly in geography education, under certain circumstances. Those circumstances largely relate to the topic of the next section, pedagogy.

Developing the pedagogy

The discussion so far indicates the need to pay attention to pedagogical issues. Pedagogy in its simplest terms is *teaching*; for the purposes of this paper its definition will include curriculum and assessment as well. In the United States and elsewhere (see Green, 2000 for a rich description of dissemination efforts in the UK) GIS has been slow to diffuse into pre-collegiate classrooms (Bednarz and Ludwig, 1997; Audet and Ludwig, 2000; Committee on Geography, 2000). The reasons have been attributed to three sets of factors. One set is related to hardware and software requirements, the need for accessible data, and other technical obstacles. A second set relates to the reluctance of teachers to invest time and effort to learn new technology without assurances of institutional support or career advantages. A third set relates to teacher technological skills, teacher preparation to teach *with* technology, the paucity of appropriate curriculum materials, and teacher conceptualizations of geography. Hardware and software remain a noteworthy issue; external forces continue to influence the adoption rate of GIS, but the teacher and his/her role in the classroom is emerging as the key determining factor. The following sections of the paper focus on pedagogical issues: teacher preparation to teach GIS, first by presenting a case study of a GIS training opportunity and second by examining briefly GIS and university-based teacher preparation; education research relevant to developing a pedagogy to strengthen GIS as a support for spatial thinking; and finally, issues related to teacher conceptualizations of geography.

Inservice teacher preparation in GIS

A continuing concern in GIS implementation has been effective ways to prepare teachers to use GIS in K-12 classrooms. Evaluation research following a cohort of educators learning to use GIS provides insight into the reasons for slow GIS diffusion mentioned in the previous section. In the summer of 1998, ESRI and partner organizations sponsored a two-week residential GIS training institute for 32 elementary and secondary educators on the campus of Southwest Texas State University. The purpose of the training was to prepare a cadre of teachers to (a) use GIS to teach geography and related environmental topics; and (b) train other teachers to teach with GIS. Thirty-two participants from 26 states and Canada were accepted, 16 women and 16 men. The majority of the participants were classroom teachers: 12 high school teachers, nine middle school teachers, two middle and high school teachers (grades 6–12), three elementary school teachers and one K-12 teacher. The remaining five had significant leadership positions: three college professors with extensive responsibilities in teacher preparation, a school district technology supervisor, and state educational outreach officer.

The GIS training was held in a lab set up especially for the training in the Department of Geography. The daily schedule began at 8:30 a.m. Most sessions began with the introduction of a new GIS skill, concept, or software. This skill, concept, or software was then modeled in a curriculum-based lesson. Detailed, step-by-step lessons outlined procedures for all lessons. Participants worked toward two major deadlines. At the end of the first week, pairs presented a project summarizing simple GIS skills and tools. At the end of the second week, teams of teachers prepared a more elaborate curriculum project that used a greater range of GIS skills and tools. These final projects were collected on a CD ROM and distributed. In between the first and second week participants took a brief regional field trip.

As follow up to the Institute, participants had two opportunities in the following year to work with Institute staff: at the annual meeting of NCGE held in October in Indianapolis, Indiana, and at GeoTech XI, an annual geography technology conference sponsored by the Archdiocese of Dallas held in April. A listserv (gisinst98@esri.com) was established in November to link participants and staff.

The Institute evaluation was both formative and summative. For the purposes of this paper, only the summative evaluation is discussed (see Bednarz, 1999 for a full discussion). A summative evaluation assesses Institute processes, outcomes, and eventual success, that is, the extent to which each goal was achieved. Such research is conducted after the impact of the Institute has had a chance to be realized.

At the end of the first school year following the Institute, approximately 10 months after the training, participants were randomly selected for a personal interview, conducted by phone. Further, the interview protocol questions were posted on the GIS Institute listserv and a request made for general comments from all participants. The conclusions summarized here are based on the interviews and emailed comments from eleven (11) participants.

Responses to questions were surprisingly similar. The conversations pointed to four issues of concern affecting GIS use in the classroom. They were time, training, institutional support, and pedagogy (curriculum, instruction, and assessment). These correspond to and confirm that factors identified previously by GIS proponents.

Time was the topic of greatest concern to Institute attendees. They identified two primary time-related issues, first, the need for personal time to learn how to do GIS themselves (practice/learning time) and second, the time needed to carry-out GIS-based instruction in the classroom (instructional time). Three respondents mentioned they wish they had had the time to practice and maintain their GIS skills following the Institute in July 1998 but that they had been distracted from that by other tasks and responsibilities. Other respondents talked about the amount of time needed to master key skills prior to implementation in the classroom. One participant wrote: *The biggest obstacle has been having enough time to get all the regular job duties done in order to learn and implement this GIS curriculum. I feel I spend way more time than other teachers I know … and I still only crawl along on the projects that I am developing.*

Another offered this piece of advice for teachers learning GIS, *Practice, and more practice for yourself. Be comfortable with the software. This takes time.* GIS was deemed by all interviewees as challenging to learn, 'a steep climb'.

Finding instructional time for GIS was a concern. One interviewee commented, *However long you think it will take (to do a GIS project), replace that time with the next available unit, i.e., two HOURS takes two DAYS.* A major barrier to implementation was the time limitation of the typical 45 minute to 55 minute class period. Block scheduling, an innovation in US middle and high schools that allocates extended blocks of time to subjects on a weekly basis, was cited as a requirement for successful GIS-teaching. One teacher, working with a colleague, had arranged her teaching schedule in order to team-teach science and social studies in a block to allow for GIS lab time.

Because of these time issues, all respondents reported that 'next year' they would be better able to implement GIS in their teaching. This was because they were now able to do GIS well enough themselves, to set up their hardware and software, and to conceptualize how to teach with GIS (see related issues in the following paragraphs).

On-going training and support/technical assistance were mentioned as needs and issues of concern by each respondent. Inter-group communication was perceived as important as well. *The listserv has been very helpful to me as an inspiration to keep at it and explore new ideas as well as a great way to follow the travels of others.* Another teacher stated, *This listserv has kept me in touch with what is going on with the others as they are using GIS. It sort of inspires me to continue. This list also enables me to ask questions because I feel comfortable with people I know.* Several participants expressed some regret at not being more communicative with other attendees and less helpful in responding to individual's requests for help and advice. This behavior was explained by one person as typical of a group of people more actively *doing* than *reflecting.* All participants wished for more listserv activity.

All interviewees expressed some degree of frustration in implementing GIS in their schools due to institutional barriers. Those barriers most frequently mentioned were inadequate hardware, insufficient access to computer labs, hardware and software installation issues, uncooperative school district technology personnel, unsupportive school administration, and disinterested colleagues. For many GIS Institute graduates, a good portion of their time in the year following the institute was spent negotiating with various powerful school entities. As one interviewee said, *Now I am ready this next school year to take off.* Not being alone in working with GIS was mentioned several times as a goal. *Networking is the key. You can't work alone; you have to help other teachers on your team learn about GIS* said one interviewee.

Once teachers were able to overcome the institutional barriers mentioned above, they faced a plethora of implementation issues related to curriculum, instruction, and assessment. In a variety of ways, all respondents reported changing their teaching styles, curriculum organization, and assessment strategies in order to teach with GIS. Most common was a shift to some form of project based or problem based learning and authentic, performance based assessment.

Those teachers reporting the greatest success in implementing GIS in the first year following the Institute did so in the context of technology courses, not science or social science classes. They were teaching GIS, not *with* GIS. Teachers in science and social studies reported greatest success in commencing GIS instruction with a relatively simple exploration of a community-based issue that fit naturally with their curriculum. Incorporating GIS throughout the curriculum was judged 'difficult'. As one respondent said, *You just can't stick GIS into the curriculum. You have to find a way to improve the delivery of your curriculum with GIS.* This same teacher said her goal was to 'problematize' all of her units in the next year or two to allow the use of GIS and other technologies.

Several teachers admitted that they were not able to integrate GIS instruction into their everyday teaching. Instead, they used it in a 'club' setting either before or after school, with a special sub-population of students. Two respondents expressed the feeling that this was a first step for them and felt confident that they would soon be able to use it with all of their students. One teacher wrote, *Most (students) only started projects that they wanted to finish in the fall during* *science club which meets twice a week after school. I hope to use these students to help train teachers when I do my workshops this year.*

In sum, while progress was made on each of these sets of factors, the linkage to the curriculum remained a significant impediment. Teachers in the US who have most successfully implemented GIS have done so through a total reorganization of their curriculum and a shift to problem based learning (Bednarz, 2000; Donaldson, 2001). Current trends in education in this country and an emphasis on high stakes assessments, however, have discouraged many adventurous teachers from taking risks and reorganizing their geography instruction and assessment. This may or may not be the case in other nations.

GIS and teacher preparation

GIS has also been slow to diffuse into an educative role in post secondary geography and teacher education. Although GIS is an increasingly important part of geography programs in higher education it is rarely used as a teaching technology. There is a great deal of instruction *about* GIS but little instruction *with* GIS. This is significant in the United States where geography is a general education course in many higher education institutions and non-geography majors are the largest constituency for geography courses. Fewer than ten percent of teacher education students were prepared to use GIS in 1999 (Bednarz and Audet, 1999). Scant attention has been paid to issues related to pedagogy and GIS at either the pre or post secondary level, leaving a number of significant and important questions unanswered. For example, does GIS facilitate student development of spatial relation skills when used to illustrate lectures? What effect will seeing university professors using GIS to teach have on the next generation of teachers? What are possible ways to teach GIS in post-secondary settings? Which methods and strategies have the greatest impact on the development of key spatial skills that will enhance further geography learning? What role can critical pedagogy play in developing socially attuned curricula and teaching strategies to produce GIS consumers with the necessary skepticism and understanding to practice its use ethically? There is a need for research in these areas and others in both pre and post secondary contexts.

GIS to support spatial learning

The literature in educational psychology indicates that it is unlikely that GIS will have a positive effect on student spatial thinking unless certain instructional conditions are met. The issue focuses on two factors: *teaching for understanding*, characterized as teaching so students gain usable knowledge connected and organized around important concepts, and *transfer*, defined as the ability to extend what is learned in one context to other contexts (Byrnes, 2001).

The relationship between learning and transfer is seminal (Bransford *et al.*, 1999). People can learn something in one context and fail to transfer that learning to other contexts. For example, using a set of procedures to solve a problem in selecting the optimal location for a new store may not help prepare a student to use the same procedures to select a location for a new fire station, school, or hospital. Transfer is affected by the degree to which people learn with understanding as opposed to memorizing facts or sets of procedures. It is also affected by how the knowledge is acquired, that is, the context and instructional experience. Certain learning experiences facilitate transfer while some may hinder transfer. For example, research findings indicate that if students learn only in specific case-based or problem-based contexts, they can fail to transfer flexibly to new contexts or cases (Cognition and Technology Group at Vanderbilt, 1997).

Using *Mapping Our World* as an example, students following directions to conduct an analysis of x, such as variable patterns of precipitation in South Asia, may not be able to draw upon that same procedural knowledge when faced with even a similar problem placed in a different context. Simply learning to perform procedures and learning in only a single context does not promote flexible transfer. Furthermore, students may become so dependent upon the steps that they never incorporate them into a more automatic cognitive strategy. Wisely, the structure of *Mapping Our World* attempts to address this problem by providing one lesson per module which is for more advanced teachers and students. To use a bicycle analogy, this third lesson is the bike with the training wheels off. It allows students to practice their GIS skills in a more independent context. However, anecdotal reports indicate few teachers using *Mapping Our World* are actually attempting these lessons (Wilson, personal communication).

Instruction that requires students to learn at a higher, more abstract level supports learning for understanding and transfer. The more students understand conceptually about what they are learning, the more likely they are to be able to use this knowledge in new and different situations. Instruction on abstract principles related to a topic can help students learn more. For example, the performance of novices learning to distinguish male from female day-old chicks (a visual learning task) was improved by just twenty minutes of instruction at a conceptual level (Bransford, 1999, p. 53). In a classic study conducted early in the 20^{th} century to study learning for understanding, two groups of children practiced throwing darts at a target underwater. One group only practiced throwing the dart. The second group learned about light refraction which can cause target locations to be difficult to perceive. Both groups did equally well on the practice task, but when the target was moved to a more shallow pool of water, only the second group which understood light refraction could hit the target. They knew the abstract principle and could transfer this knowledge to a new context. A possible explanation for this is that students who are taught at the abstract level are then better able to relate new learning to their existing broader knowledge networks (schemata). Learners construct new knowledge based on their current knowledge. Teaching new knowledge in such a way that it connects to common elements in the existing schema helps to make students truly understand and be ready to apply that knowledge in new learning contexts. If knowledge is power, knowing abstract knowledge is more powerful and helps produce independent, critical thinkers. It is clear that these findings need to be incorporated into the development of a pedagogy appropriate for GIS.

Teacher conceptualizations of geography

Perhaps the most important area for pedagogical research in this country is in the role of the teacher in GIS instruction. Unlike other nations, most US geography and science teachers, the educators more frequently implementing GIS in schools, are relatively poorly prepared in geographic and spatial skills. They may be comfortable with the technology and research methods, problem based learning, and other aspects of typical GIS use, but they may be under-prepared to conduct the spatial analyses or tasks listed in Table 1 let alone to teach others to do them.

It appears few teachers are aware of the growing importance of maps or mapping science or are excited about spatial thinking and reasoning, problem solving, or even teaching with and about maps. Teaching *with* maps means using maps in instruction to help students learn key geographic concepts and relationships. Teaching *about* maps means providing students with the skills and understandings required to read, interpret, and produce maps. The map skills components of most US textbooks and other map-teaching materials focus on teaching *about* maps and are often dry, skill-oriented, and not well connected to the real world. Few textbooks or other teaching materials offer teachers concrete strategies to teach *with* maps. In addition, given that most educators teach the way they were taught, if educators have not had the opportunity themselves to be taught with maps, they may not be familiar with the technique.

This lack of interest in maps and skill in map teaching is a barrier in GIS implementation. Teachers may simply not have the skills or knowledge to prepare students to function successfully in a map-rich world let alone to fully use a GIS. This inability to use maps is obvious from the results of the 2002 National Assessment of Educational Progress in Geography. The hardest test items at each grade level (grades 4, 8, and 12) required students to use and interpret maps (Weiss *et al.*, 2002).

Teachers appears to be ‘the weakest link’ and a serious component limiting diffusion of GIS. Further evidence to support this observation comes from a recent survey conducted in Texas of geography teachers, members of the Texas Alliance for Geographic Education (TAGE). These educators were identified as a ‘pool of experts’ who, by their membership in TAGE, expressed an interest in both geography and pedagogy. This survey provided baseline data about how teachers – likely the best of the best – think about map skills and how they consequently teach them. While analysis is ongoing, initial results show respondents have a minimal understanding of maps and how to teach with or about maps (Acheson and Bednarz, 2003).

Implications

This paper began with the premise that GIS education is at a crossroads and that there is a need for a new, research-based, society-oriented rationale for the role of GIS in K-12 education. Three existing justifications were reviewed and evaluated, and weaknesses in at least one, the case for GIS in geography, were identified. Next, the reasons affecting the slow diffusion of GIS were examined in an attempt to link the justifications with barriers, perceived or real, hindering adoption of GIS. Pedagogy emerged as a persistent problem.

The implications of this discussion for geography and environmental educators are significant and focus on building a stronger justification for GIS as a support for spatial thinking and on developing the pedagogy to do that.

Geography and environmental educators need to be clear about the role of GIS in promoting the core tenets of our disciplines, including spatial thinking and reasoning, before proceeding to invest continued time and effort on its behalf. It has not been persuasive enough or sufficient for us to assume that GIS promotes and develops spatial skills. We need to know *if* it occurs and under what conditions in order to further expand its practice – or to find better and simpler ways to achieve the same goals. The value of working with GIS to explore the local environment needs to be placed within larger education objectives, and those should relate to subject-specific goals, not school-to-work transition issues exclusively. We do not need to join a technology-driven-workplace-oriented crusade on behalf of GIS unless we are convinced that it is in the best interests of students and their personal, social, and spatial development.

As in most geography (and environmental) education papers, there must be a plea for research. Geography and environmental educators need to conduct research on a wide variety of pedagogical issues. Once the justification case issue is resolved, then we can begin to devote the time and effort needed to prepare GIS-literate, spatially attuned teachers, GIS-enabled classroom instructors, and the developmentally appropriate curricula needed to support spatial thinking and reasoning. In arguing the educative value of GIS, we can assert that students *may* be taught spatial thinking through GIS if certain instructional strategies are in place. These instructional strategies may include teaching in different contexts and teaching for understanding by explicitly emphasizing abstract representations, cognitive strategies, and spatial thinking and reasoning. We cannot afford to continue to assume that simply by doing GIS, students will recognize or learn cognitive mapping processes, spatial analysis, or spatial thinking. Geography and environmental educators need to explore metacognitive approaches to teaching GIS that reinforce student awareness of their thinking processes and which make spatial thinking explicit. We also need to explore ways to make students learn how experts solve spatial problems, perhaps by mediated GIS instruction and use. The implication is that there is a tremendous need for the development of a research-based, classroom-tested set of instructional materials for teaching and learning with GIS. Such research can serve dual purposes by contributing to the development of theory on spatial thinking and reasoning processes while also laying the groundwork for more applied approaches to specific teaching and learning strategies. A project to do that is already underway in Australia (Robertson, 2003). It can also help in the development of a new generation of software designed with assisting spatial thinking in mind.

An interesting realm for research related to pedagogy lies in the ideas of naïve geography. Egenhofer and Mark (1995) extend the analogy of naïve physics proposed by Hayes to suggest that GIS should capitalize on the naïve knowledge of geography that is held by people. This idea supports research in science education on the role of misconception in concept development (Bransford *et al.*, 1999). An examination of what students already know about spatial relations could help teachers construct and develop learning opportunities with GIS more closely related to human cognition. If GIS actually matched the cognitive processes used to develop cognitive maps more effectively, it could be hypothesized that it would have a greater effect on students' abilities to develop a more sophisticated and accurate understanding of geography (Raper, 2000).

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