The Implementation and Effectiveness of Geographic Information Systems Technology and Methods in High School Education

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Abstract:
Geographic information systems (GIS) technology and methods have transformed decision-making in universities, government, and industry by bringing digital spatial data sets and geographic analysis to the desktop computer. Some educators consider GIS to be one of the most promising means for implementing educational reform. However, GIS technology has been adopted by only 1% of India high schools. The reasons behind the interest in GIS technology and methods, their slow implementation, their extent in the curriculum, and their effectiveness in teaching and learning are unclear. To address these concerns, this research: (1) describes the geographic and curricular extent to which GIS technology and methods are being implemented in secondary education in the United States, (2) explains why and how GIS is being implemented, and (3) assesses the effects of inquiry-based lesson modules that use GIS technology on teaching and on the acquisition of standards-based geographic content and skills.

Keywords: *Geography, GIS technology*

1. Introduction

GIS provides the opportunity for issues-based, student-cantered, standards-based, inquiry-oriented education, but its effectiveness is limited primarily by social and structural barriers. Technological barriers to the adoption of GIS, such as limited hardware and software, were found to be less significant than time required to develop GIS-based lesson modules, inadequate student access to computers, inadequate training, and pressure to teach a given amount of content during each term. GIS is being implemented primarily by veteran science teachers at public high schools who perceive that GIS provides real-world relevance, provides interdisciplinary education, and increases student interest. These teachers persist in developing and implementing inquiry-based GIS-based lesson modules despite perceived lack of time and training. Sults of experiments with standardized and spatial analysis tests were mixed, although students using GIS performed significantly better on their assignments than those using traditional methods. Case studies showed that GIS changes teacher and student roles, communication, and methods of teaching and learning.

2. The Research Problem

Geographic information systems (GIS) technology and methods have transformed decision-making in society--in government, academia, and industry. Some educators consider GIS to be one of the most promising means for implementing educational reform. However, GIS technology has been adopted by less than 2% of India high schools. The reasons behind the interest in GIS, its slow implementation, its extent in the curriculum, and its effectiveness in teaching and learning are unclear.

To address these concerns, this research describes the geographic and curricular extent to which GIS technology and methods are being implemented in American secondary education, explains why and how GIS is being implemented, and assesses the effects of GIS-based lesson modules on teaching and on the acquisition of standards-based geographic content and skills.

The first goal of this study was to describe the extent to which GIS is implemented in secondary education in the United States. A review of the related research showed that although GIS and educational reform in geography are each separately in the mainstream of research, the combination of GIS and education clearly is on the periphery. Most of the literature on the extent of implementation came from anecdotal accounts, rather than from national or regional analyses.

This study's second goal was to explain why and how GIS is implemented through an analysis of challenges and catalysts. Diffusion research and a few GIS implementation models provided a framework within which to analyse implementation. The third goal was to assess the effectiveness of GIS on secondary geography teaching and learning. Studies thus far showed mixed results in a few classrooms scattered across the country. GIS-based lesson modules are few and the technology is largely untested. The expansion of GIS as an educational tool, despite its slow diffusion in education compared to business and industry, far outpaces the associated research in its implementation and effectiveness. Research thus far has emphasized teaching about GIS, rather than teaching with GIS (see Sui 1995). It is still unclear how and why GIS is being implemented in the high school curriculum both on a national level and within individual schools, and what difference it really makes in education.

3. Connecting GIS to Tenets of Educational Reform

The unprecedented attention to geography education at all levels since 1985 may be strengthened and extended with the aid of properly-applied GIS technology. The U.S. Labor Secretary's Commission on Achieving Necessary Skills (SCANS) stated that the most effective way to teach skills is "in context" (U.S. Department of Labor 1991). The SCANS competencies include identifying and using resources, working with others, acquiring and using information, and understanding complex interrelationships (Hill 1995a and 1995b). Interdisciplinary education, rather than teaching each subject in isolation from the others, may be a more effective means to help students solve problems (Jacobs 1989). Implementing GIS into the curriculum may encourage students to examine data from a variety of fields (Furner and Ramirez 1999; Sarnoff 2000).

Since the publication of the first national content standards in geography (Geography Education Standards Project 1994), social studies (National Council for the Social Studies, National Task Force for Social Studies Standards 1994), science (National Research Council 1996), and technology (International Society for Technology in Education 2000), educators nationwide have been progressing toward a model of "inquiry-based" instruction that emphasizes a hands-on, research-based learning experience. Inquiry draws upon learning theory known as constructivism, which holds that rather than being transferred from teacher to student, knowledge is constructed by the learner based on his or her own experiences (Driver et al. 1994).

4. National GIS in Education Survey

A mailed survey of 33 items was sent to 1,520 high school teachers who owned a GIS package, to describe the extent to which GIS technology and methods are being implemented in the USA. No assumption was made as to whether the teacher was actually using GIS. The best approximation to surveying teachers using GIS in the curriculum was a list of teachers who owned a GIS software package. A listing of teachers owning any one of three brands of GIS software was procured and became the survey's sampling frame. The national survey revealed that GIS has not made significant advancements in terms of the number of secondary schools using it. Over 500,000 users of ArcView GIS exist worldwide (Environmental Systems Research Institute 1999), but less than 1,500 users were in the database of educators.

The number of high schools owning one of three main GIS software packages numbered less than 1,900, representing fewer than 5% of all secondary schools. Even among teachers who own GIS software, nearly half are not using it. To put it another way, the state of the art is far beyond the state of practice (Means 1994). Only 3% of schools in the U. S. are effectively integrating technology into all aspects of their educational programs (according to Viadero 1997). Those who are using GIS do so in a wide variety of settings, in different degrees, and in many ways, ranging from preparing maps to be used as tests and on overhead projectors, to incorporating it into fieldwork and with global positioning systems (Figure 1). Only 20% of teachers using GIS use it in more than one lesson in more than one class. GIS is being implemented in standard-sized schools and classrooms, primarily by veteran science teachers. Science teachers outnumbered geography teachers by approximately two to one in the use of GIS. Chemistry teachers were the most-represented single group, primarily through water quality studies.

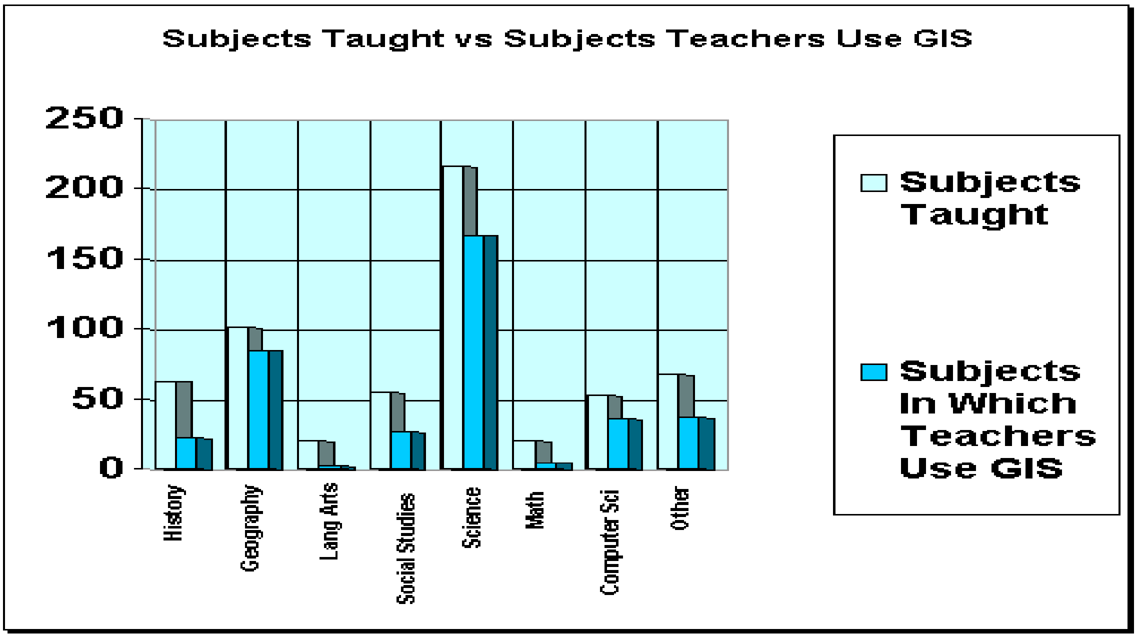

Fig. 1. Subjects Taught vs. Subjects in Which Teachers Use GIS

Although technological and administrative support is lacking, teachers who have adopted GIS are enthusiastic and active. Lessons are constructivist, reformist, and interdisciplinary in nature, emphasizing teaching with GIS in a content area, rather than teaching about GIS. Implementing GIS is a complex process; evident in such survey data as lag periods of up to several years between the time teachers obtain GIS software and the time they implement it.

Despite a growth in GIS implementation in education, the survey revealed several patterns that signify restraints on its expansion. Even more telling of the challenges teachers encounter when implementing GIS is that nearly half of all responding teachers (45. 1%; n=370) are still not using GIS in the curriculum. These include teachers who indicated that they are “not yet” using GIS or that they “plan to” use GIS in the future (Figure 2).

Considering that the survey is biased toward GIS adopters than non-adopters, it is likely that less than half of the total population of secondary teachers owning GIS software are actually using it.

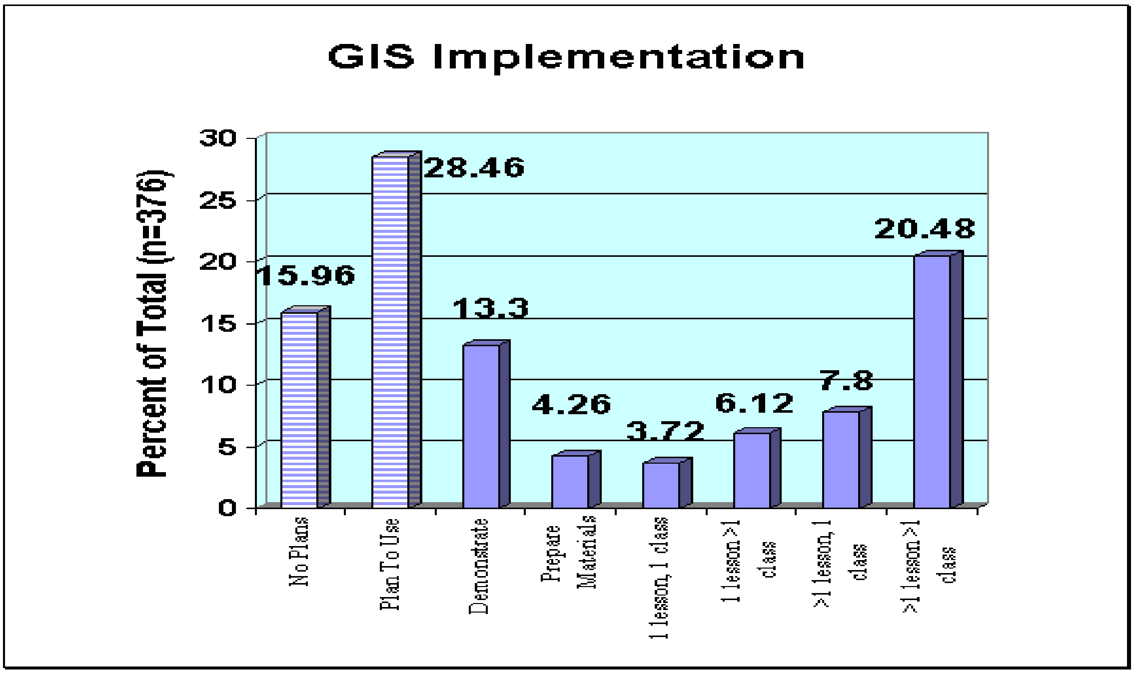

Fig. 2. Extent of GIS Implementation in the Curriculum

Measuring the time between the date that the software was obtained and the date that the teachers began using it in the curriculum indicates that implementation challenges exist. In less than half of the cases (44.4%, n=351) did the teacher obtain and begin using GIS in the same academic year. In 35.9% of cases, a one-to-two year delay occurred, and in nearly one out of every five schools (19.7%) at least three years; delay took place. In 17 schools, the delay was over five years.

Teachers are first trained in GIS largely through in-services. Preservice teachers have little opportunity to learn about GIS. Positive factors in implementing GIS fall mostly on the learning side, while on the teaching side, some are negative. A lack of education-specific training, time to prepare lessons, and the complexity of the software are the chief challenges to implementing GIS. Providing real-world relevance, integration of different subjects, providing an exploratory skill, and enhanced learning and motivation are cited as the main benefits.
Teachers were asked, "To what extent will you use GIS next year compared with this year?" They could choose among decreasing use, maintaining present use, or increasing their use. Even though GIS cannot be quickly mastered and implemented, teachers are apparently willing to invest in making it a success. Indeed, the teachers were enthusiastic about the technology. Nearly three out of four teachers (71.9%; n=327) planned to increase their use of the software; only 4.3% planned to decrease their use (Figure 3).

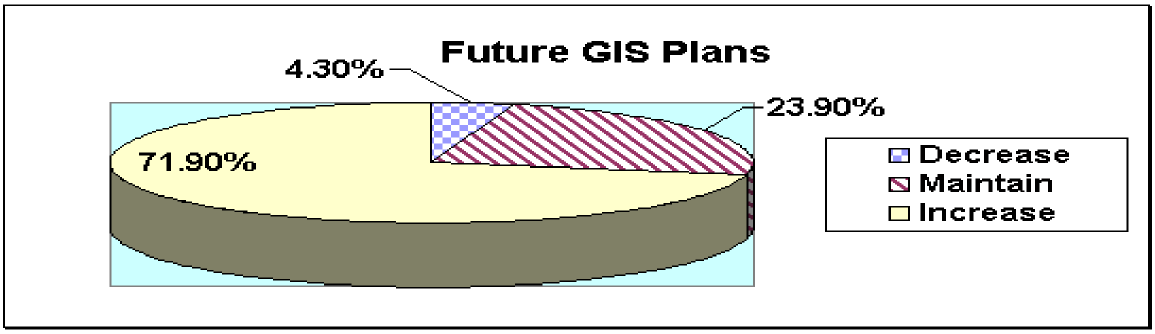

Fig.3. Teachers' Plans for Future Use of GIS

The large amount of time teachers spend with GIS indicates both their enthusiasm with the tool and also the time-intensive nature of mastering and using it in the curriculum. Most teachers are so enthusiastic about this technology that they invest their own time to learn it. Over 62% of teachers said that they spent at least one hour per week outside of class time with GIS. Over 21% of teachers using GIS were using the tool at home. Teachers, already under pressure to perform a host of other tasks each semester, were willing to invest their personal and professional lives in this tool. The fact that most of these teachers have been in the profession at least 20 years adds significance to this finding: they are more likely to carefully consider the advantages and disadvantages to GIS, rather than "jumping on the bandwagon" of technology. Their acceptance of the tool encourages others to adopt it, rather than to dismiss it as a fad.

Most teachers (88%; n=342) believed that the use of GIS makes a significant contribution to learning (Figure 4). Only 1.8% of teachers did not believe that GIS made a significant contribution, and 10. 2% were uncertain. Part of the explanation for the overwhelming support is because the surveys were sent to teachers who had originally expressed an interest in and obtained GIS software. There is also a natural reluctance to disclose that something a person has invested in is not worth the effort that was spent. Still, the evidence is clear that teachers, despite the challenges, believe that GIS is worth it.

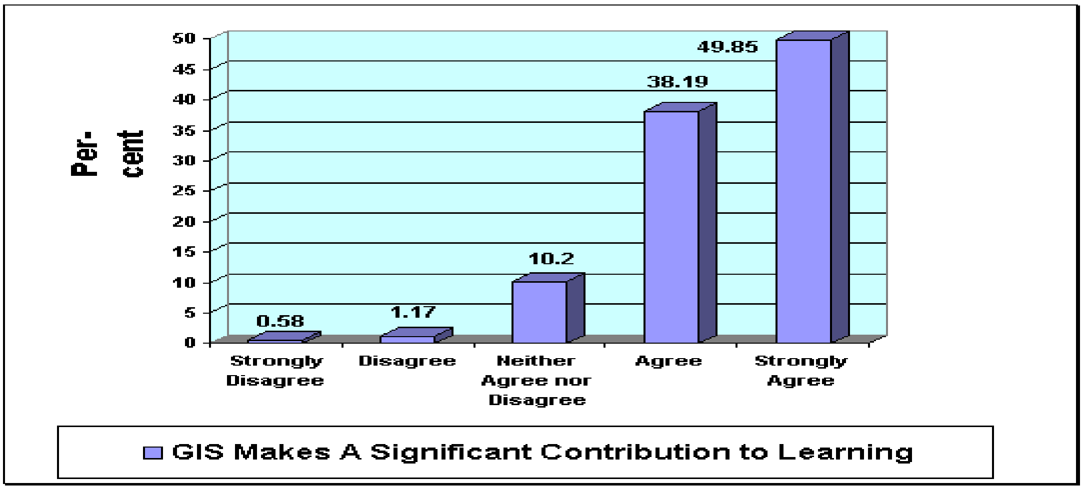

Fig. 4. Teachers' Beliefs about the Contribution of GIS to Learning

There is no mandate requiring the use of GIS in the educational curriculum. However, a small percentage of teachers nationwide have taken it upon themselves to solve problems and conduct workshops to promote its implementation. Convinced of its benefits, these teachers amount to about 15% of survey respondents, and spend a great deal of personal time with GIS.

GIS implementation was examined through a GIS implementation model by Audet and Paris (1997), through Rogers'(1995) diffusion of innovations model, and a social interactionism model. Predictors of GIS implementation in education include good computer file management and database skills, and comfort in giving students the freedom to explore in class. Spatial thinking and the existence of an implementable project should be added to these predictors. The survey showed that the best predictor of a teacher using GIS is if more than one teacher in the school is using it, followed by the number of hours spent in GIS training.

Because GIS is being implemented largely by individual teachers, there may be instructional materials development principles that are not being incorporated into preparing curricula. Most GIS-based lessons are not widely available or easily used, inhibiting the speed of GIS diffusion throughout secondary education.

One teacher conducting a peer training session commented that at the end of the training, a teacher asked, "Can I print out blank outline maps with this program?" This indicates that some teachers view GIS as nothing more than a computerized atlas. Thinking in a different way is perhaps the one factor that hinders GIS implementation in education the most. With advances in accessibility of hardware, software, and data, learning is increasingly dependent on the adaptability of teachers more than accessibility of technology. Powell's (1999) study found that although innovative science curriculum materials do influence teachers'; practice, even more important is whether a teacher's beliefs are aligned with the philosophy of these curriculum materials. The implication for GIS is that only those teachers who value an open-ended, exploratory approach to learning will adopt it.

Teachers felt that the lack of time to develop GIS-based lesson plans was the chief challenge to implementing it in the classroom (Figure 5). These findings suggest that organizations interested in the spread of GIS might maximize their impact on implementation by committing resources toward building these GIS-based lessons.

Constraint to GIS Implementation	Φ	σ	Degree of Constraint: None 1 — 2 — Some 3 — 4 — Very Much 5
Complexity of software.	3.69	1.01	M
Cost of hardware and software.	3.13	1.34	M
Computers not accessible to my students.	3.17	1.52	M
Computers not capable of handling GIS.	3.03	1.49	M
Lack of time to develop lessons incorporating GIS.	4.00	1.14	M
Little administrative support for training.	3.07	1.43	M
Little technical support for training.	3.24	1.36	M
Class periods too short to work on GIS-based projects.	2.49	1.35	M
Lack of useful or usable data.	2.42	1.22	M
Lack of geographic skills among students.	2.54	1.09	M
Variable skill levels among students.	2.88	1.14	M

Fig. 5. Perceived Constraints on GIS Implementation

5. The Effectiveness of GIS: Experiments

To supplement the national assessment with a detailed assessment at the local level, a series of experiments and case studies were conducted. One teacher responding to the national GIS education survey, although experienced with GIS, expressed concerns about its effect on learning:

I personally have been troubled with the question of whether students are learning geographic inquiry strategies or merely learning to use a very powerful tool without much thinking about the underlying questions under consideration.

Experiments were conducted in three public high schools in metropolitan Denver, Colorado, USA: Riparian, Hope, and Prairie Vista High Schools (see endnote). The schools were selected based on criteria aimed at ensuring that the schools, courses, teachers, and students would be as equivalent as possible so that experimental results could be compared. First, each school had to have an active, distinct geography program, taught in at least one class for at least one full academic year, where GIS and the national geography standards were used.

The experimental design included the creation of 12 geography lessons, each with two versions—a GIS-based version, and a version using traditional print materials. In each school, experimental groups were sections, or class periods, of a geography course in which students used GIS to complete the lessons. Control groups were comprised of other sections in the same geography course in which students used maps, texts, and paper graphs. Pre-tests and post-tests consisted of "standardized tests" -- based on national, state, and district geography standards, including one from the NCGE (1983), and a spatial analysis test that I created where students chose the best sites for a "Spiffy's" fast food restaurant.

GIS was tested for its influence on the dependent variables--knowledge of geography content and geographic skills, defined by scoring guides based directly on the national geography standards (Geography Education Standards Project 1994). Two-sample t-tests with equal variances were conducted on both the standardized and the spatial analysis tests, and pertest scores were compared to post test scores via paired t-tests to determine the amount of change over the semester and between each group. Scores from the lesson modules were also analysed with a two-sample t-test. ANOVAs and t-tests provided data on gender differences. Several regression models were established to investigate the relationship between GIS, pertest scores, and the difference between pre-test and post test scores. Analyses were conducted on individual classes, between classes, in each school, and between schools.

Eighty-seven tests were conducted on data obtained from six experiments conducted in three high schools. The effectiveness of GIS on student performance using standardized and spatial analysis tests showed mixed results in each school and considering all schools together. Spatial analysis test scores either did not change or declined between the beginning and end of the semester. Declining student performance suggests inadequacies with the spatial analysis test and a disincentive for students to thoughtfully complete it at the end of the semester. If a teacher uses GIS, he or she is not able to spend as much time on “testable” content that would appear on a standardized test. GIS did not typically appear to affect the stagnant or downward trend in spatial analysis scores. However, linear and non-linear regression models considering all schools showed that GIS did make a difference in the relationship between GIS and the difference in test scores from the beginning to the end of the semester. Tests on GIS on final course grades suggest that average and below-average students improve more with GIS than above-average students.

GIS did have a significant effect on student performance on the lessons themselves. In four out of nine tests, students using GIS scored significantly higher than their counterparts who were using traditional methods, and demonstrated a better ability to synthesize, identify, and describe reasons for human and physical patterns. GIS appears to improve learning of geographic content, not just skills. Furthermore, GIS fostered higher-order analytical and synthetic thinking, and it also increased students’ knowledge of absolute and relative locations of places across the globe. GIS appeared to affect performance by gender in only four of 26 tests.

6. Recommendations and Final Considerations

Insight could be gained by conducting a longitudinal study of the same schools, a national resurvey, and the inclusion of K-8 and university instructors, learning styles, better assessments, and an affective analysis. Educationally-based curriculum materials need to be developed with an easy-to-use GIS package capable of performing robust spatial analysis and problem-solving. I believe that the geographic perspective is in high demand partly because of the success that GIS users have had in solving problems. I recommend that teaching with GIS be used as the primary method of integrating geographic thinking into other disciplines. Finally and perhaps most importantly, I recommend that the approach to GIS should not be, "How can we get GIS into the curriculum?" but "How can GIS help meet curricular goals?"

This study was entitled "The Implementation and Effectiveness of Geographic Information Systems Technology and Methods in Secondary Education, because GIS was found to be more than just a technology, but also a method. The methods that GIS uses to understand the world make GIS attractive to those advocating educational reform. These same methods, more than the tools, make GIS difficult to implement. GIS allows students to do geographic and scientific analysis, not just read about the results. For GIS to be effective, schools must build an environment of curiosity about investigating the world. Downs (1994) advocated an empirically and theoretically sound, practical, relevant base of knowledge for geography education. This dissertation provides lesson modules that teachers can test in their own classrooms. It is hoped that this study will encourage others to pursue avenues of research and development to take advantage of GIS technology and methods to improve the quality of education.

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