Maximizing the Potential for GIS to Enhance Education

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Abstract: *GIS is increasingly being recognized as a valuable tool for use in K-12 classrooms. Based on the history of previous applications of technology to enhance instruction, one could reasonably raise questions about whether GIS wil have a lasting impact or is just a passing fad in a field which is all to anxious to grab the latest trend and discard what was seen as valuable only a few years ago. In this paper, the role and prospects of GIS in K-12 education will be considered in light of these factors. Recommendations will also be given to better support the potential for GIS to achieve lasting significance.*

Since the dawn of the personal computer in the early 1980s, well-meaning educators have sought to bring their power to the classroom. This process continues unabated, with schools now spending more than five billion dollars a year on hardware, software, and training in an effort to improve students' learning opportunities (Cuban, 2001). Quite often, schools attach unrealistic, almost millennial hopes to these acquisitions, hoping that the computers will provide the missing link needed to achieve educational excellence. As a result of this high priority placed on computers in the classroom, funding is often available for technology initiatives that wouldn't be available for other purposes, regardless of their educational merit. Such is the faith that we place on computers in education.

Viewed more broadly, this rush to infuse the classroom with technology is part of a much larger tradition dating back nearly a century, if not longer. As Cuban (1986) notes in his history of educational technology, movies were seen as the bold and innovative new way to learn in the 1910s. No less a figure than Thomas Edison weighed in on this with grandiose claims for using then-current technology in education (Cuban, 1986, p. 9):

> I believe that the motion picture is destined to revolutionize our educational system and that in a few years it will supplant largely, if not entirely, the use of textbooks.
>
> I should say that on average we get about two percent efficiency out of schoolbooks as they are written today. The education of the future, as I see it, will be conducted through the medium of the motion picture…where it should be possible to obtain one hundred percent efficiency.

Since then, a continuing stream of new educational technologies has come on to the scene, promoted by their developers and forward-thinking educators as *the* solution to what ails education. From the days of film and radio to educational television and now with computers and the internet, considerable faith has been placed in the power of technology to help schools achieve goals that they have previously been unable to realize. Just in the past twenty years, we have seen schools rush to adopt computers in the name of diverse purposes, such as programming, multimedia, building intercultural understanding, and gaining access to a wealth of information online. Each time, the new capacities brought forth by a technological advance are seen as the key to unlocking students' heretofore unrealized potential. It has almost become a "fill in the blank" exercise: Now that ______ is available, students can learn critical thinking, become 21st century learners, and so forth.

While there have been well-publicized success stories for each of these uses of technology, the day-to-day life of most students remains largely unchanged in the nature of the tasks in which they engage. This spring, I had an opportunity to visit an urban middle school that was participating in an intensive laptop initiative. While the provision of a dedicated laptop computer to each student in a school could very well be used to revolutionize the learning environment, this was not the case. Instead, literature students were searching with Google and Yahoo to identify an author's age and current residence, a social studies class was summarizing current events stories found online, and a science class was visiting a set of zoo web sites given by the teacher to look up where in the world each species on a list of animals lives. Thus, despite the investment of hundreds of thousands of dollars of infrastructure in this school alone, education as a learning enterprise continued on much as it had in the past. Sadly, this school was not unique in my experience or in the eyes of many other observers. Even with the addition of technology, core school tasks are remarkably resistant to change.

In the past few years, there has been a growing effort to integrate geographic information system (GIS) software into the classroom—one of the new crop of technologies that is trumpeted as a means to revolutionize education. As in the past, the operating premise for many GIS advocates has been that if only more people would adopt these marvelous new tools, students and teachers would move into an educational utopia filled with meaningful learning opportunities. As the growing literature in the field notes (e.g. Audet and Ludwig, 2000; Green, 2001), there are a number of situations in which educators have been able to achieve significant results through the use of GIS. These efforts on the part of pioneering teachers are to be lauded—they have helped to demonstrate that powerful analytic tools can be made accessible to students. It is sobering, however, to compare the current trajectory of GIS integration with the rise and fall of previous technologies. Grizzled veterans of previous fads such as Logo and HyperStudio will appreciate that the lifespan of a revolutionary technology in schools is quite short, soon to be replaced by the next great thing, which of course, will at last be *the* answer educators have been waiting for.

As proponents of GIS in education, it is incumbent upon us to seize the opportunity we have to define a different path. Phrased differently, the increasing awareness of GIS and related technologies (such as GPS and remote sensing) gives us a platform from which we can promote a larger educational agenda. Instead of seeking ways to get GIS into classrooms, we should be seeking ways to create meaningful learning opportunities in which the need for GIS is obvious. Just as you don't go into a hardware store to buy a hammer and look for things to pound, we shouldn't simply be looking for ways to infuse GIS into the curriculum. Instead, we need to build on the successes of the past few years in proving that despite its complexity GIS is accessible to students, and move from there toward a more substantive engagement that goes beyond hooking the "early adopters" who latch on to innovations with comparative ease. While most would agree that this larger engagement is something to be desired, we have not yet developed the programs and infrastructure to make it happen. Thus, we have many short-term "drive-by trainings" and isolated lesson plans, but comparatively few instances of more comprehensive integration of GIS into the everyday teaching and learning environment. The balance of this paper presents reflections on how we might move in this direction productively.

Creating the Future of GIS in Education

If the current growth in the use of GIS in education is not to become just another fad, we as the leaders in the field will need to stake out new territory. There are three "levers" which can be used to effect meaningful change: curriculum, assessment, and teacher learning (Cohen and Hill, 2001).

Support engaging and meaningful curriculum. Throughout our advocacy on behalf of using GIS in education, our focus needs to remain on the possibilities it offers to improve the curriculum, not on features of the software. Too often in educational technology, learning has been feature-driven. For example, in the heyday of Logo (and its successors), programming was made accessible to students. While this hadn't been an important educational goal prior to the arrival of Logo, it suddenly became a rationale unto itself, along with the requisite supporting beliefs in the importance of logical thinking. Similar "feature shift" can be traced in the history of most other educational applications of technology as well. As a result, it shouldn't be surprising that teachers who are not part of the early adopters have been hesitant to integrate new technologies into an already crowded curriculum. Until the benefits are obvious, teachers are rightfully skeptical.

In the context of using GIS in the classroom, using the software's power simply to teach students how to map data such as earthquake locations is pedagogically insufficient. Instead, we need to focus on more substantive educational considerations such as how we can deepen students' understanding of concepts such as seismic activity and plate tectonics through analyzing spatial patterns in real data. Ideally, this engagement with data should be sustained over time so that students have extended opportunities to work with a given set of data, and so that working with real data in the classroom becomes the norm rather than the exception. Simply doing an isolated GIS-enhanced lesson is a good start, but ultimately inadequate if the end result is to be a substantive improvement in the nature of students' experiences.

Based on recent work supported by the National Science Foundation and a variety of developers, there is an emerging consensus as to the characteristics of effective curriculum materials. These materials should support a number of diverse goals, including (U.S. Department of Education, 1997, p. 77):

- Turning students on to a discipline;
- Making students think;
- Embodying high-quality content and pedagogy;
- Enabling meaningful classroom assessments; and
- Encouraging teachers to teach differently.

As the growing body of case studies and research in the field documents, GIS-enhanced inquiry can support these goals quite well. One promising mechanism for enabling this to happen on a more regular basis is to achieve a meaningful alignment with national curriculum standards. These standards represent the best current thinking in specific academic disciplines and as such, they help to define the intellectual territory of their field. In turn, GIS-enhanced inquiry offers a means for schools to meet the challenging demands offered by these standards documents. For example, the new *Principles and Standards for School Mathematics* developed by the National Council of Teachers of Mathematics (2000) promotes students engaging in the full spectrum of mathematics, including developing skills in data analysis and measurement, working with a variety of mathematical representations, and exploring the many connections between mathematics and other disciplines. While it is not yet commonly used as such, GIS offers considerable potential for schools to meet these demands (Coulter and Kerski, 2003). Similarly, the *National Science Education Standards* (National Research Council, 1996) promotes a vision of education that is consistent with in-depth investigation of phenomena, grounded in authentic data. Again, as schools move in this direction, GIS becomes an essential tool to meet these goals, and not simply an addition to an already crowded curriculum.

Along with the work being done in curriculum design and standards, there is now a much greater understanding of how people learn. Cognitive science and educational research are converging on general principles of the science of learning that can make valuable contributions to designing and structuring students' (and teachers') learning experiences (Bransford et al, 2000; Bybee, 2002). Knowledge of key contributions being made by educators and cognitive scientists in this realm—such as the importance of building from existing knowledge to create new knowledge, making connections among different concepts and contexts, and building a strong and organized knowledge base—will be essential to creating improved learning experiences. Students routinely engaging in investigations by analyzing authentic data both quantitatively and spatially creates a learning environment in which these goals can be realized. Early conceptions can be challenged and/or reinforced as students seek to confirm or disconfirm them by reference to the data, often leading to greater understanding that reflects the nuances of the field. For example, a few years ago I worked with a group of third graders on a study of plant emergence and blooming patterns. Most of the children had a generic concept that it was warmer in the southern parts of the United States than it was in the northern regions, and predicted that the red emperor tulips that were part of the study would emerge first in the south, and then in the north—essentially a straight-line progression covering the continent. As the data was reported from school sites across the United States and

Canada, they soon learned that they needed to refine their "south to north" idea to better reflect what the data was showing them. This more refined understanding not only enhanced the success of this project; it also proved to be valuable in later studies undertaken by the students in fourth grade as they compared migration patterns for bald eagles in the western and eastern parts of North America. They were able to use their now greater understanding of regional climate patterns to understand why the western eagles wintered further north than their eastern counterparts, left earlier in the spring, and went further north into Canada. Throughout, the engagement with authentic data (enabled by GIS) was the key to remarkably sophisticated thinking by elementary school students.

As we seek the best means of deploying GIS-enhanced inquiry into schools, we would do well to consider these larger initiatives around curriculum standards and the science of learning, and align our work with them. Being part of a larger, unified trend toward improved educational opportunities is far more likely to be successful than will any of a wide range of "splinter movements." In particular, educational technology initiatives have a long and well-documented history of failing to establish a significant presence in the educational landscape on their own.

While alignment with certain overarching initiatives can be helpful, there are also strong curriculum trends that are currently common in schools that are not conducive to deeper, more meaningful inquiries. Thus, we need to choose our path wisely. In many states and local school districts, "curriculum standards documents" (not to be confused with the documents described above that were developed by recognized experts in a discipline) often require that students at a given grade level cover an unreasonable number of discrete topics. Such a conceptual buffet offers little opportunity for in-depth learning. One teacher I had the pleasure of working with this spring in a graduate seminar had a district curriculum mandate to "cover" oceans with her fourth grade students in a week. Given approximately three hours of class time to "do oceans," it is unlikely that much productive learning could take place. Similarly, a major urban school district expects that students will "learn" the hydrologic cycle in third grade. Exactly how a typical, very concrete-thinking eight year old is going to master a complex and abstract concept such as the hydrologic cycle is not specified, and in fact defies comprehension. Academic standards are a good thing when they are wisely chosen; used capriciously, they can foster confusion and disorganized learning.

Support meaningful assessment: Working hand in hand with the demands of curriculum standards, pressures for accountability in schools have led to the development of an expansive (and expensive) testing industry that seeks to measure students and teachers at every turn. As with curriculum standards, assessment of student achievement and program accountability are good ideas that are all too often poorly done. In the current educational climate, we as developers and users of GIS resources need to be particularly attentive to assessment issues. If we expect a substantial involvement in the educational process, we need to be able to document what students are learning, and how their learning is improved through the use of geospatial technologies. Simple claims and desires or isolated vignettes will not raise our work to the level needed. Fortunately, we can use this opportunity to constructively engage the educational community in larger issues of assessment. GIS-enhanced inquiry lends itself particularly well to the development of tangible artifacts such as maps and graphs that show student understanding. These artifacts are precisely the type of material that feeds into a system based on portfolios or "authentic assessment," the radical idea that student achievement is best measured by the work that they do.

As pervasive as state (and now federally) mandated tests are, they have significant limitations in their ability to document student learning and to provide useful and timely feedback to teachers and administrators. In terms of documenting student learning, any formal testing situation will be biased by the artificial environment in which the test is taken. This environment serves to constrain the time, place, and means by which students can demonstrate their understanding of relevant concepts. While the claims made by proponents of learning styles and multiple intelligences are often overstated, any educator knows that each student has distinctive strengths and ways of approaching learning situations. For some students, these match the testing situation quite well; for others, the match is less complete. Also, since state curriculum frameworks generally do not specify in detail the content fields to be studied, test questions cannot assume a specific background. As a result, test questions—even if they are veiled in a quasi-authentic context—cannot draw from a rich base of knowledge that one school may have developed while another had not. For example, a recent 7th grade science test in Missouri was heavily laden with questions about water quality, which had been a focus that year for a number of schools working with the Missouri Botanical Garden. Hence, those students did comparatively well (based on reports from their teachers); students whose science focus was in a different area that year likely did not fare as well. Since the test questions change each year, there is no incentive for schools to adopt a particular curriculum focus. Thus, the knowledge and skill focus needs to remain generic, literally to be called on in a moment's notice once students are confronted with a test question. As a result, depth and complexity of thinking take a back seat to rapid deployment of more superficial bits of knowledge.

Given the limitations of standardized testing, a broadening of the evidence base will be needed if meaningful assessment is to be achieved. One means of balancing the limitations of standardized testing is the development of portfolios of student work. These portfolios have the potential to capture significant examples of student work that document students' growing understanding of key academic concepts and skills. Thus, while standardized testing removed from a learning situation offers the certainty of a specific number score, authentic student work has much greater capacity to capture students' real understanding. There are, however, significant professional development challenges involved in productive use of alternative assessment methods. Most fundamentally, teachers need to know how to do their own assessment of student learning (and how to document growth over time), and know which concepts and skills are most essential for students at a given age need to develop. One key to improvement in this area is to create stronger teacher professional development opportunities that promote enhanced understanding of academic content and pedagogy. Means to achieve this are discussed below.

Until better curriculum and assessment designs become commonplace, there will be strong forces of inertia that support less coherent curriculum and less meaningful assessment results, making the deeper, sustained investigations that are enabled by GIS less likely to take strong root. For the foreseeable future, there will be a dynamic tension between the larger curriculum purposes described previously and the narrower mandates of current practice and assessment. Given what is known about how people learn (Bransford et al, 2000; Bybee, 2002), it is incumbent upon us to use our efforts to advocate movement toward the former and away from the latter. Throughout, we need to frame our work in these larger contexts of improved curriculum and assessment, or be relegated to the sidelines as a minor player in the educational reform movement.

Support teacher learning—Don't build a bypass. Previous generations of educational reform sought to create a "teacher-proof" curriculum. This lack of confidence in teachers as professionals has also been seen in the myriad teacher competency testing programs dotting the landscape, and current efforts to shame teachers and schools into "higher performance" by publishing test scores as a measure of the quality of education students receive. As discussed briefly above and much more extensively by others (e.g. McNeil, 2000; Kohn, 1999, 2000), these test results quite often do not reflect students' understanding adequately, and thus are a limited measure of school success. Blaming aside, the fact remains that the teacher remains one of the most critical variables in education, as a guide and facilitator of learning and as a model of how to engage in productive inquiry. While there are legitimate concerns about the content knowledge and pedagogic effectiveness of many teachers, efforts to bypass them while hoping to improve students' learning will be ineffective. Instead, concerted teacher professional development efforts need to be undertaken that build teachers' understanding of relevant content and pedagogy. Tom Snyder, a pioneer in educational technology, has often remarked that "the solution to bad teachers is good teachers." The formidable challenge we face is how to create more good teachers out of (or in some cases in place of) current teachers.

Fortunately, there are useful standards for teaching practice for specific disciplines in documents such as the *National Science Education Standards* (NRC, 19996) and *Principles and Standards for Schools Mathematics* (NCTM, 2000), as well as general standards and methods for professional development that provide a road map to improved teacher quality (e.g. Locks-Horsley et al, 2003).

One of the most powerful concepts emerging out of the professional development literature is pedagogic content knowledge (Bransford et al, 2000.). Increasingly, it is being recognized that it is not sufficient simply to be an expert in a given field such as history, chemistry, or literature. Similarly, it is not sufficient to be expert in generic pedagogic strategies. True teaching expertise is found in the fusion of the two to create a strong base of pedagogic content knowledge in which a teacher has a solid grasp of the most central concepts in a discipline and the skills needed to help students at a given age develop a lasting understanding of those concepts. Previous research on technology use in schools (e.g. Feldman, Konold, and Coulter, 2000) has cited the difficulties many teachers face in engaging students in productive data analysis, and in leading discussions informed by that data. In part, these difficulties stem from low levels of pedagogic content knowledge that keep teachers from knowing the rich interconnections among concepts students are studying, and knowing how to engage students productively in making these connections. As a result, too often classrooms remain sterile environments based on a set of discrete facts grounded in the authority of a textbook or (increasingly), a web site.

As schools move toward more substantive engagement with core concepts as advocated by the national standards documents and by learning science research, and as assessment demands grow, professional development initiatives will need to keep pace. Workshops will need to continue to build familiarity with the curriculum materials and with general GIS skills, but much more is required. If teachers are to be equipped to lead productive inquiry, they need experiences that enable them to learn the most central concepts in a field, how these concepts interact with each other and with related concepts in other fields, and how students can be expected to respond. This latter component—often based on "misconception" or "alternative conception" research—is rich in some areas, but often not well articulated in professional literature, which makes it difficult to do a quick study on how students will learn a given set of concepts. It does come, however, from careful reflection on practice in which teachers develop real expertise based on strong pedagogic content knowledge. We need to develop means by which teachers can, as Judith Newman (1998) notes, move "beyond tips to critical reflection."

The professional development challenges facing education are enormous, and will require concerted, long-term efforts. Without this effort, however, even the strongest curriculum and assessment programs will not achieve the level of success needed to support all students' learning.

A Proposal for Action

If we are to develop a model that goes beyond simply infusing GIS into the curriculum and toward meaningful use of GIS as one of many learning tools, we will need to attend to larger issues of curriculum, assessment, and teaching. To that end, the Education Division at the Missouri Botanical Garden has been working for the past five years to develop just such a model. In our earliest phases we developed a number of individual success stories that make productive "proof of concept" case studies that document the utility of GIS as an educational tool. We have also developed and now distribute through our web site (www.mobot.org/education/mapping) a series of instructional modules focusing on science topics such as seismic activity, severe weather, climate patterns, ecoregions, and urban forestry. All of this has been productive for our local efforts and well received by the larger community of GIS users. It is, however, only a starting point. For the potential of GIS to be realized, much more is needed. Our current efforts are a modest step in that direction. We look forward to working collaboratively with others to refine and advance this agenda.

Rather than conducting a GIS training workshop, each summer since 1999 the Missouri Botanical Garden has hosted a science education institute that focuses on a significant content area that is relevant for upper elementary and middle school teachers. In the past these have included studies of local watersheds, natural disasters, ecoregions, and urban forestry. This summer, we will be focusing on the science of the Lewis and Clark Trail. In each, the work is guided by larger questions, for which GIS-enhanced analysis and many other resources are brought to bear on the study. For example, in the watershed study, teachers (and in turn their students) were supported in developing a greater understanding of general concepts of watersheds as well as specific monitoring techniques to measure the biotic and abiotic health of area streams. Within this larger study of watersheds, the utility of GIS tools becomes evident. Few would argue that students should only read about watersheds and water quality, though in the rush to "cover" many discrete topics there is often little time to do more. As schools move from reading to field-work, there are a number of high-quality water testing protocols available to schools, such as GLOBE or GREEN. These, however, are limited in that they collect only quantitative data. To truly understand watersheds and be able to analyze the many issues that are associated with them, spatial analysis is essential. It is insufficient simply to know that the water quality decreases downstream—students must be able to analyze where the quality changes, and what other factors have changed as well. Has the land use changed? Have tributaries entered the main stream, potentially bringing in pollutants? Thus, the *need* for GIS as an integral learning tool is apparent, and not just as a technology add-on.

This in-depth learning is also consistent with what is known about how people learn. As noted previously, learners need to build from their existing knowledge to create new knowledge, make connections among different concepts and contexts, and build a strong and organized knowledge base. GIS as a tool can be a natural fit in these more substantive learning environments, which is a productive step forward in that we are not seeking to graft an alien technology into an existing program. Looking more closely, one could make the case that GIS as a suite of tools is more than just a good fit—it actually *enables* the learning environment to exist. A good fit may or may not be taken along, depending on whether or not it fits in your metaphorical suitcase. Something that is essential—as GIS is, in many cases—reaches "must fly" status. Thus, if GIS can be seen as the enabler of greater learning, it has a much brighter future in the educational world.

Before this lofty goal can be realized, however, more needs to be done than simply holding evangelical workshops. Teachers need strong curriculum materials, which are increasingly available (e.g. Malone, Palmer, and Voigt, 2003) and ongoing support in their use. Short-term workshops—"drive-by trainings" —that don't provide sustained support will be of limited utility. The Missouri Botanical Garden has found that they are productive in whetting appetites and helping teachers to make informed choices about the appropriateness of GIS in their teaching situation, but they rarely result in prolonged and substantive use in the classroom. Longer-term endeavors that promote the development of pedagogic content knowledge are needed if meaningful change is to occur.

Beyond the utility of more content-focused workshops, there is a need to develop leadership in the field. For this, we have found GIS Leadership Institutes productive. These Institutes are designed for teachers experienced in using GIS with students who are looking to develop advanced skills in both GIS applications and pedagogy, to build on their existing practice. Whereas in the past we were voices in the Missouri wilderness on behalf of GIS-enhanced education, we now have leaders making conference presentations across the state, assembling parent-education nights, and helping with our student and teacher programs. Providing continuing support for these leaders will be integral to our mutual success.

Schools engaging in the approach to education described here based on deeper, more substantive investigations are, unfortunately, not very common. If this is an approach we value, however, our advocacy can be well supported by aligning our efforts with the curriculum, assessment, and teaching standards that promote this way of learning as best practice in the field. While the term "standards-based" is frequently used quite casually, a consideration of what it means for schools truly to be standards-based (instead of merely identifying a few points of overlap) lends considerable support to our work. As we do this, we will be moving toward wider opportunities for schools to achieve what Rodger Bybee (2003) has called strong "content, coherence, and congruence" in their work. While the challenge is great, so are the rewards when it succeeds.

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Missouri Botanical Garden
See the World

Mapping the Environment

...Making GIS Accessible

...Helping Teachers Meet Standards

Mapping the Environment is a program based at the Litzsinger Road Ecology Center of the Missouri Botanical Garden. Strategically placed to help teachers meet state and national standards in science, math, geography, and technology, this program involves 3,500 middle school students across Missouri in collaborative investigations of their environment. ArcView® is used to support students' analysis of their data in comparison to data collected by others locally and (where appropriate) nationally and globally. Teacher training, curriculum development, and field work with students all contribute to the success of the program.

One of the most critical needs identified by teachers participating in Mapping the Environment has been the lack of easily used GIS curriculum resources. To address this need, we have developed and field tested six modules designed to support teachers' efforts to make use of GIS to teach significant science concepts. After completing any of these modules, students are better equipped to conduct further investigations of the data provided, or to conduct similar investigations with their own data.

Link to My Natural Community

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