Professional Development for Teaching Science with Geospatial Technology

by
Karen Edelstein
Nancy Trautmann
James MaKinster

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Abstract

GIT Ahead is an NSF-funded project that helps secondary teachers to use geospatial information technologies (GIT) to teach core science concepts and environmental topics using an inquiry-based approach. Teachers are trained to create original projects that incorporate GIT into their curricula. Some teachers may also adapt GIT lessons that are written by other educators. In addition, we have developed Internet-based software to simplify the challenges secondary school teachers face in finding and applying appropriate spatial datasets for exploration of environmental issues in New York State. This session focuses on opportunities and challenges inherent in teacher professional development focusing on geospatial technologies. We also present data documenting growth in geospatial interests and skills in teachers participating in GIT Ahead.

Introduction

This paper presents the professional development approaches implemented in GIT Ahead (pronounced “get ahead”), a multi-institutional collaboration focusing on use of geospatial information technology (GIT) in secondary science. Launched in 2006 with funding through the National Science Foundation’s Advanced Technology Education program, the project aims to enable secondary teachers to design and implement curriculum projects in which students apply geospatial technology to relevant local environmental issues. GIT Ahead includes teacher professional development, curriculum and software development, and establishment of internships, job shadowing and other career awareness opportunities for students in the Finger Lakes Region of New York State. Here, we focus on the teacher professional development aspects of GIT Ahead, addressing opportunities, challenges, strategies, and results from the first year of implementation. In addition, we share observations anecdotally about some of the changes and successes that have taken place during the second year of the project (school year 2007-08).

Conceptual Framework

One of the key components of successful use of technology in science teaching is technological literacy, defined to encompass three dimensions: 1) factual and conceptual knowledge about various technologies and their functions, 2) capability to use and troubleshoot selected technological options, and 3) critical thinking and decision making about appropriate uses (Garmire & Pearson, 2006). Teachers interested in engaging their students in high-level computer use must become comfortable with these three dimensions. For example, teachers interested in using geospatial software must select one of several software options, develop ideas of potential classroom applications, assemble appropriate datasets, and make all the arrangements needed to install and use necessary software on school computers. However, technological literacy alone is insufficient. Teachers must be able to integrate technological skills and understandings with considerations about pedagogy and subject matter. This comprehensive set of competencies has been termed “Technical Pedagogical Content Knowledge” (TPACK) (Mishra & Koehler, 2006). Given three circles representing pedagogical knowledge, content knowledge, and technical knowledge, the triangle formed where these three circles overlap represents TPACK (Figure 1). The size of this overlap indicates the extent to which a teacher has developed an integrated understanding of the complex relationships between subject matter understanding, pedagogical goals, and available technologies.

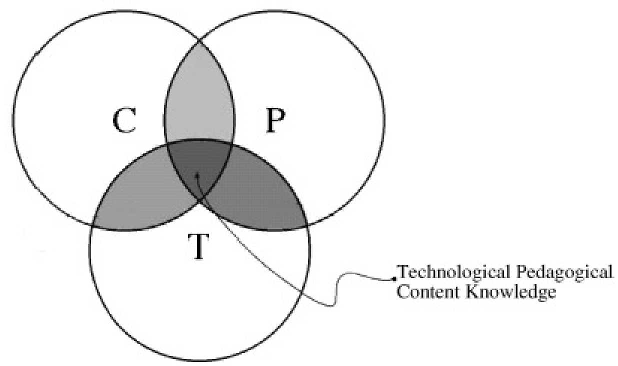

Figure 1. Technological Pedagogical Content Knowledge (TPACK) (adapted from Mishra & Koehler, 2006). Three circles representing knowledge of content, pedagogy, and technology overlap to form a triangle representing TPACK.

The TPACK framework makes it clear that training teachers how to use technology is not sufficient for effective implementation. Instead, teachers must be given opportunities to develop appropriate, context-specific strategies for integrating use of technology into their teaching (Mishra & Koehler, 2006). For example, the purpose of using GIS in science teaching is not simply to train students how to use the software, but rather to enable students to manipulate spatial data in new ways, analyzing and synthesizing complex datasets to address environmental issues (Hall-Wallace & McAuliffe, 2002). Teacher professional development focusing on implementation of geospatial technology therefore needs to provide training in how to use relevant hardware and software, accompanied with ample opportunity for teachers to explore how best to use the capabilities presented by GIT to improve the ways in which their students learn desired content (McClurg & Buss, 2007).

A common approach in technology-focused teacher workshops is to model the implementation of a lesson or series of lessons to illustrate a particular pedagogical strategy for addressing specific subject matter content. For greatest effect, lessons modeled for teachers should be challenging and engaging, pushing teachers beyond their comfort-level while also providing the support and resources necessary for success (Jeanpierre *et al.*, 2005), as well as providing confidence to teachers to modify the lesson scope and content to suit their own classroom needs. Exposure to multiple models of use of technology in science teaching enables teachers to choose and adapt those that best meet their classroom needs. In making such choices, teachers balance personal interests with curricular mandates of their department, district, or state, and possibly also with the expectations of the professional development provider. A teacher may choose to apply a particular lesson intact, or perhaps to apply the demonstrated technological tool or technique to a different topic. For example, after learning how to use an online database to explore the extent and nature of earthquakes, a teacher might choose to use that same database to develop a lesson on geologic fault lines and plate tectonics. Alternatively, a teacher might choose to use the same pedagogical strategy in a different context, for example employing use of online databases for student investigations of waste management needs and strategies.

Application of geospatial technology in teaching provides exciting possibilities. However, it also can be daunting because of the complexity of the technology, and its ever-expanding capabilities. In addition, teachers who are comfortable with other computer technologies are sometimes intimidated by the *terra incognita* of mapping software. Ongoing technical and pedagogical support are vital in helping teachers overcome these daunting aspects and grow in interest and ability to implement innovative teaching practices making use of computer technology (Ertmer, 2005).

Teacher Professional Development in GIT Ahead

GIT Ahead begins each year with an 8-day summer institute during which secondary science teachers learn how to address relevant local environmental issues using GPS, GIS, and related technologies. The goal is to provide teachers with tools, skills, and experiences that they can adapt and modify to meet their own curricular objectives. During the summer institute, teachers begin developing course-specific curriculum projects. They receive ongoing support through six Saturday workshops offered during the academic year, along with weekly virtual office hours, informative email updates, and individualized assistance from project staff as needed, often during school vacation weeks. We encourage teachers from the first year cohort to help mentor newer participants, and invite these “veteran” teachers to attend the weekend workshops, as well.

In the first year of the project, 15 teachers participated in the summer institute, 11 remained active through the 2006-07 school year, and seven of these chose to earn graduate credit for their work in preparing, implementing, and reflecting on GIT-enhanced curriculum projects. In one project students use AEJEE (ArcExplorer Java Edition for Education) to explore complexities of invasive species management. In another, students collect GPS waypoints to map the extent and condition of roadside ditches, then import these data into ArcGIS and estimate the impacts of stormwater runoff on quantity and quality of surface water in the watershed. In yet another, student import a variety of data layers (topography, hydrography, landuse, roads, etc.) and, constrained by specific regulatory elements, determine the best place to build a WalMart.

In the second year of the project, 20 teachers participated in the initial training, with all but one remaining active throughout the school year. 19 chose to earn graduate credit. Participating teachers represent widely ranging curricular needs because the project encompasses sixth through twelfth grades, with science courses ranging from remedial through advanced levels, in settings ranging from large urban schools to very rural school districts. Subject areas include general science, biology, earth science, environmental science, and various elective courses.

Below is a sampling of the projects proposed by teachers during the second year of the GIT Ahead Project. Some of the projects were implemented during the school year, while others are still in development.

<u>Middle School Science</u>

- Exploring the Glen Creek Watershed
- Topography and Changes in Trumansburg Over Time
- Monitoring Monarch Migration
- Science Trail Investigation
- Google Earth Tour of Charles Darwin's Voyage

<u>Earth Science</u>

- Contour Maps
- Tour of the World
- Exploring Surface Topography, World Geography, Plate Tectonics
- Navigating with GPS
- Glacial Geology Tour
- Characteristics of Tompkins County and Dryden
- Hurricane Monitoring
- Climate of New York State
- Alternative Energy: Oil is expensive Wind is FREE*

<u>Biology</u>

- Using Geospatial Data for Wetlands/Stream Monitoring Program
- Frogs in Heat (environmental restoration activity),

<u>Electives</u> (Environmental Science, Natural Disasters, Forensics)

- Assessing the Health of our Local Watershed/ Recommending Strategies for Improvement
- Topographic maps
- Golf Course Analysis
- Demographic Inquiry
- Looking for a Suspect in Schuyler County, New York
- Arboretum Development at Marcellus Central Schools
- Darwin's Voyage
- Exploring World Biomes

To meet this broad range of needs, GIT Ahead workshops present geospatial lessons representing various content areas and designed to be applicable at all secondary grade levels. Teachers who implement these lessons adapt the experience to the appropriate level of conceptual understanding and technical analysis for their students, often using a combination of ESRI products and Google Earth.

GIT Ahead teachers not only teach a wide range of students, they also bring to the program a diverse range of expertise and self-efficacy with regard to geospatial technology. Some have considerable experience using GIT and join the project to focus on curriculum development within a supportive environment. Others can envision the potential of GIT but have little or no prior experience using such technology. Setting the right pace is challenging considering this wide range in expertise, and our staff work hard to meet teachers at their level, wherever that may be. The summer institutes and Saturday workshops address this challenge by providing flexible skill-building experiences, discussion of ideas for curricular applications, and time during which teachers can receive individualized technical guidance. Each event also includes time for teachers to work on developing their curriculum projects, either individually or with partners. To reduce the need to travel in potentially inclement weather, workshops in winter months are held via web conferencing using Adobe Acrobat Connect.

Anonymous web-based questionnaires elicit feedback from teachers at intervals throughout the summer institute and at the conclusion of each of the Saturday workshops. Indicating points of both frustration and excitement, the questionnaires have helped the GIT Ahead team to continually refine plans and tailor the types of support offered to help teachers grapple with the complexities of using geospatial technology and of fitting their curricular ideas into the highly constrained environments of secondary science classes. Based on findings from the first year in this three-year project, as well as anecdotal evidence from the second cohort (year-end evaluations for those teachers were not complete at the time this paper was submitted), this paper focuses on lessons learned related to effective strategies for helping secondary teachers to implement geospatial technology in their science teaching.

During the first Summer Institute, in June 2006, we realized that a critical bottleneck to teacher success in learning geospatial technology was easy access to sensibly symbolized, consistently projected, well-documented spatial data. Initially, we had planned to train teachers in locating and processing GIS data that they could find on the Internet. Quickly (and somewhat painfully!) it was apparent that we could spend the bulk of our training time concentrating on these skills, rather than helping teachers to use GIT as a tool for scientific inquiry. We made a decision to assemble a robust library of over 200 datasets, accessible both by our Blackboard site, and through our project website (http://fli.hws.edu/gitahead).

Next, we worked with a collaborating organization to develop a web-based interface that could deliver these same data clipped to either subwatershed extents or to individual counties. Users select their data from a menu of options, and with a single click, download a packet of zipped GIS data, symbolized and ready to use. Included in the packet is a KML file for each dataset so the data also can be used in Google Earth. This service is free, and available to anyone. Participation in GIT Ahead is not a requirement. Initially dubbed the “Finger Lakes Geospatial Explorer,” this tool is currently being expanded and refined to include datasets for all of New York State, and has been renamed “SDNY”, or Spatial Data for New York.

Methodology

The extent and conditions under which participating secondary teachers could effectively implement geospatial technology in science teaching is addressed here using mixed-methods analysis of quantitative and qualitative data collected during the first year of implementation of the GIT Ahead project. Anonymous data sources include web-based questionnaires administered at intervals during the summer institute and at the conclusion of each school year workshop. Attributable data include an application questionnaire, curricular resources developed and implemented by each teacher, a post and reflective pre-questionnaire administered at the end of the school year, and written reflections and sketches in which teachers discussed or illustrated their experiences weaving GIT into their science teaching. Teachers who earned graduate credit completed written statements answering the questions posed in Figure 2.

Post Teaching Reflective Analysis

Answer the reflection statements/questions below for each lesson you teach in your unit. This is your opportunity to demonstrate that you are modifying your lessons to meet the needs of your students or future students. For example, you might decide to change the whole lesson or to suggest a slight modification for a special needs child in your class.

1. Briefly discuss your overall impressions of the lesson. What went well? What didn't go as you expected?
2. Describe a particular problem or situation within the lesson.
3. What questions or observations do you have about this situation or problem?
4. What might you do differently next time to address this issue?

Reflective Statement

This assignment is a chance for you to reflect on your GIT Unit in its entirety, examining the impact that your experience has had on you and your students. Below is a series of questions. Your reflection should be 2-3 pages in length (single-spaced) and include 2 or 3 paragraphs on each of these questions:

1. Thinking back to the beginning of the school year, how would you characterize the views you held at that time of geospatial technologies and their potential applications in your teaching?
2. Have your conceptions changed of the role of geospatial technologies in the classroom? Explain based on your experiences.
3. Has your teaching changed in any way because of these experiences?
4. To what extent do you feel empowered to discuss, evaluate, and assess the advantages and disadvantages of various geospatial tools and applications in the classroom?
5. How do you view the implementation of your unit overall? What went well? What would you do differently next time?
6. Finally, do you plan to continue teaching with geospatial technologies in the future? Why or why not? What additional support, if any, would you like to receive?

Figure 2. Reflection questions addressed by GIT Ahead teachers

One-tailed, paired t-tests were used to evaluate the significance of teachers' perceived growth over the course of the year in interests and skills related to teaching with GIT. Qualitative data were analyzed using the constant comparison method (Glaser & Strauss, 1967), which includes open coding, axial coding and selective coding as advocated by Strauss and Corbin (1990). As themes and patterns emerged in one set of data, other data were examined to confirm or reject individual interpretations. Finally, member checking (Stake, 1995) was employed to determine the validity of the case summaries by asking each teacher to review and provide feedback on the portrayal of his or her experiences.

Results

Anonymous surveys administered at intervals during the 2006 summer institute and at the conclusion of each 2006-07 school-year workshop indicate high levels of teacher satisfaction with the value of these experiences.[1] A deeper question is the extent to which these professional

[1] For example, anonymous surveys after each of the Saturday workshops included the question, "The day as a whole – was your time well spent?" Responses to this question averaged 3.8, with 1=Not Useful, 2=Slightly Useful, 3=Useful, and 4=Very Useful.

development opportunities enable teachers to implement meaningful GIT-enhanced projects with their students. At the conclusion of the first year in GIT Ahead, teachers reported having used GIT anywhere from a single week to throughout the entire school year (Figure 3).

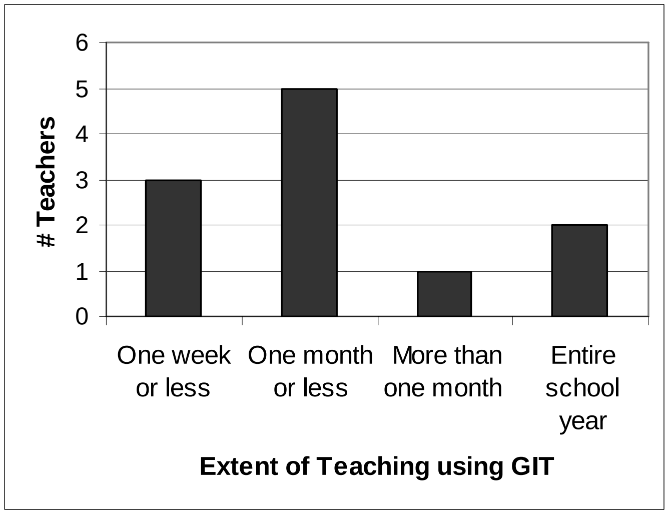

Figure 3. Teachers' response to the post-survey question, "How extensively have you used geospatial technologies in your instruction this year? (If you teach more than one type of course, please answer for the course in which you have made most extensive use of GIT)." *N* = 11.

The end-of-year written questionnaire asked teachers to rate their current skills and interests in use of GIT and application of these technologies in their teaching. Separate questions asked them to think back and evaluate their standing with regard to these same skills and interests before they began the GIT Ahead program. Responses to these post and retrospective questionnaire items show significant growth in teachers' perceived expertise in using web-based geospatial programs such as Google Earth, and in making and using maps with GIS software such as ArcView (Figure 4). Furthermore, teachers showed significantly heightened interest in building geospatial analyses into their science teaching, along with enhanced self-efficacy to accomplish this goal (Figure 5).

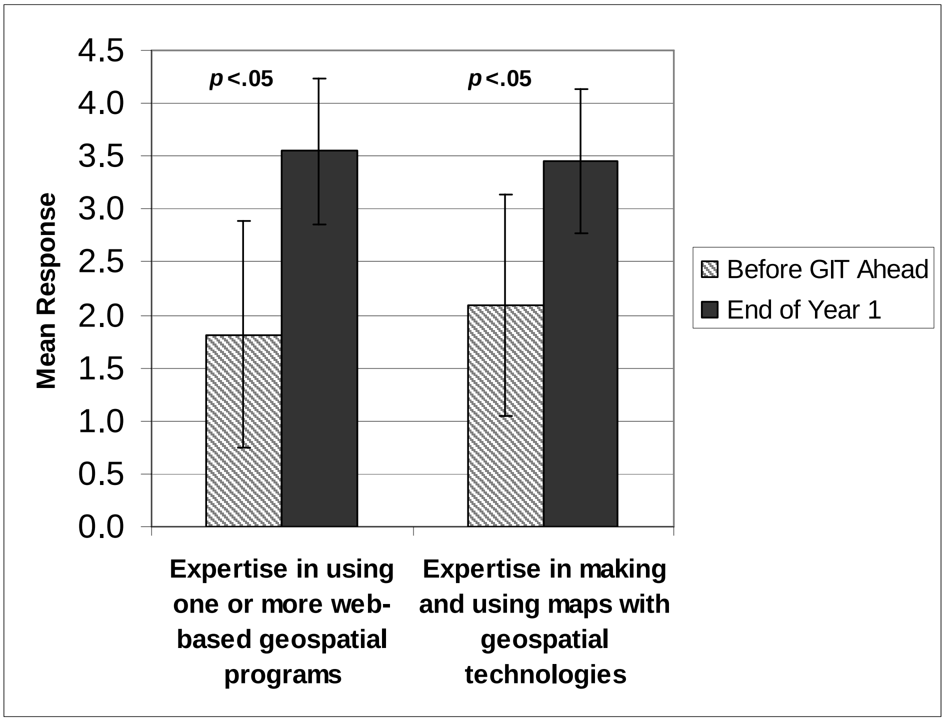

Figure 4. Teachers' perceived growth in GIT-related expertise through participation in GIT Ahead (as indicated in end-of-year written questionnaire, with 1=None, 2=Novice, 3=Advanced Beginner, 4=Competent, and 5=Expert). *N* = 11.

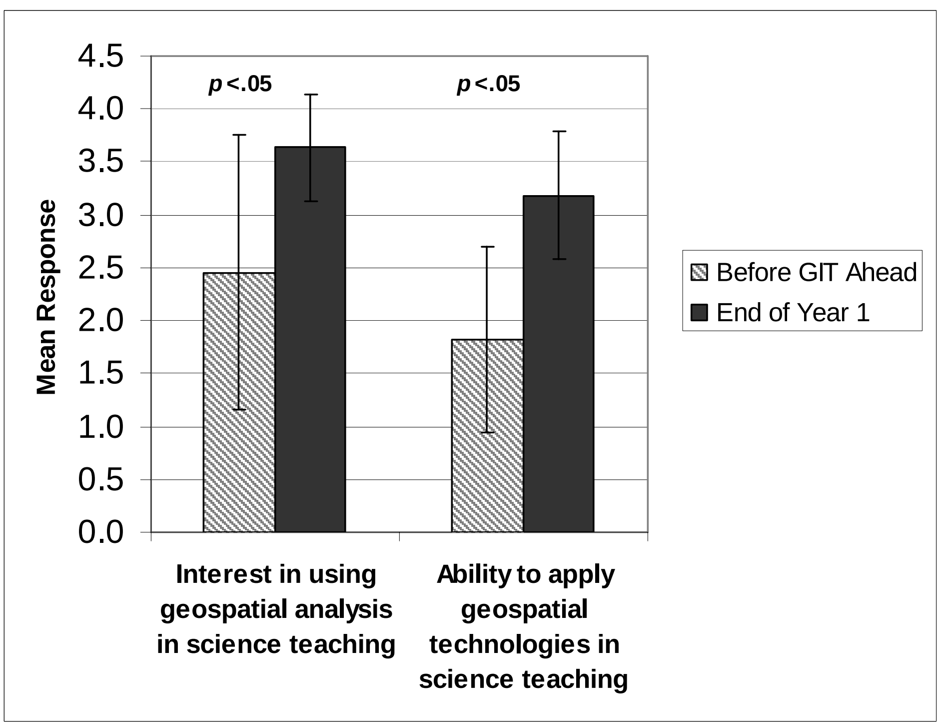

Figure 5. Teachers' perceived growth in interest and ability to use geospatial analysis in science teaching through their participation in GIT Ahead (as indicated in end-of-year

written post and retrospective pre-questionnaire, with 1=None, 2=Low, 3=Moderate, 4=High). ***N*** **= 11.**

End-of-year reflections reveal the steep learning curve faced by teachers interested in using geospatial technology. When asked to depict their experiences over the course of the year, one GIT Ahead teacher drew a window framing her beginning-of-the-year vision of potential classroom applications of geospatial technology. Opening the window, she described the limitless world of ideas she was envisioning by year's end.

Another teacher drew herself descending into the fires of hell during the summer institute when she felt technologically illiterate, followed after much hard work with "This is pretty cool stuff." and eventually "The sky is the limit!" at the end of the year (Figure 6).

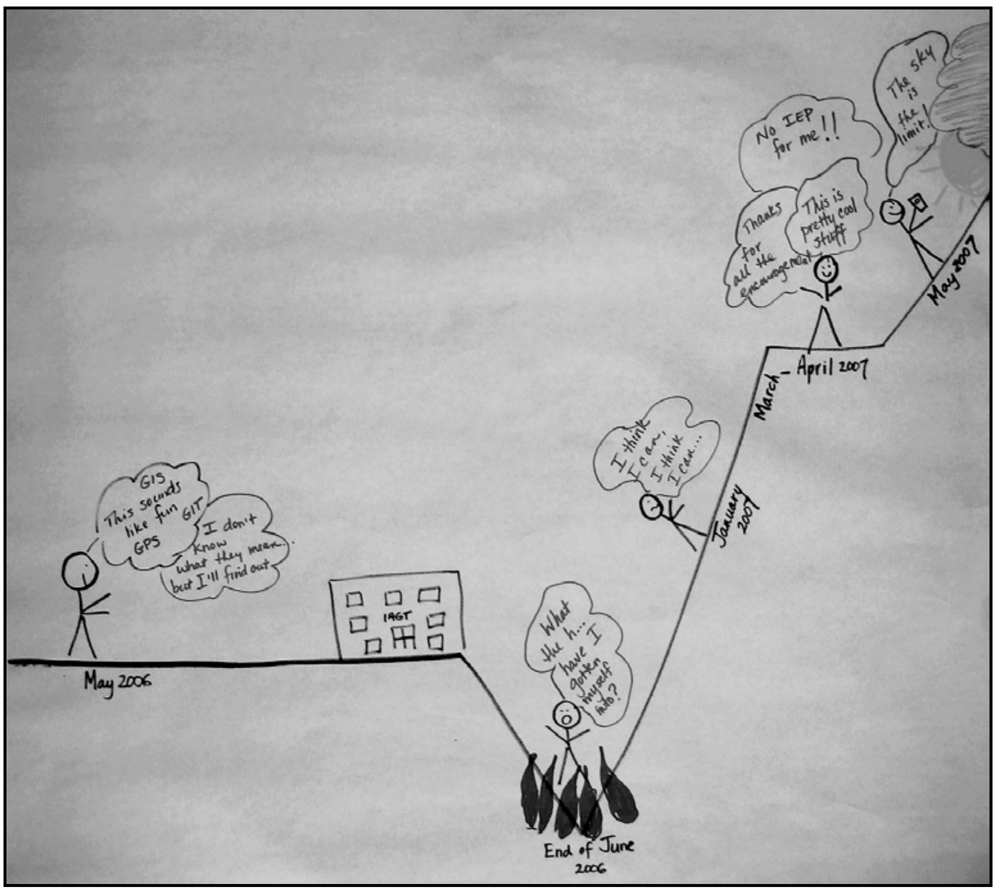

Figure 6. One teacher's depiction of her year in GIT Ahead. *She starts the year walking happily to the summer institute and thinking, "GIS, GPS, GIT… This sounds like fun. I don't know what they mean, but I'll find out." At the end of the 8-day summer institute, her stick figure is shouting, "What the h… have I gotten myself into?" January through March represent a steep uphill climb, with her chanting, "I think I can, I think I can…" By April, the learning curve has leveled out, and she says, "Thanks for all the encouragement. This is pretty cool stuff. No IEP for me!!" Finally, in May she is ready to proclaim, "The sky is the limit!"*

In response to Likert-scale questions, all 11 teachers active in the first year of GIT Ahead reported beliefs that geospatial analysis had moderately or greatly increased their students' science content knowledge, interest in the course, and awareness of the relevance of science (Table 1). Ten of 11 teachers indicated that geospatial projects had moderately or greatly increased their students' critical thinking skills and ability to think spatially. Nine teachers attributed to the program increases in students' understanding of environmental issues and capability to use geospatial technology. Lowest percentages of teachers thought that use of GIT had affected their students' motivation to succeed in school or go into GIT-related careers.

Item	**Responding "Moderately" or "Greatly"**	**Mean Response**	**SD**
Awareness of the relevance of science	100%	4.4	0.5
Interest in this particular course	100%	4.3	0.5
Science content knowledge	100%	4.0	0.0
Ability to think spatially	91%	4.3	0.6
Critical thinking skills	91%	4.0	0.4
Understanding of environmental issues	82%	4.5	0.8
Capability to use geospatial technologies	82%	4.1	0.7
Interest in going on in science	64%	3.7	0.6
Motivation to go into GIT-related careers	45%	3.5	0.5
Motivation to succeed in school	27%	3.3	0.5

Note: N = 11. Values represent responses to the question, "Judging from your experiences this year, how would you rate the effect on your students of the GIT-related projects you implemented (compared with if you had taught the same course without GIT applications)?" with 1=Decreased to a Great Extent, 2=Decreased Moderately, 3=No effect, 4=Increased Moderately, and 5=Increased to a Great Extent.

Table 1. Teachers' estimation of student learning gains through engagement in GIT-enhanced projects in science classes.

All 11 teachers intended to continue integrating geospatial analyses into science classes in coming years. Responding to questions about anticipated impact of expanded use of geospatial technology, all 11 teachers predicted further enhancement of their students' science content knowledge, critical thinking skills, understanding of environmental issues, and ability to think spatially. Three teachers became so excited about the potential of GIS for student learning that they proposed to their school districts the establishment of new high school GIS courses.

Examination of data from individual teachers reveals the complex nature of teacher professional development focused on geospatial technology and raises a variety of issues relating to how best to help teachers develop technological literacy.

Discussion

Integrating GIT into secondary science teaching requires motivation, effort, persistence, and skill. Teachers must become comfortable with use of assorted technologies and adept at deciding how best to apply various options to meet their pedagogical goals. They also must troubleshoot a wide range of problems related to gaining access to suitable computers, installing software, downloading data, and acquiring administrative approval for not-yet-mainstream uses of technology in their schools.

The experiences of GIT Ahead teachers through the first year of the program demonstrate the tremendous potential of geospatial technology to engage students in learning core science concepts and exploring environmental issues, along with the substantial challenges that teachers face in bringing these goals to fruition. End-of-year reflections and questionnaire responses provide evidence of teachers' growth in GIT skills and self-efficacy, along with expanding ideas for ways in which they can weave these technologies into their teaching.

Typically, teachers began with a well-defined unit for which they have carefully carved out time, often as a supplemental project. Successful implementation helps teachers gain confidence in their own technological capabilities and in the motivational power of GIT to engage their students in learning. As teachers become more confident in their own GIT skills and view the impacts on student engagement in learning, they find ways to weave geospatial technology into a growing list of topics throughout the school year.

Participation in GIT Ahead has expanded teachers' Technological Pedagogical Content Knowledge (TPACK) by enhancing their technological literacy and helping them to integrate their new technological competencies with their pedagogical and content knowledge. We saw clear evidence of teachers integrating these three elements of TPACK as they designed curricular applications of GIT and then implemented, troubleshot, and evaluated the effectiveness of these lessons. We also saw indications of growth in TPACK over the course of the year, with teachers reflecting on their increased technical competency and growing awareness of the curricular potential of geospatial tools including both web-based and desktop applications of GIT. Expansion of TPACK is particularly evident when teachers begin viewing geospatial technologies as valuable pedagogical strategies rather than as new topics to be added into their curriculum. For example, one teacher concluded that he could fit use of GPS into his highly constrained earth science classes if he treated GPS as a tool for learning about mapping rather than a topic in its own right.

The competency of the GIT Ahead professional development team also expanded over the course of the year, with growing awareness of how best to meet teachers' needs. The first cohort of GIT Ahead teachers served as pioneers, and their experiences have greatly helped to refine the project's model for professional development. Ongoing formative assessment has provided a number of lessons about how best to meet the needs of teachers in learning complex technologies and applying these technologies in science teaching. One of the primary lessons is that effective professional development in support of teacher-designed geospatial curriculum projects should be highly flexible rather than aiming for teachers to master a specified set of GIS skills and use a specific set of pre-designed resources.

GIT Ahead aims to provide flexible professional development designed to meet the needs of a disparate group of teachers and provide each with the learning, support, and resources necessary for success. All teachers bring their talents, experiences, needs, and expectations to the table, and the project team strives to create opportunities that will enable them to design and implement lessons and units that will meet or exceed their expectations. This approach evolved over the course of the first GIT Ahead summer institute. This institute began instead with heavy emphasis on developing teachers’ ability to make GIS maps and import various types of data. Although most of the teachers persevered and successfully implemented geospatial projects in their teaching, the daunting challenge of mastering complex GIS software initially made it difficult for teachers to integrate what they were learning with their pedagogical goals. As the 8-day institute progressed, disparity in teachers’ technological competencies and curricular interests motivated the project team to revamp plans and adopt instead the flexibly adaptive model of professional development which has carried through Saturday workshops and into the second year of the project.

The second summer institute, with a new cohort of teachers, began by setting technological considerations aside and focusing first on potential applications of spatial data in science teaching and learning. Teachers worked in groups to discuss an intriguing collection of paper maps and aerial images and to generate ideas for potential applications in their science classes. Unlike many other geospatial technology teacher workshops that might focus exclusively on ArcGIS, GIT Ahead provides multiple starting points for understanding GIT, on a continuum from using pre-packaged lessons using simplified software products, up through the development of original lesson plans that creatively combine datasets using ArcGIS. This approach enables teachers to use technology while focusing primarily on subject matter, and acknowledges that there is no “one-size-fits-all” strategy that will effectively empower all users.

Rather than launching directly into learning how to manipulate complex geospatial software to make and use maps, the first software applications to which this second cohort of teachers were exposed consisted of prepared curriculum units with straightforward directions. Exploration of teacher-created Google Earth tours provided another effective entry point helping teachers envision potential applications of GIT in their science teaching. Building on these initial experiences with user-friendly programs, teachers progressed to use of ArcExplorer – Java Edition for Education (AEJEE) and ArcView GIS software. These applications require greater technical skill but afford greater capacity for analysis of user-entered data. Throughout the institute, time was provided for sharing of ideas about possibilities for curricular implementation.

In the second cohort of teachers (2007-08), several felt so engaged by the new technology during the school year that they spent many extra hours outside their classroom prep time to increase their skills with the software. In the late winter and spring leading up to the third summer institute in 2008, one very motivated earth science teacher was so excited about the potential for integrating GIT into her curriculum that she spent several days working one-on-one with GIT Ahead staff. By the start of the summer institute, she not only had a good foundation in using ArcGIS, but also had created a website for sharing her maps and other resources relating to local geology.

Most Saturday workshops during the school year include time in which the group collectively reflects on successes and challenges the teachers are experiencing in implementing GIT in their classrooms. Affectionately dubbed “kumbaya time” by GIT Ahead teachers, these frank and supportive discussions are helping to build a tightly knit professional development community. Major challenges go beyond the large amount of time required for teachers to develop and implement new curriculum projects, for example also including school-specific hardware and software limitations, regulations, and scheduling difficulties. Successes shared by teachers include satisfaction with finding ways to work around obstacles and excitement about seeing students’ reactions to learning science using GIT.

As we prepare to welcome our third cohort of teachers this summer, we plan to draw heavily on successes over the past two years, and also to modify or augment portions of the program that will help to better support teachers in their work. For example, several “veteran” GIT Ahead teachers will be sharing their stories during the Summer Institute, and will serve as role models for the new group. We also intend to hold a half-day conference early in the fall where GIT Ahead teachers, along with their buildings’ technology coordinators, participate in a round table discussion focused on incorporating new software into their schools. In the past year, delays in implementing GIS lesson plans were frequently due to reluctance of the schools’ technology professions to install ArcGIS, and, somewhat surprisingly, Google Earth. We hope that the experiences of teachers and tech staff who have navigated these difficulties can serve as guides to our new participants and their support teams, and more efficiently allow our new cohort to “hit the ground running” after completion of the Summer Institute..

Based on lessons learned in GIT Ahead, effective professional development in support of teacher-designed geospatial curriculum projects must be flexibly adaptive to meet individual teacher needs while providing technological skills and curricular support. Intensive training to develop technological skills is essential but not sufficient. Teachers face a steep learning curve in becoming comfortable using geospatial technology, but they can begin with user-friendly programs and build up to use of complex technologies over time. More essential than development of technological skills is development of vision of how geospatial technology can best be applied in helping students learn science. Other essential components include ongoing technological and curricular support to help teachers maintain momentum and overcome inevitable glitches, and a supportive community in which both challenges and successes are shared.

Conclusions

The major finding in GIT Ahead outcomes to date is that middle and high school teachers are enthusiastically embracing the possibilities of teaching core science content using geospatial technology. Teachers are designing and teaching GIT-enhanced lessons and units for remedial through advanced secondary science courses, and their students are rising to the challenge of learning and applying geospatial technology to relevant environmental issues. However, attempting to master geospatial technology can be daunting, compared by one teacher to trying to “take a sip of water from a fire hose.” Crucial aspects of GIT-related professional development appear to be intensive summer training, ongoing technological and curricular support throughout the school year, promotion of a supportive learning community, assistance in development and implementation of individual curricular plans, and program flexibility to meet individual teacher interests and needs.

Time presents a major challenge in two ways. Teachers must invest substantial amounts of their own time to learning new technologies and figuring out how to implement them in their teaching. The second challenge relates to time in the classroom, with over-packed curricula leaving little room for new topics. However, as teachers gain GIT skills and confidence in the effectiveness of related teaching strategies, they begin weaving geospatial technology into a growing list of topics throughout the school year, teaching required content in new and hopefully more effective ways. In coming years, we intend to continue following teachers' experience implementing GIT, and we also plan to explore the extent and ways in which exposure to geospatial technology in secondary science classes impacts student learning, including motivation to pursue further studies and potential careers in related fields.

Acknowledgments
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