James MaKinster
Nancy Trautmann
Michael Barnett *Editors*

Teaching Science and Investigating Environmental Issues with Geospatial Technology

Designing Effective Professional Development for Teachers

Springer

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Foreword

> *"If we teach today's students as we taught yesterday, we rob them of tomorrow."*
>
> – John Dewey

For over two decades, researchers, trainers, and curriculum developers have designed, conducted, and evaluated teacher professional development supporting the use of geospatial technologies in education. These trailblazers pushed toward better practice in science teaching, using methods and principles that extended inquiry in personalized and authentic ways for students. That path, while sometimes bumpy and always shifting, shows signs of success emerging in classrooms, laboratories, the field, and beyond. This volume celebrates the hard work of many and the notable success of a few.

Science education is at a watershed moment, squarely in the public spotlight with the recent release of The Next Generation Science Standards,[1] and calls for increased STEM (Science, Technology, Engineering, and Math) education from the White House to learners. Over the past decade, STEM job growth has been three times higher than non-STEM[2] and annual earnings are typically 11 % higher.[2] To better prepare for twenty-first-century careers and college, all students must better leverage data analysis technologies to extend "science and engineering practices" as envisioned by the new standards, while fostering critical thinking and great decision-making. Effective professional development is the first step in this process.

In this landscape, geospatial technologies – geographic information systems (GIS), global positioning systems (GPS), remote sensing (RS), and digital globes – provide limitless STEM-rich opportunities; they allow students to analyze climate change, design cities, inventory geologic samples, plan ecological models, catalog contents of an archaeological site, and endless choices. They affect all sectors of society and every arena of employment, from local to global and across all aspects of business and government. The geospatial technology sector is expanding, with estimates of global revenue as high as $270 billion annually[3] and nearly 10 % growth in the identified US geospatial workforce through 2020.[4] The future is bright! Students educated using geospatial technologies are now estimated to have at least a 3 % higher starting salary on average.[3] Students, as future geospatial professionals or as spatially literate citizens, must be able to effectively understand and analyze location-based information to succeed in the world today, but especially tomorrow.

Across society, technology is evolving at a blistering and accelerating pace, and this evolution is changing education. Mobile devices, cloud computing, and broadband Internet access are changing the way we teach and learn. Today, 75 % of teens in the USA carry a mobile phone.[5] The move to cloud computing means fewer software installation issues, more personalized interfaces, and expanded collaboration for students. Cloud computing is the architecture that supports the current vision of "Geography as a platform" with over 50 % of Europeans using cloud computing to access geospatial and location analytics services.[3] These consumer technologies are blending with and reshaping geospatial technology, creating entirely new technical niches and knowledge in education and across society.

Despite our rapidly changing world, we still contend with some of the same core professional development challenges faced years ago. The grand challenge might be summarized as, "How do we design and implement effective professional development that leads to a lasting, positive change in tomorrow's spatially enabled science teacher practice?" There are no easy answers, but there is promise.

This collection is part of that promise. It describes some practices and approaches in science education that have worked, and some that have not, yielding critical recommendations for sighting our way forward. While some conditions have changed and technologies have evolved even since these studies took place, their lessons retain valuable meaning. For those who design or implement professional development with advanced technology, this volume will greatly inform your professional practice – a critical first step toward enhancing teaching and learning.

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Geneva, USA

Thomas R. Baker
ESRI

Preface

Geospatial technologies provide unique ways in which to view, explore, and understand our world. Over the past 20 years, GIS, GPS, and other geospatial tools have moved from the hands of geographers and scientists into the realm of everyday life. The scope and reach of geospatial technologies have grown immensely through the development of user-friendly software such as virtual globes and web-based GIS. At the same time, the widespread adoption of tablets and smartphones has greatly simplified location-based mapping and brought it into the public sphere.

This book is situated within the time frame of this sweeping transition in the ways in which we view and relate to our environment. The projects represented here were undertaken because their leaders recognized tremendous opportunity in using geospatial tools to help students and teachers better understand the world around them and because funding agencies recognized the need for students to become better versed in technological applications and related careers.

Our goal is to share the challenges, successes, and lessons learned across a broad range of projects designed to help teachers integrate geospatial technologies into their science teaching. We aim to inspire continuing innovation in project implementation paired with research into best practices in teacher professional development in support of teaching science with geospatial technologies.

The projects represented in this book were supported through grants from the National Science Foundation, NASA, Environmental Protection Agency, Toyota USA Foundation, Hewlett Packard Foundation, National Geographic Education Foundation, and other agencies. We extend thanks to the directors, program officers, and staff of these agencies who strive to improve K-12 education through providing essential support for educational innovation, collaboration, and the translation of contemporary science into learning experiences for students.

We greatly appreciate the work of everyone at Springer who helped to bring this volume to fruition.

Most of all, we wish to thank the teachers and students who we have served and worked with over the years. It is through their eyes that our work has meaning and they have taught us so much. We are eternally grateful.

Geneva, USA

James MaKinster
Nancy Trautmann
Michael Barnett

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Chapter 1
Introduction

James MaKinster, Nancy Trautmann, and Michael Barnett

> *Last year students were amazed when we explored the Genesee River as it ran from farmlands into Lake Ontario. You could see the upper-reaches of the river miles and miles and miles away as it runs through all of these really nice farmland areas. Then it starts to get slightly dirty from soil runoff, but all of a sudden it starts to come through the city of Rochester and the color of the water changes. It gets much darker. And you can see where it hits Lake Ontario, and there's this huge influx of sediment into the lake. So, for them to get to see examples like that was incredible. My students were able to see some of the environmental concepts that we talked about such as runoff, non-point source pollution and related ideas.*
>
> Middle school teacher in New York

> *My students used GIS to analyze a variety of factors that might contribute to lobster settlement. Our goal was to help the local lobster hatchery determine where it might be best to release their larval stock. The students were able to focus on a project and problem that they knew was important to the local economy and many of the families in their community. Both the technology and the focus were extremely compelling to the students.*
>
> High school teacher in Maine

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> *Using geospatial technologies made science fun and made it very connected to real life situations for these students. The fact that we could go look at geographic data for the oil spill in the Gulf, satellite data for the tsunami disaster in Japan, or other things in the news was powerful. So it's definitely tied in a lot to the real world experiences, which I think they really appreciate and are interested in. I definitely think it gave them almost a hunger for learning about different scientific discoveries and things like that.*
>
> High School teacher in New York

> *Looking at landscapes from a GIS perspective is certainly a powerful way to examine what's happening on the planet. There's no doubt about it. Where land is being deforested, where lakes are being drained, where flooding is occurring. For example, we looked at the Three Gorges Dam in China, and tried to understand the effect that was having on the land.*
>
> Junior/High school teacher in New York

Keywords Designers • Geographic information systems • Geospatial technologies • Professional development • Researchers • Science education

In these vignettes, teachers relate creative ways in which they are using geospatial technology to bring science to life for their students. Their reflections demonstrate the application of skills, abilities, and knowledge developed through intensive professional development experiences profiled in this book.

Geospatial technologies enable teachers to teach in fundamentally new ways, building student interest and skill through active engagement in critical thinking and project or inquiry-based learning. Students are naturally drawn to looking at landscapes and interpreting features through analysis of shape and form. Given the chance to manipulate spatial data, students revel in deciphering mysteries, exploring scientific explanations, and linking causes with consequences. As in the examples above, students learn from what they are seeing and they are drawn into wanting to know more.

The purpose of this book is to provide research-grounded and practically minded insights into teacher professional development focused on using geospatial technologies to teach science. Over 40 designers and researchers have shared their experiences, knowledge, and lessons learned in ways that make it possible to identify specific paths forward regarding both research and practice. Our primary audience includes faculty members and other educators who are designing teacher professional development programs or teaching preservice science teachers and wish to include geospatial technologies in these efforts. The chapters included in this volume have specific lessons to share but are also intended to serve as models for others to use in their own work as appropriate.

Part I authors provide in-depth, explicit discussions of why and how they have chosen to provide certain experiences and resources for teachers and the resulting outcomes. In contrast to the traditional approach of training teachers in detail how to use GIS software, these authors provide insights into how to prepare and support teachers in *using* the software to explore and answer specific scientific questions. Theoretical underpinnings are discussed, and many chapters describe evolution of projects over time in response to evaluative research and practical experience.

Part II focuses on curriculum design and implementation, integrating across projects to take a deeper look at issues and reflect ongoing conversations in science education, geography, and the geospatial industry. Opportunities and challenges are discussed in relation to project design, and theoretical frameworks are presented. From this part come a number of lessons regarding how we can continue to improve the ways in which we support teachers in making productive use of geospatial technology, data, and thinking to engage students in learning science.

The book is designed as a resource that can be read in whole or in part. Collectively, the chapters provide a portrait of the field, the commonalities across projects, and the various ways in which teachers and scholars are pursuing the goal of preparing teachers to make effective use of geospatial technology in student-active science.

1.1 What Is Geospatial Technology?

Geospatial technology refers to equipment and software used to visualize and analyze Earth's features. In this book, we refer to four types: global positioning systems (GPS), virtual globes (such as Google Earth), geographic information systems (GIS), and web-based mapping applications (such as Google Maps). These tools have come into widespread use in a variety of academic disciplines and also in our everyday lives, and they have become increasingly affordable and accessible for use in science teaching. Like any educational technology, what is available and what is possible are changing rapidly.

GPS technology has come into common use over the past decade, replacing paper maps with navigation apps on smart phones as well as stand-alone GPS units in cars, boats, and used by hikers. Through triangulation among three or more satellites, a GPS identifies the user's location and tracks his or her movement. The simplest handheld units allow the user to record locations, called "waypoints," and to note the name, elevation, latitude, and longitude of each. "Tracks" are a way of recording a series of waypoints that follow the path traversed by the user.

Virtual Globes are three-dimensional software representations of Earth, the most popular of which is Google Earth. Users can explore satellite images of Earth from various altitudes, zooming in and out to examine the Earth's surface, landforms, and other features at various resolutions or levels of detail. Users also can selectively turn on and off layers that portray various types of data or information such as photographs of specific locations, political borders, places of interest, roads, and weather.

Increasingly, virtual globes such as Google Earth, ArcGIS Explorer, and NASA's WorldWind enable users to import and manipulate GIS data layers. This capability provides almost endless capability to a user who understands how to access, create, or manage these data. It is possible to overlay point-based or continuous maps of data such as precipitation, temperature, topography, land cover, and animal populations, combining layers to explore relationships among such features across the digital landscape.

Web-based mapping applications include some of the same functionality as virtual globes but in two dimensions. It is relatively simple to create web-based maps and host them on the web. The term "mashup" refers to an application that visually integrates data and information from two or more sources. For example, Google Maps mashups combine spatially referenced data with a default map. Interactive map-based infographics have come into common use by news media to represent data, ideas, concepts, and arguments. Use of geospatial technology in classroom science has increased dramatically over the past decade, in large part because the advent of web-based maps and virtual globes has lowered the bar and made geospatial tools simpler to access, learn, and use. However, these tools do not provide the wealth of data analysis options provided by GIS software.

Geographic information system software represents the most powerful option for visualization and analysis of geospatial data. Using GIS, users can overlay layers of georeferenced data, explore the distribution of specific attributes, and investigate interrelationships. This analysis can be purely visual, or it can involve querying the dataset to determine the intersection of two or more types of data. The ability to overlay spatial data and analyze interrelationships makes GIS a central tool for decision-making that requires spatial thinking. Consequently, while GIS originally was used primarily in geography and science, rapid growth is occurring in use in economics, political science, criminology, history, and other fields.

1.2 Why Use Geospatial Technology in Science Teaching?

Using geospatial technology, students can learn science in new ways. Some concepts come to life and make intuitive sense in ways that cannot be accomplished with a static representation such as a map or image. Manipulating real data, students build skill in data analysis, problem solving, and spatial thinking. Using the same data and analysis tools used by professionals, students can address real-world problems and make management decisions. They explore data in new ways and discover relationships, for example, between environmental factors and the distribution of a species.

Another reason to incorporate geospatial technology into student experiences is that it represents one of the three most rapidly growing fields in business and industry. The vast career potential and unmet workforce demand has led to rapid growth in funding of geospatial education programs by the National Science Foundation within the Advanced Technology Education (ATE), Discovery and Research in K-12 (DRK-12), and Innovative Technology Experiences for Students and Teachers (ITEST) initiatives.

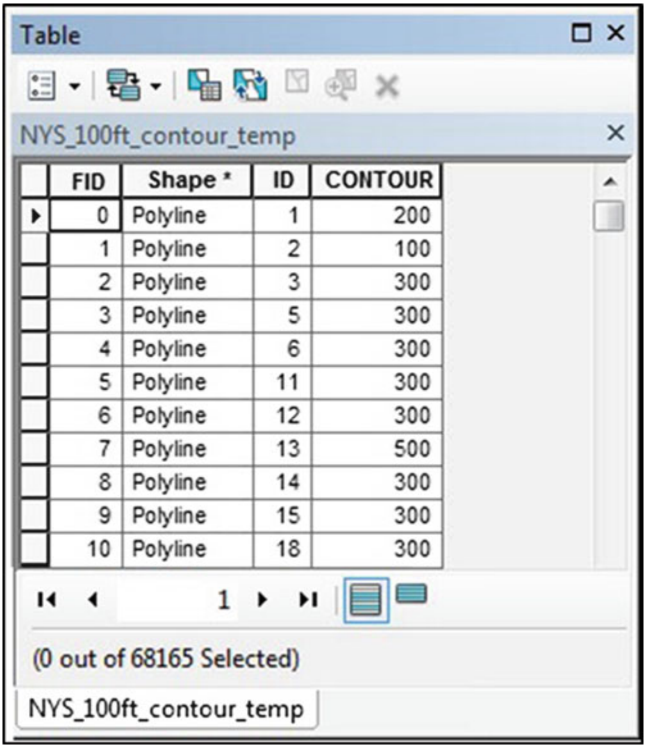
1.3 How Can Geospatial Technology Be Integrated into Science Teaching?

Virtual globes are the geospatial technology most commonly used in today's science classrooms. They are intuitive to use, hard to "break," and provide compelling imagery over the internet. With little to no training, most people can explore maps and data in Google Earth and other virtual globes. Science teachers use virtual globes in three primary ways. First, they use these tools to provide students with a geographic reference for a place, event, or concept. When studying volcanoes, for example, it is relatively easy to navigate to Mount St. Helens, Mt. Rainier, or the Hawaiian Islands to show specific examples. Second, teachers have students create their own "tours" or "explorations" in Google Earth. These consist of a series of related locations that include pop-up windows with supplementary pictures, text, and other information about each location. Students might create a tour that represents the "food miles" traveled by the food they ate in a day or a collection of sites that illustrate landforms they are learning in Earth Science. Finally, a handful of teachers use virtual globes to access data and information needed to explore specific scientific concepts or phenomena. An example might be isoline maps that represent the average annual temperature or precipitation in an area. Students use these data in a virtual globe to explore relationships between elevation and temperature or elevation and precipitation. Using virtual globes in this manner is similar to using a GIS, but the interface is simpler and focuses more on visualization rather than on data manipulation and analysis.

GIS software enables students to explore and analyze data, visually exploring relationships among data layers and posing or addressing questions. Students also can use tools within the software to quantitatively analyze the data, for example, measuring areas of overlap between two data layers (such as housing values and crime statistics) or distances from one point to another (such as between cities). Each data layer is tabular and has an attribute table that includes the latitude and longitude for each data point along with an almost endless number of other data categories. Consequently, students can query the data or make graphs to visualize specific relationships. They can also perform calculations and create new data layers based on the intersection of two or more existing data layers (Fig. 1.1).

Teaching students to use a GIS typically has involved providing them with cookbook-style instructions that specify each and every click to make. This "clickology-focused" approach requires students to rely heavily on the instructions and does little to help them actually learn how to *use* the software. Students become so focused on the steps that they often don't internalize what they are asking the GIS to do and how one tool relates to another.

A more productive approach is to provide students with a specific problem that requires them to learn and use a specific set of tools. Given the chance to explore, students recognize many GIS buttons and tools that are similar to what they have used in other software. Following a series of questions or prompts rather than detailed how-to-do-it instructions, students can engage in a certain level of inquiry



FID	Shape *	ID	CONTOUR
0	Polyline	1	200
1	Polyline	2	100
2	Polyline	3	300
3	Polyline	5	300
4	Polyline	6	300
5	Polyline	11	300
6	Polyline	12	300
7	Polyline	13	500
8	Polyline	14	300
9	Polyline	15	300
10	Polyline	18	300

(0 out of 68165 Selected)

Fig. 1.1 Example of an attribute table from a GIS

and focus on how to address a scientific question using the data available. Once they learn a few basics such as how to use the measure tool, or to query the data, students can creatively use the software to explore data, address questions that have been assigned, and pose additional questions of their own.

Use of GIS enables teachers and students to explore and analyze data in almost limitless ways. First, students can make maps. In the context of science teaching and learning, maps are best used to make or support a specific argument. For example, if working on a service-oriented project in their community or engaging in a simulation regarding global climate change, students can create maps that represent their results. Second, students can use maps to discover relationships among data layers. For example, they can begin to construct an understanding of the orographic effect by exploring the relationship between elevation and temperature. Overlaying these two layers, they can begin to discover relationships between these variables across a geographic region of choice. They also can take this one step further and use a GIS to explore numerical patterns and relationships. This type of constructivist approach (Tobin, 1993) reflects an approach that reflects the type of teaching and learning that is called for in the new Frameworks for K-12 Science Education (Committee on

Conceptual Framework for the New K-12 Science Education Standards, 2012) and the Next Generation Science Standards (Achieve, Inc., 2013).

The ability to query data using Boolean operations makes it possible to conduct at least three basic types of operations: (a) attribute queries, (b) spatial queries, and (c) generation of new data sets. *Attribute queries* involve using the numerical data in the attribute table for a GIS data layer to calculate a statistic or set of statistics such as the average land parcel size in a particular county. A *spatial query* uses the same data but also requires processing of spatial information. For example, one might choose to calculate the area of agricultural land within 1 km of a large lake. Finally, a user can use two or more data layers to *create a new dataset*. For example, one might choose to find the relationship between CO_2 levels and proximity to freeway toll plazas. To accomplish this, the GIS uses the CO_2 level map and the toll plaza map to create a new dataset, which will include new geographic delineations and a new data table that combines these relationships.

The emergence of web-based GIS with increasing functionality is making such analyses much more accessible and user-friendly. Previously, teachers who wanted to use a GIS had to acquire the software, install the program on every student computer, and invest significant time in mastering the software before introducing it to their students. Challenges of technology, bureaucracy, and time prevented many teachers from using desktop GIS (Baker, Palmer, & Kerski, 2009). Web-based GIS greatly reduces these challenges. Only a web-browser is required, with no specialized software, and developers are making an increasing number of tools and analytical capacities available within these web-based applications. In recent years, a variety of exciting new software options have emerged that support widespread use of geospatial technology in education. These include:

- ArcExplorer Online (http://www.arcgis.com/explorer/)
- My World GIS (http://www.myworldgis.org/)
- Digital Worlds (http://www.esriuk.com/schools/)
- CommunityViz (http://www.communityviz.com/)
- National Geographic's Fieldscope (http://www.fieldscope.us/)

Each of these customized tools combines visualization and analytic capabilities in ways that facilitate the use and analysis of relevant data (e.g., Edelson, Smith, & Brown, 2008).

GPS has become ubiquitous in our everyday lives, embedded in a variety of smartphone applications as well as in stand-alone units. Students use GPS units to record location-based data, then download and import these data into a GIS for mapping and analysis. For example, students might conduct a mapping project focused on recording the location of a specific invasive plant species within a local park. When downloaded into a GIS, these data enable them to see the distribution of this plant, relate this to attributes of the landscape, and perhaps make recommendations about management or removal.

Students can use a GIS to visualize relationships among their GPS data points, for example, by color-coding different species or creating new data layers that represent spatial relationships such as areas of overlap between two species of interest. In this way, students are able to use the data they have collected to explore environmental relationships and build a better understanding of concrete scientific concepts. While some GIS projects focus on creating maps, far deeper learning occurs when science students have opportunities to create and use maps in meaningful ways.

Other web-based mapping applications such as virtual globes require an internet connection. Kerski (2012) reviews many of these applications, which include:

- American Factfinder: Provides map-based data from the 2000 U.S. Census of Population and Housing
- Worldmapper: Includes nearly 700 world maps portraying everything from fuel use to religion or language
- National Geographic's Map Machine: Includes a variety of map-ready data from around the globe
- GPS Visualizer: Enables users to create maps based on GPS data collected in local and regional environments
- USGS Earthquake Maps: Provide real-time and near-real-time data for earthquakes throughout the world
- Rand McNally Classroom: Facilitates access to historical maps from the US History Atlas and Goode's World Atlas
- David Rumsey Historical Collection: Includes over 10,000 historical maps

Each of these applications provides users with opportunities to retrieve, explore, and analyze web-based map data.

1.4 How Can We Best Support Teachers in Use of Geospatial Technology?

Teachers who desire to integrate geospatial technology into their teaching must find the proper fit between technological options, curricular resources, and pedagogical goals. This book presents a variety of professional development projects that have successfully enabled teachers to take these bold and potentially daunting steps. Looking for commonalities, tensions, and lessons learned, we aim to advance both theory and practical application of teacher professional development in support of teaching science with geospatial technology.

In spite of the positive learning outcomes achievable through involving students in use of geospatial technology, relatively few resources exist that relate specifically to creating meaningful science learning opportunities for students. The goal of this book is to highlight current best practices in science teacher professional development in this field, building on the framework established by Loucks-Horsley, Love, Stiles, Hewson, & Mundry (2003) and extended by others to identify characteristics that contribute to reform-based teaching practices (e.g., Jeanpierre, Oberhauser, & Freeman, 2005; Parker et al., 2010; Windschitl, 2009).

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Part I
Designing Effective Professional Development Projects

Chapter 2
Participatory Professional Development: Geospatially Enhanced Urban Ecological Field Studies

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Keywords Field Studies • Urban Education • Urban Ecology

2.1 Introduction

Urbanization trends of the past century show a dramatic rise in the size of cities worldwide. More than 300 cities have more than one million inhabitants, and 16 "megacities" have populations exceeding ten million. With increased urbanization of rural landscapes and densification of existing cities, greater pressure is placed on critical urban natural resources, such as watersheds, forests, and wildlife. These resources are critical to maintaining ecosystem health and to providing economic, civic, and public health benefits for metropolitan area residents (Grimm, Grove, Pickett, & Redman, 2000). At the forefront of ensuring that urban ecosystems are

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healthy and sustainable are the young people that live in cities. Unfortunately, all too often, students and their teachers are not provided with the necessary knowledge to understand and appreciate the ecological richness and value of cities. Many students lack the necessary scientific skills to understand how their actions impact local urban ecosystems, how they can improve and change their city's ecosystem for the better, and how healthy urban ecosystems benefit their own lives (Manzanal, Barreiro, & Jimenez, 1999). To date, the teaching of ecology in high school classrooms has primarily focused on the study of areas where there has been relatively minimal human intervention. For example, in their 2004 review of environmental science high school textbooks, the Environmental Literacy Council (2004) found that very few books critically examined urban ecosystems, the impact of cities on the environment, and the role that humans have had in creating, changing, and impacting urban ecosystems. With the goal of improving students' and teachers' understanding and appreciation of their local urban ecosystems, we developed and implemented an urban ecology education program that utilizes a number of geospatial technologies.

Geospatial technologies such as geographic information systems (GIS) have emerged over the last 15 years as one of the primary research tools used by environmental scientists; however, a disconnect exists between the research conducted by professional environmental scientists and how environmental science is taught in typical public school classrooms. Few students work with tools regularly used by scientists or pursue authentic inquiries using current scientific data, regional or global information, and available research tools (National Research Council [NRC], 2006); however, recently there has been a dramatic increase in the availability of relatively user-friendly geospatial and visualization technologies, such as MyWorld GIS, Google Earth, and ArcGIS Explorer, and access to scientific data for educators. The availability of these programs at lost costs has increased the potential for integrating geospatial technologies in classrooms.

In this chapter, our summer secondary science teacher training program, called the Urban Ecology Institute, will be described, along with the challenges and

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lessons learned on how to design an immersive professional development program to improve teachers' knowledge and use of geospatial technologies. To that end, we first describe why urban ecology is a scientific basis for our work. Next we describe our theoretical and conceptual foundations that guide our work which is followed by a general overview of our program including details of our summer institute and the three individual investigations in which students and teachers engage. In presenting our program, we describe the final iteration (as of this writing) of the structure program. Next we present the results of our research and evaluation efforts that lead us to our existing programmatic structure.

2.2 Scientific Framework: Urban Ecology?

Urban ecology has been called an important frontier for educators because the core skills and concepts integral to urban ecosystem education are well established in national and state science education standards (Hollweg, Pea, & Berkowitz, 2003). Thus, the field of urban ecology affords an integrated curriculum that combines the power of science *as a way of knowing* with the direct impact of active learning about and in service to the local community (Berkowitz, Nilon, & Hollweg, 2003). By developing science curricula around urban ecology constructs, students are immersed in relevant local and inquiry-oriented learning environments. This curricular strategy emphasizes both process and content, moving away from the "survey of the sciences" and "skill and drill" approach often found in traditional classrooms and textbooks, which, all too often, saps the excitement and curiosity from many urban students (Kahle, Meece, & Scantlebury, 2000). Lastly, using urban ecology as a framework involves students directly in data collection and engages them as active participants in improving their neighborhoods (Carter, 1997).

One of the most popular technologies used in urban ecology are geographic information systems (GIS), broadly defined as a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world (Edelson, Smith, & Brown, 2008). GIS models are integral to many scientific fields but particularly important to urban ecologists and environmental scientists as GIS can be used to analyze spatial information and develop solutions to problems. The technology allows one to ask fundamental questions about locations and relationships between objects. For example, one might explore how the urban environment and corresponding ecological services of a system change in response to environmental and sociopolitical conditions or identify and highlight patterns and relationships among disparate phenomena. With the current level of GIS and visualization technologies, it is now possible to combine these systems with computational modeling tools. These computer systems make it possible for urban ecologists to explore multiple potential solutions to problems by asking "what if?" questions and obtaining feedback that informs the decision-making process (Maguire, 1991). In these ways, geospatial tools support the practices of urban ecologists and thus potentially provide access to those practices for students and teachers learning about the ecology of complex urban relationships (Beckett & Shaffer, 2005).

Urban ecologists engage in a variety of practices to understand urban ecosystems. Their specific research approach considers that biogeophysical systems are tightly linked to the socioeconomic aspects of human life. Ecological systems are dynamic and shaped by forces that occur over long periods of time (presses) such as climate change, and short-term impacts (pulses) such as cataclysmic storms, tornadoes, or fire. Cities are studied as coupled human-natural systems. Given their holistic paradigm, urban ecologists tend to take a central role in trying to keep urban ecological systems sustainable through understanding the deep interconnectedness between humans and the natural environment (Alberti, 2008). Unlike traditional ecology which often attempts to understand an ecological system devoid of human interference and impact, urban ecology as a discipline embraces humans as a keystone species and tries to understand the impact that the human-built system is having on the environment and how these anthropogenic changes feedback on the forces and drivers that shape urban ecosystems. Thus, an urban ecologist collects data with the goal of understanding how to solve complex urban problems, both social and natural, by developing land-use plans, wildlife management strategies, and ecosystem service protections that function to simultaneously accommodate human needs and ease the burden on the natural places people use (for a review of the discipline, see Marzluf, 2008).

One approach urban ecologists commonly take is the development of data-driven models that allow them to visualize potential future scenarios, compare alternative scenarios, and describe implications of potential changes in the urban environment for both humans and the natural world. These findings are then communicated to stakeholders so that policy makers can make informed decisions about future development. In short, urban ecologists live at the intersection of social science, policy, and scientific research and through their expertise and interdisciplinary collaborations are well positioned to understand the unique problems facing urban areas today. As such, the field of urban ecology is nuanced and consists of multiple layers that make the use of geospatial technologies a critical tool to identify relationships and patterns between the various components of urban ecosystems. It is our hope that, through meaningful field study science projects, teachers will be able to use geospatial technologies to engage in the practices of urban ecology.

2.3 Theoretical Framework of Our Professional Development

2.3.1 Pedagogical Praxis

The theory of pedagogical praxis suggests that new technologies make it possible for students to participate in meaningful learning activities by serving as a bridge between professional practices and the needs of learners (Shaffer, 2004). In other words, new technologies make professional practices, previously only available after years of training, accessible to novices. This is perhaps no more apparent than with the rapid increase in the use of GIS and similar tools to explore the natural world. For example, Google Earth and Google Maps, two of the most well-known geospatial technologies, have enabled not just specialists to overlay data and to evaluate the relationships between objects, locations, and other types of data but have engaged the general public in performing simple geospatial analyses. With the emergence of these new tools, attempts have been made to engage teachers and students in becoming urban ecology scientists through the evaluation of the ecological, economic, and social benefits of green space for urban residents. To do this, our professional development program has been constructed around the typical practices of professional urban ecologists and informed urban planners. This latter point is critical because according to the theory of pedagogical praxis, successful learning environments depend upon the alignment of authentic professional practice (Beckett & Shaffer, 2005).

2.3.2 Participatory Learning

Our model for professional development has been jointly informed by Shaffer's theory of pedagogical praxis, described previously, and a participatory learning environment framework as described by Barab and his colleagues (Barab, Hay, Barnett, & Keating, 2000). Participatory learning environments have five characteristics: (1) they should be designed to engage learners in authentic science; (2) learners should be engaged in the "making of science," and not simply memorizing a set of ready-made knowledge; (3) learners should be engaged in participatory science learning activities with others who have less, similar, and more experience and expertise than themselves, supporting the emergence of collaborative group work, and not simply individuals working in isolation (Resnick, 1987); (4) learners should not be simply completing the task for some reward (e.g., grades, professional development points) but should be working toward addressing a real-world need that they have identified as important to themselves and to society (Savery & Duffy, 1996); and (5) learners should be working in participatory science and should be given the opportunity to participate in a professional community, not simply hearing about the work of other authentic science communities.

2.4 Participatory Science Teacher Development

Building from both the theories of pedagogical praxis and participatory learning environments, as well as the research base on what constitutes effective professional development (McClurg & Buss, 2007), the notion of a participatory learning environment has been extended to professional development by adding new categories to the model which is now called *participatory science teacher development*. Three additional categories have been added to the model. First, the model includes explicit opportunities to learn urban ecological content through the doing of authentic science and then through the teaching of that science to students. Thus, understanding of content is intertwined with the development of both good scientific and pedagogical practices. Second, the model includes ample opportunities to engage teachers in thinking about that teaching and how to implement the technology and tools with students. This idea builds off Shulman's (1987) recommendation that professional development should help teachers to think and reason about their teaching role. Shulman correctly pointed out that it is the subject matter knowledge and the associated pedagogical content knowledge that hold real challenges for teachers who must learn about an innovation and somehow convert their new knowledge into a pedagogical form. To that end, teachers must have opportunities to develop understandings of how students with diverse interests, abilities, and experiences make sense of scientific ideas and what they as teachers can do to support and guide all students in learning. Third, the model also includes ongoing opportunities for reflection, feedback, and sharing of challenges and ideas regarding teaching of both the content and the use of technological tools with students. That is, during the summer program, described later, there is regular group reflection time, as well as time for teachers to work with their peers, while students are engaged with other aspects of the program such as career development training. During this time, teachers evaluate how their students are doing in terms of learning the science and the technological components of the program.

Rather than just relying on the summer program, we also set out to provide just-in-time resources for teachers. As a result, we developed a rich set of digital materials that teachers could access including audio and video podcasts of content and technical troubleshooting. During the implementation phase, we soon found that most teachers relied upon the curriculum materials as their primary means of support and as such we began embedding a significant amount of professional development experiences within the materials themselves by emphasizing the educative components of the materials (Houle, 2007). These educative materials provided teachers with a variety of supports such as potential misconceptions, teaching strategies, field-based strategies, questions to ask students, and potential technological challenges to expect during the implementation of the materials. The goal of these supports was to help teachers develop flexible knowledge and make informed decisions about the adaptation and implementation of the curriculum materials at times when they most needed it, namely, during their planning periods. To evaluate the effectiveness of the participatory science teacher development program in improving

- Teachers' urban ecology content knowledge
- Proficiency with geospatial technologies
- Their ability to leverage these new skills to positively impact student learning

the driving research question for our summer professional development program has been: What effect do the project's professional development strategies have on the skills and content knowledge of participating teachers specific to conducting information technology-enhanced field studies?

2.5 Structure of Our Program

Davis and Krajcik (2005) argue that multiple forms of professional development are more effective than any one approach; consequently, curriculum materials, particularly those that are technologically rich, will be more effective when coupled with other forms of support. This program has evolved to include several different types of supports for teachers. First, an intensive summer program, referred to as the summer institute, is executed in which teachers are immersed in the doing and learning of urban ecology content through the use of technology. Second, just-in-time academic year workshops are conducted which are refresher learning experiences. Third, the curriculum materials are developed from an educative framework which embeds supports for teachers into the materials. The curriculum materials have incorporated three components with each lesson. First, the teacher version provides the structure and "how-to" of the lesson. Second, the student version of the lesson is distributed to the students by the teachers. Third, the teacher version of the student handouts provides potential student questions, potential student responses to teachers' questions, misconceptions that students may have, and key areas in which teachers should focus when evaluating student work.

Our initial summer program began with two major technology-enhanced projects. The first focused on bioacoustics (more detail below) and the second major project focused on urban trees and the use of GIS and computer modeling technology. Even though the basic structure of our program has remained the same with time for teacher training and then time for teachers to work with students, we added a third project after our initial year as we found that many of our participating teachers needed additional support either in the form of more scientific research skills, how to conduct a field study, or content background on urban ecology. In the following we describe the latest structure of our program based upon the data that we collected regarding the efficacy of our program.

The current version of our summer program consists of 4 weeks of instructional time for teachers and 2 weeks for students. The first week of the summer institute focuses on providing teachers with the skills and knowledge to conduct technology-enhanced field studies. Teachers start by learning about urban ecology and conduct preliminary field studies while learning about how the technologies support data collection and analysis. During the second week of the institute, teachers focus on a particular project: (1) Foundations of Urban Ecology, (2) Bird Bioacoustics, and (3) Urban Street Trees. Our program has been built around the model of having teachers with various levels of experience simultaneously traverse two parallel learning trajectories – learning urban ecology content and the technology that is used to support the scientific processes that undergird the field of urban ecology. Thus, we try to have teachers progress through the program starting with Foundations of Urban Ecology and culminating with the Urban Tree Project; however, many teachers over the 3 years of our work have, not surprisingly, chosen the project that best connects to what they intend to teach or are teaching during the school year.

Within each project, teachers conduct short investigations, while exploring in greater depth the science content and methods of data collection and analysis, using relevant technological tools such as GIS or Google Earth. During the third and fourth weeks, inner city middle and high school students attend the institute. The teachers then have the opportunity to apply what they have just learned and to use the corresponding instructional materials to help teach the students. Each teacher works with four or five students on a project during the last 2 weeks of the summer institute. This model provides teachers with an opportunity to both "act" as students walking through the projects and an opportunity to "try out," and often teach, material which requires teachers to use new content and pedagogical skills in a safe and supportive environment. The details of the current versions of the projects are described in the following sections.

2.6 Curriculum Projects

2.6.1 Project #1: Foundations of Urban Ecology: Google Earth and Data Representation and Wikis

Foundations of Urban Ecology is designed to be a gateway project for teachers either not familiar with urban ecology or not familiar with geospatial technologies. Foundations of Urban Ecology projects focus on using Google Earth to enter data regarding water quality, urban street trees, bioacoustics, and soil quality with the goal of looking for patterns. In essence, the participants in this project collect their own data and use it in combination with data collected by other groups to better understand the differences and similarities of the geographic distributions of health parameters for local urban ecosystems. In essence, during the summer the teachers were split into groups and each group would collect data such as water quality, soil quality, and temperature and enter that data into Google Earth which can then be viewed by other groups in the same project. By having all groups' data available for rapid viewing in Google Earth, it is possible to look for patterns and discern any potential relationships and trends in the data rapidly. Further, with Google Earth's ability to layer the information, teachers are starting to become familiar and comfortable with the concept of layering of data. By focusing on the use of Google Earth, teachers are eased into the use of geospatial technologies to explore and understand their environment.

In many ways this project was the most challenging of the three projects to design and implement. As this project needs to serve the dual role of helping teachers learn new technologies, field-research techniques, and the conceptual basics of urban ecology. This project, in year 2, focused on basic data collection and entering that data into Google Earth. Much of the data remained isolated to the participants in that project and, as such, was of limited value and teachers did not have an opportunity to see how their data compared or contrasted with other groups. In year 3, there was a significant increase on the use of wikis to collaborate and share data within and across the groups and to place data from the bioacoustics and tree groups within their Google Earth projects. In this way it was far more possible to develop a significantly more holistic view of the health and features of the field sites under study. The other change that occurred prior to year 3 was that for new teachers this project would be the first project in which they would enroll. This was especially important for teachers who were not comfortable with either the technologies or urban ecology field studies. In the future, they would then be able to transition to the more advanced projects. This decision enabled us to not only develop longitudinal relationships with teachers but also provided a trajectory for teachers who enter our program who are either new to science, new to urban ecology, or new to the use of technology in science teaching.

2.6.2 Project #2: Bird Bioacoustics

This curriculum project was sparked by recent research in urban bird communication and challenges students to explore how birds adapt their communication systems to deal with urban noise. In 2003, a landmark study published in *Nature* found that Great Tits (*Parus major*), a small songbird breeding within the Dutch city of Leiden, sang at a higher pitch than those in quieter locations (Slabbekoorn & Peet, 2003). The study was elegant, simple, and ripe for replication by student scientists. Recent studies have found that other species of birds are able to raise the pitch of their song (Wood & Yezerinac, 2006) or increase song intensity in response to urban noise (Warren, Katti, Ermann, & Brazel, 2006); however, little is known about how most local species deal with noise pollution in urban areas (Warren et al., 2006), especially with respect to individual variation in adaptive strategies. Leveraging this research gap, students explore the challenges of bird communication in their urban environments through posing researchable questions and collecting and analyzing data to address these questions. These data are made more powerful by the emerging consensus on the scientific and social processes that drive urban ecological systems (Shochat, Warren, Faeth, McIntyre, & Hope, 2006). Once students have collected their data in the field (a city street corner, a park, etc.), they upload their data to a computer and use RAVENlite, a bioacoustics analysis software package developed by the Cornell Lab of Ornithology (Charif, Clark, & Fristrup, 2003), to examine the spectrograms of their recordings (see Fig. 2.1). RAVENlite allows students to quickly view and visualize their data, evaluate their recordings, and explore

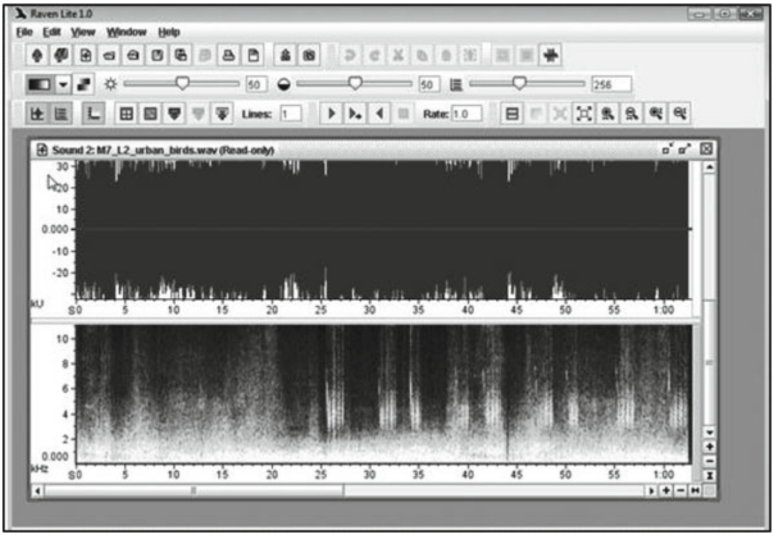


Fig. 2.1 Student audio recording of birdsong as viewed in RAVENlite

how urban noise in their city impacts birdsong, comparing their data with existing birdsong recordings. During the summer, the data that is collected is also shared with the Foundations of Urban Ecology group such that the data can be mapped in Google Earth. Following this analysis, students generate research questions, conduct additional research, and present their findings to their peers.

2.6.3 Project #3: Urban Street Trees: GIS and Ecological Impact

The Urban Street Tree Project capitalizes upon the increased recognition that city street trees have significant positive ecological impacts (McPherson et al., 1997). The urban street tree inventory is conducted using tablet PCs and CITYgreen, a software package developed by American Forests that plugs into the geographic information systems (GIS) software package, ArcView. CITYgreen is a personal computer desktop-based software application for comprehensive urban ecology benefit analysis and environmental modeling (UEAM) using high-resolution satellite and aerial photography images. The CITYgreen application is designed as extensions to the Environmental Systems Research Institute (ESRI) software platform of geographic information system tools ArcView and ArcGIS, which are GIS industry standards. CITYgreen was originally designed to allow city planners to

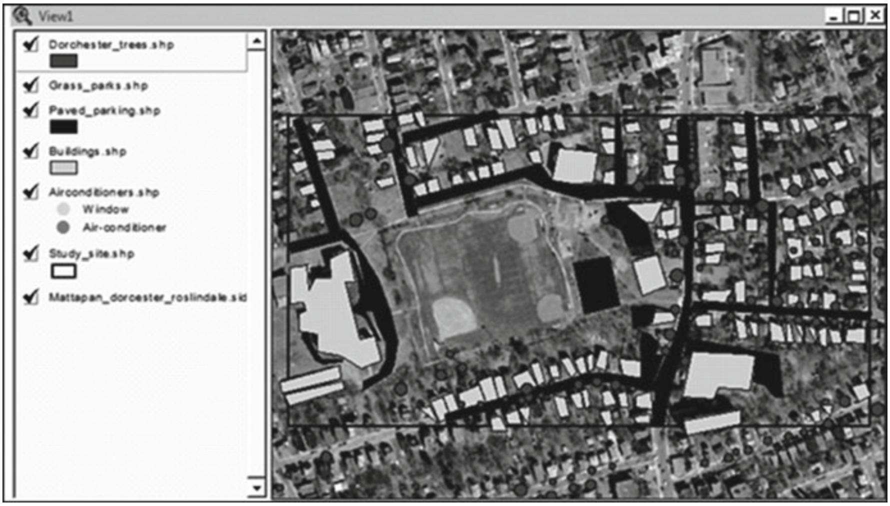
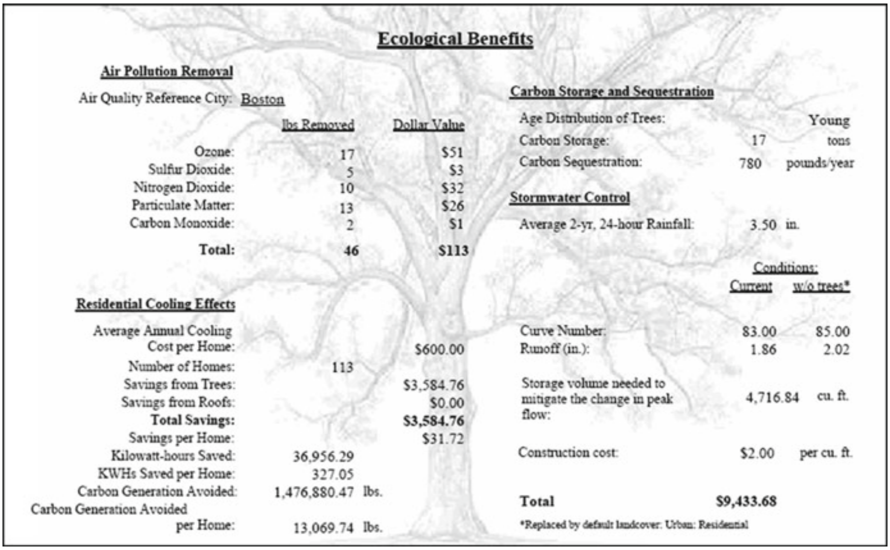


Fig. 2.2 Placing of trees and other land cover uses in CITYgreen

evaluate the ecological and economic green space in their cities (see http://www.americanforests.org/productsandpubs/citygreen/ for a more in-depth description of CITYgreen); however, teachers have been among the prime users of CITYgreen, because CITYgreen allows students to connect computer modeling and real-world data collection in order to conduct tangible, meaningful projects and make useful recommendations.

Students and teachers collect data on tree location and condition and use CITYgreen to evaluate the economic value of street trees on such outcomes such as storm water runoff, energy savings, and air pollution removal. The students can also evaluate the impact of street trees on air quality and the rate of carbon sequestration and determine how much carbon is stored in their urban street tree sample; however, what is perhaps most powerful about this project is that once students have collected their data (or used data from an existing street inventory for a given neighborhood, schoolyard, or park) and conducted an initial baseline data analysis, they can then ask “what if” questions. For example, in the city of Boston, there has been significant news coverage of the “Big Dig,” a decadelong road construction project in which the city has diverted the major interstates that were running through city into underground tunnels and is currently in the process of converting the reclaimed land into green space. Through the use of CITYgreen, students can now model both the economic impact and the ecological benefits of the Big Dig. In another example, students can explore the impact of planting trees around their own school or neighborhood and evaluate the impact on the school’s energy savings over time (see Fig. 2.2 for a screenshot of CITYgreen and Fig. 2.3 for a report). This latter



Ecological Benefits

Air Pollution Removal

Air Quality Reference City: Boston

	lbs Removed	Dollar Value
Ozone:	17	$51
Sulfur Dioxide:	5	$3
Nitrogen Dioxide:	10	$32
Particulate Matter:	13	$26
Carbon Monoxide:	2	$1
Total:	**46**	**$113**

Residential Cooling Effects

Average Annual Cooling Cost per Home:		$600.00
Number of Homes:	113	
Savings from Trees:		$3,584.76
Savings from Roofs:		$0.00
Total Savings:		**$3,584.76**
Savings per Home:		$31.72
Kilowatt-hours Saved:	36,956.29	
KWHs Saved per Home:	327.05	
Carbon Generation Avoided:	1,476,880.47 lbs.	
Carbon Generation Avoided per Home:	13,069.74 lbs.	

Carbon Storage and Sequestration

Age Distribution of Trees:		Young
Carbon Storage:	17	tons
Carbon Sequestration:	780	pounds/year

Stormwater Control

Average 2-yr, 24-hour Rainfall: 3.50 in.

	Conditions: Current	Conditions: w/o trees*
Curve Number:	83.00	85.00
Runoff (in.):	1.86	2.02

Storage volume needed to mitigate the change in peak flow:	4,716.84	cu. ft.
Construction cost:	$2.00	per cu. ft.
Total	**$9,433.68**	

*Replaced by default landcover: Urban: Residential

Fig. 2.3 An example CITYgreen report showing the ecological value of urban trees

Fig. 2.4 Tree canopy in 20 years

investigation is possible because CITYgreen allows students to model tree growth over time, with sophisticated species- and tree-age-specific modeling algorithms, which enables them to evaluate what their urban street canopy will look like in 10 years, 20 years, and so on under alternative planting regimes (see Fig. 2.4).

2.7 Findings and Discussion of Our Research and Evaluation

2.7.1 Study Context

Our professional development program is intended to support teachers in continuous learning of both urban ecology content and technology used to carry out urban ecology science investigations. Although our program is now designed so that teachers should progress from the simplest technological project, Foundations of Urban Ecology, to the most technologically challenging, the Urban Tree Project, teachers often chose to participate in the project most aligned with what they intended to teach in the future. At the time of this writing, we have data from the first three summer sessions; however, in year 1, the reliability of our research instruments was quite low and as a result we will not present the results here (although we did use the results internally for improving our program). In addition, in year 1 the Foundations of Urban Ecology project did not exist. Therefore, for the purpose of presenting the outcomes of our program, we focus our description on year 2 and 3 of the summer program as the data from those 2 years provide the best insights into what has worked well and what aspects of the program was less successful.

2.7.2 Methods: Data Collection and Sample

The major goals of our summer program have been focused on improving teachers' understandings of student career development and improving their knowledge and confidence in conducting urban ecological investigations. To evaluate the efficacy of our program, we have been conducting pre-post surveys and focus group interviews with teacher participants. The summer pre-post "test" or assessment consisted of multiple scales (see Table 2.1) ranging from career knowledge and preparedness to scientific-inquiry beliefs. In Table 2.1 we present the four areas that we were interested in evaluating, the scales and a corresponding description of the scales, and the number of items in each scale. In Tables 2.2 and 2.3, we present the survey results from year 2 to year 3, respectively. Although we have conducted research on teacher understanding of STEM career development, we focus our discussion on inquiry science, learning and teachers' technology use, and their perceptions regarding their ability to use technology in their teaching.

Table 2.1 Scale reliabilities for the pre-post teacher surveys

Domain	Scale description	Cronbach's alpha (year 2)	Cronbach's alpha (year 3)
Science learning and teaching	Educators' self-efficacy in teaching science field investigations (comfort with site selection, managing students, and equipment outdoors)	0.927	0.818
Technology use	Educators' attitude about the usefulness of IT to engage students with scientific content	0.932	0.920
Inquiry science	Educators' self-efficacy in teaching students to formulate scientific explanations, models, and arguments	0.967	0.954
	Educators' self-efficacy in teaching students to design and conduct scientific investigations	0.986	0.974

Table 2.2 Year 2: Self-efficacy and other attitudes regarding career education, science teaching, and technology use

	Pretest scale scores		Posttest scale scores		
Scale name (N = 21)	*M*	*SD*	*M*	*SD*	t-value
Self-efficacy teaching field investigations	3.79	1.10	4.28	0.58	2.17*
Technology use	4.09	.75	4.38	0.45	2.72*
Formulating explanations, models, and arguments	3.88	1.04	4.32	0.61	2.46*
Designing and conducting investigations	3.72	1.17	4.32	0.60	2.88**

*$p < .05$, **$p < .01$

Table 2.3 Year 3: Self-efficacy and other attitudes regarding career education, science teaching, and technology use

	Pretest scale scores		Posttest scale scores		
Scale name (N = 19)	*M*	*SD*	*M*	*SD*	t-value
Self-efficacy teaching field investigations	4.36	0.55	4.66	0.37	−3.01*
Technology use	4.42	0.64	4.49	0.62	−1.27
Formulating explanations, models, and arguments	4.34	0.37	4.39	0.42	−.45
Designing and conducting investigations	4.44	0.45	4.59	0.34	−1.38

*$p < .01$

2.8 Findings and Discussion

2.8.1 Overall Findings

Across the last 2 years of our program, we found that, generally, participants in our program improved in their knowledge and skills in urban ecology and their perceptions of their ability to teach science through the use of geospatial technologies.

2.8.2 Year 2: First Year of Three Projects

We found statistically significant levels of skill improvement in teachers' skill with classroom uses of technology (teaching students to use technology, helping students to use technology in class as part of a lesson, and designing lessons that make use of technology to teach science) and their use of software tools specific to the summer institute (bioacoustics and GIS software). This finding was supported by focus group data as some teachers also mentioned being introduced to or improving their skills with specific technologies, such as GIS or Google Maps, whereas others specifically mentioned that they gained practice in explaining to students' software that they already knew how to use. What was perhaps most important thought was that several had begun thinking about new ways to use technology in their work. "I feel comfortable enough to begin to work on developing a course in GIS for science students," said one teacher. Unfortunately due to space limitations, the details of teachers' implementations will be reported elsewhere.

In terms of content knowledge, participants demonstrated improvement in their ability to define the term "urban ecology" with more complexity, recognizing physical, biological, and human components to urban ecology, but remained consistent in describing the primary benefit to society of studying urban ecology as helping solve urban problems and improve urban planning. The focus groups revealed that participants, in general terms, confirmed that their urban ecology content knowledge had increased during their 2 weeks of work with the students. Several gained a clearer understanding of urban ecology as a science and they reported learning specific content, such as identifying birds or trees. Others cited improvement in skills such as using water and soil test kits, collecting data, or using technology.

2.8.3 Year 3: Moving Toward a Final Iteration

In year 3 we used the same pre-post teacher survey used in Year 2 with a few additions. Generally we found there were statistically significant increases in participants' self-reported levels of skill with two of the software tools specific to this year's summer institute, bioacoustics and Wiki software. Teachers' skill with the third featured software tool, GIS, did not increase significantly. We suspect this was because the teachers had seen this technology in the previous years and as such we have begun to ramp up the sophistication of our GIS beginning with the integration of CommunityViz (http://www.communityviz.com/) for more complex modeling of urban planning contexts.

In terms of content understanding, there was no statistically significant change in any of the five ratings showing participants' level of sophistication about urban ecology content. Given that we had several repeat teachers in the program, we suspect that we experienced a ceiling effect which also has suggested that we are succeeding in raising teachers' knowledge and skills with GIS which further suggests the integration of more complexity. However, in participants' definitions of urban ecology (UE), we saw an increase in the number of people who mentioned the human, biological, and physical components of this discipline, noted the importance of interactions among factors, and referred to urban ecology as a study or science.

In terms of conducting field studies, which has historically been a major stumbling block for many teachers in doing environmental science activities, we found statistically significant changes over the course of the summer institute in their self-efficacy in teaching science field investigations. The major difference between year 2 and year 3 was that most respondents said that the time spent with students during the last 2 weeks of the summer institute was useful in helping them to better understand how to conduct a field study. However, a few felt that working with a small group of self-selected students was not realistic practice for actual classroom conditions. We suspect that this later belief came from the bioacoustics group where there were some challenging social and cultural dynamics between the teachers, the teacher leaders, and the students. This latter speculation seemed to be confirmed during the focus groups when the teachers reported that the urban tree group had especially effective student-leaders and cooperative student-participants this year, while in the bioacoustics group, certain social tensions among students affected the work.

2.8.4 Curriculum Implementation During the Academic Year

We observed and interviewed 13 teachers who implemented their chosen modules with anywhere from one to five class sections during the school year, with class sizes ranging from eight to more than 30 students. Three teachers had seventh or eighth graders; three had ninth, four had twelfth, and three had mixed or ungraded classes. Two teachers had special education classes, one had English Language Learner (ELL) classes, and one taught in a school where students were grouped by language competency; other teachers did not describe any special student characteristics. Overall, teachers felt the modules had worked well, though not flawlessly. The most frequent barriers to implementation were limited access to technology and time constraints. In turn, these barriers were often the key drivers of the modifications that teachers made to the unit. Although hands-on work with the software was a key component of each of the modules, many of the teachers had problems making that happen for their students primarily due to technical issues. During the academic year, our teachers have experienced technical problems such as not (1) being unable to install the software on their computers, (2) having sufficient computing capacity (particularly in our urban school settings), (3) having the time to learn how to troubleshoot technical issues within ArcView, and (4) having sufficient technical expertise to customize the software to meet their specific needs. In fact, in interviewing our teachers who used GIS technologies in their classroom, a common issue that arose was expressed succinctly by one:

> The potential for this [GIS based] project is immense. The students loved working on the project and learning the technology. We spent so much of our time trying to figure out what went wrong with the technology. I'm fortunate in that I have some time to play around with it, but I don't know how other teachers can use this as they simply won't have the time to learn the technology.

In addition to the lack of resources, another issue that arose during classroom implementation was unexpected technical trouble. Despite the fact that most of our teachers became comfortable with using the technology with their students during the summer and follow-up workshops, given the sophistication of the geospatial technologies, it proved to be very difficult to troubleshoot problems, which often leads to the loss of instructional time. For example, on several occasions a student would simply hit the wrong button in ArcView and cause some change to occur, but that change either corrupted their project files or changed their project files that resulted in errors when they attempted to run CITYgreen. This unexpected and difficult to predict challenge has led us to develop "troubleshooting" pathways for the most common errors and "points of trouble" for teachers, and we are embedding these into our program and the curriculum.

In evaluating our professional development program, we have also learned the value of providing a developmental pathway for teachers that slowly ramps them up in terms of their geospatial technology skill levels. The following teacher excerpt illustrates this point:

> I'm so happy that I didn't start with the tree project. I really needed to learn just learn about Google Earth and the idea of layers and how to input data. Then I could learn more about themes in ArcView. I think this just helped me to be less intimidated.

This idea of a gradual pathway took some time to implement as our program was designed to allow multiple entryways for teachers into learning about geospatial tools. As a result, our project team has experienced a continuous tension between providing a more structured trajectory for teachers versus allowing them the freedom to choose where they wish to start in the program. The latter option provides teachers with more ownership over their own development; however, it requires significantly more effort on behalf of our project team to support a teacher if their technological knowledge is low and they wish to participate in the more advanced GIS-based aspects of our program, and based upon our third year results, we are starting to expand our program to include more sophisticated GIS and geospatial technologies.

A particularly interesting finding was that teachers reported that their classes seemed evenly divided with regard to what engaged them most, the field work or the computer work. Almost all teachers said their students "loved" the technology; however, we think that a major strength of the curriculum was the strong connection between the students' real-world data collection and their in-classroom modeling and analyses of that data. This was pointed out by one teacher:

> You know the technology is fantastic. You can do so much, but you know what I think is most powerful about the project? I think it is that the students are collecting their own data and then using CITYgreen as a way to analyze their data. The students are given their data like so many other GIS based materials but they have to decide what to collect, where to collect, and then evaluate their data. I think this is what I like best about the project; it doesn't take data ownership away from the students.

That said, there was considerable variation in teacher assessments of whether or not the unit had helped students understand the scientific-inquiry process, and to some extent, their answers seemed to demonstrate differences in their understanding of the question. For example, one teacher described his/her students mastering several critical steps of a scientific investigation: "thinking about what a testable question is," "seeing if the data supported their hypotheses," and "using a model." Another described the use of a hands-on process to examine phenomena and to problem-solve: "They had to think a lot when they were outside. I gave them a number of trees; they had to identify them, see if they were healthy or unhealthy, [figure out] good places to plant." Other teachers reported that the project was more structured and they did not describe the project as inquiry for the students. They did, however, describe the student work as extremely important because it caused them to analyze their own data and to think about research questions even if the process that they (the students?) went through was highly structured. As we explored this issue in more depth with teachers, we began to notice that those teachers who had implemented the project for more than 1 year were more focused on the inquiry components of the project rather than on the technology. In fact, we have observed that teachers who had implemented the project over the 3 years of the grant have shifted from a more technological and rather structured pedagogical approach to a more open-ended inquiry approach, shifting from focus on the use of the technology to a focus on the science with the technology as a part of their instructional toolkit.

2.9 Implications and Closing Thoughts

Firsthand experience with conducting scientific inquiry, gaining proficiency with high level, professional grade technology, and introduction to the burgeoning field of urban ecology can provide students with the twenty-first century skills required for functioning in an increasingly technological society. Several research and development studies have found that GIS has the potential to provide students in all grades with a rich, inviting, and challenging problem-solving environment (Akerson & Dickinson, 2003; Baker & White, 2003; Carlson, 2007; Kerski, 2007; NRC, 2006; Stubbs et al., 2007). In fact, many educators have been successful with using GIS in K-12 classrooms (Alibrandi, 2003; Barnett, Houle, & Strauss, 2008; Bodzin, 2008; DeMers & Vincent, 2007; Doering & Veletsianos, 2007). The complexity of the technology, however, has hindered widespread acceptance and only a limited number of students have access to the technology (NRC, 2006). Researchers and practitioners have found that existing GIS software packages (such as *ArcView*) are very difficult to use as general educational tools for the K-12 context. In particular, the National Research Council (2006) noted that the practical problem of adapting GIS in its current desktop-based form to the K-12 environment is immense. As argued by the NRC, current GIS technologies are expert-based, "industrial strength" technologies that are inviting because of the potential for engaging students in authentic science yet are difficult to learn and challenging to install and manage in most school computer laboratories. Through the implementation of our program, we have found this to be all too true; however, we have also found that an immersive professional development program appears to offer great promise in helping to improve teachers' ability to use and implement geospatial technologies. To that end we now believe that professional development programs that focus on the use of geospatial technologies should have:

1. Scaffolding of the curriculum to anticipate what might go wrong with the technology and troubleshooting hints and strategies to assist with potential technological problems and provide teachers experience in solving these problems within the professional development experience.
2. To learn how to use GIS, in particular, a professional development needs to be immersive and not just a series of workshops.
3. A learning trajectory that starts teachers at lower level, introductory geospatial technologies such as Google Earth and supports their progress toward more sophisticated geospatial tools such as CityGreen.
4. Opportunities for teachers to work with students to conduct geospatial analyses as this appears to be critical to enhance teachers' self-confidence and ability to conduct scientific-inquiry investigations. However, there needs to be a balance for teachers for opportunity to reflect, revise, and learn from the experience with students during a program like ours.

We have found the design and implementation of our program challenging, rewarding, and enlightening in regard to how to support teachers in implementing cutting edge technologies to teach students scientific concepts. We hope that our growing pains, the lessons learned along the way, and the work of others in this volume provide some insight regarding how we can develop effective programs to support teachers in using geospatial technologies in the coming years.

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Chapter 3
Field-Based Research Partnerships: Teachers, Students, and Scientists Investigate the Geologic History of Eastern Montana Using Geospatial Technologies

Heather Almquist, Lisa Blank, Jeffrey W. Crews, George Stanley, and Marc Hendrix

Keywords Field work • GIS • Google earth • Paleontology • Scientific inquiry

3.1 The Paleo Exploration Project

The Paleo Exploration Project (PEP) was a University of Montana (UM) professional development program serving K-12 teachers from eastern Montana. This area encompasses approximately 75,000 mile^2 of open plains east of the Rocky Mountains. Substantive professional development opportunities for K-12 teachers have been historically scarce in this region and area schools face chronic fiscal challenges. Therefore, PEP strove to implement trainings locally and to craft the science component around a scientifically compelling and regionally significant resource – 65-million-year-old fossils.

Eastern Montana is one of the most fossil-rich areas in the American West. The area contains extensive Upper Cretaceous rocks representing terrestrial environments with interlaid units of marine sediments that were deposited in the Western Marine Seaway during cyclic sea-level fluctuations. Local sedimentary units include terrestrial floodplains, lakes, rivers, beaches, and ocean environments (Weimer, 1960). These units have not been deformed by tectonism and thus remain in relatively horizontal layers that have been subsequently eroded by wind and water into magnificent badlands. Exposed rock faces reveal telltale sedimentary structures and fossils, including marine invertebrates, both marine and terrestrial reptiles (i.e., dinosaurs), and a wide variety of plants. Thus, the region provides a perfect setting in which to demonstrate principles of stratigraphy, paleontology, and environmental reconstruction,

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and a compelling backdrop for incorporating the use of geospatial technologies in authentic scientific inquiries into the spatial and temporal dimensions of earth history, earth surface processes, and the evolution of life.

The primary goal of PEP was to prepare a core group of K-12 teachers to use geospatial technologies and inquiry-based approaches to teach science, math, and technology content to their students. Project objectives deriving from this goal included (1) increasing teachers' skill and confidence in using geospatial technologies, including GPS, Google Earth, and GIS; (2) increasing teachers' understanding of the process of science; (3) preparing teachers to develop and implement age-appropriate, technology-embedded, inquiry-based learning activities in their own classrooms; and (4) developing a transferable approach for professional development initiatives with similar goals. In addition, the project sought to help develop a community of learners in the region to provide peer-to-peer support in furthering the use of geospatial technologies in K-12 education.

The project relied on peoples' almost universal fascination with fossils to attract program participants. It also provided teachers with travel reimbursements, GIS software and video tutorials, loaner GPS receivers and cameras for school projects, and continual online technical support. Teachers received modest stipends and graduate credit for successful completion of project components.

Two cohorts of 25 teachers each completed the program. Each cohort was engaged in the training for 12–18 months. The program began with several 2-day teachers' weekend workshops during the spring semester. The following summer, teachers attended a weeklong summer research institute with middle-school-aged students. Over the next academic year, teachers took part in a final weekend workshop and developed, and in most cases implemented, their own learning activities with their students.

The project was originally aimed at middle-school science teachers from northeastern Montana east of Havre along the so-called Montana Hi-Line (Route 2). This area includes three Indian reservations (Rocky Boys, Fort Belknap, and Fort Peck), as well as many other small, rural schools. However, during the recruiting effort for Cohort 1, several high school and lower-level teachers asked to participate and were admitted into the program as space allowed. For Cohort 2, it was necessary to increase the recruitment effort to include all Montana K-12 teachers east of the Continental Divide in order to attract enough participants from eastern Montana's small, isolated schools. Thus, Cohort 2 included teachers from schools serving two additional Indian reservations (Crow and Northern Cheyenne), a Hutterite colony, and a Billings suburb, as well as numerous other small, rural schools.

For both cohorts most teachers came from schools with fewer than 50 pupils. Most taught multiple subjects and several grade levels, many in combined classrooms. One participant served as guidance counselor in a tribal school. Each cohort included teachers with a broad range of scientific background and technical abilities.

Project staff included University of Montana faculty, professionals, graduate students, and undergraduates in paleontology, sedimentology, paleoecology, and education. The staff conducted the teacher workshops and facilitated research conducted by teachers and students during the summer institutes. This research focused on investigating the nature of the ancient environments of eastern Montana and discovering fossils of scientific value using geospatial technologies and standard geological and paleontological techniques. Project leaders also coached teachers in the design of classroom projects and offered ongoing technical support.

3.2 Theoretical Framework: Design Experiments

Brown (1992) defines design experiments as "to engineer innovative educational environments and simultaneously conduct experimental studies of these innovations." Design experiments begin with conjectures about learning that are based in educational research, theory, or practice. These conjectures form the basis of the design innovations. Learning or outcomes relating to each intervention are traced, and lessons learned are then cycled back into the next iteration of interventions (Barab & Luehmann, 2003; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003).

Design experiments have been shown to effectively promote innovative educational practices in the classroom by bridging the persistent gap between well-established theories of science learning and school practices and by supporting "flexibly adaptive curricular interventions" (Barab & Lehmann, 2003, p. 460; Cobb et al., 2003). An important goal of PEP was to promote an expanded use of innovative geospatial teaching strategies by K-12 teachers teaching across traditional school content domains and in a wide array of school environments. To accomplish this, the project design needed to anticipate, adjust for, and support a wide range of teachers' needs and local curriculum adaptations (Trautmann and MaKinster, 2010).

Project leaders had significant previous experience in providing professional development in geospatial technologies to K-12 science teachers, including coaching teachers in classroom project development and implementation. Based on this experience, PEP teachers were expected to be capable of mastering basic mapping and analysis skills in GIS. Further, hands-on experience conducting research together with practicing scientists was expected to instill in teachers an understanding of scientific ways of thinking and inquiry-based approaches.

Previous studies have shown that teachers most likely to use inquiry approaches in their classrooms "were individuals who had significant undergraduate or professional experiences with authentic science research" (Windschitl, 2003). Authentic research experiences with scientists have been shown to increase teachers' understanding of the nature of science, self-efficacy in science, time spent on science teaching, and communication with students about the roles of scientists (Dixon & Wilke, 2007). A related conjecture was that giving teachers the opportunity to work with students as part of the professional development program would help them gain skill and self-confidence, better preparing them to attempt new approaches in the classroom.

However, PEP leaders were aware that the unique demands on participating teachers stemming from teaching in small, isolated, underserved schools might require adaptations to the curricula that had been used in other programs. It was anticipated that adaptations to the scope, level, pace, and schedule might be required "on the fly" as the first cohort of teachers proceeded through the program and project staff evaluated their progress. A final round of adaptations would be made for the Cohort 2 program based on data collected during and after the Cohort 1 activities. These data included:

- Teacher program applications outlining various aspects of their professional preparation, access to and experience with technology, and teaching environment
- Retention rates of teachers in the program
- Observations made by PEP staff during workshops and institutes
- Teacher responses to anonymous post-workshop and post-institute surveys
- Assessment of completed homework assignments
- Interviews and classroom observations conducted by external evaluators
- "SCOOP" notebooks containing the daily lesson plans, teacher's reflections, photographs of project activities, and examples of students' work (Borko, Stecher, & Kuffner, 2006)

3.3 The PEP Cohort 1 Program

3.3.1 Cohort 1 Spring Teacher Workshops

In the first iteration of the program, PEP leaders offered two weekend teacher training workshops during the spring semester. Workshop 1 was held in February 2007. On Day 1, teachers received an introduction to the PEP program, PowerPoint presentations on fossil preservation and use as environmental indicators, a fossil preparation demonstration, and a hands-on exercise exploring the concept of speciation. The geosciences lectures and activities were derived from upper-level college paleontology courses. On Day 2, an introduction to Google Earth was given using a generic tutorial developed through previous projects. GIS was introduced using animated tutorials designed by project staff and general examples of data analysis from a GIS Tutorial (Gorr & Kurland, 2005). Teachers were assigned an exercise out of that text as a homework assignment.

Of 29 participants responding to the post-workshop survey, 27 responded that the workshop had met their expectations. However, 15 teachers noted concerns over the pace and/or level of content for both the geoscience and GIS portions, and three teachers left the program. All remaining teachers were able to complete the GIS homework assignment. With these results in mind, adjustments were made to the Workshop 2 schedule to allow teachers more time to absorb the material presented.

Workshop 2 was conducted in April 2007. On Day 1 teachers were taught how to use GPS receivers using hands-on instruction and a local geocache activity. This was followed by lessons on importing GPS points and creating placemarks in Google Earth. Day 2 was dedicated to map making using ArcMap. The assignment involved a mock "planning your dig" exercise to help teachers understand how GIS might be used to prospect for fossil deposits. Teachers were assigned a second exercise from Gorr and Kurland (2005) as homework.

In the post-workshop survey only 7 of 25 respondents noted concerns about the pace of instruction or difficulty with grasping the geospatial technology content. Four teachers commented on technical problems encountered during the workshop, but most reported no weaknesses in their workshop experience. Still, two additional teachers dropped from the program. Those remaining were able to complete the GIS homework assignment.

In interviews conducted by the external evaluators, teachers stated that they appreciated the technology training they received in the weekend workshops and the tutorials provided to use at home. One teacher commented on the pride felt in learning to use new technology. Another stated, "It's opened my eyes as far as the technology to use. It's endless as far as what you can use in the classroom." Many of the teachers had had some exposure to GPS tools, but only a couple had really used it with students. Two of the teachers discussed the pragmatic issues of using technology back in the classroom. This included having a variety of equipment, training students on using different types, and having time to use the equipment in class. However, they knew that The University of Montana would loan them a classroom set of GPS receivers if they requested them. It was also pointed out that for non-technology-experienced teachers, PEP can be very difficult. A suggestion was made to have more self-paced tutorials.

3.3.2 Cohort 1 Summer Research Institutes

Two 8-day summer research institutes were held in Fort Peck, Montana, in June 2007. Two sessions were needed to provide adequate housing and supervision for participants. The institutes provided teachers with authentic research experiences in partnership with practicing scientists. This collaboration was intended to improve teachers' understanding of the process of science, fundamental earth science concepts, and the application of geospatial technologies in data analysis. The institutes also provided teachers an opportunity to test teaching approaches with middle-school-aged students who had been recruited from the region.

The Cohort 1 summer research institutes began with a one-day orientation for teachers. Students arrived on Day 2, and four research teams were established pairing three to four teachers with six to eight students. The teams spent 4 days working in an arroyo (an eroded basin) where, on a 2 h basis, they rotated through a series of research stations. Projects included the excavation of a site with abundant fossil plant material, excavation of a *Triceratops* "frill" or head shield, excavation of a bone bed with some *Tyrannosaurus rex* fossils, and measurement of several stratigraphic sections within the arroyo. GPS receivers, total stations (an optical instrument that combines an electronic transit, an electronic distance meter, and data collection software for precision surveying), digital cameras, video, and PDAs were used to record data and activities. Each team conducted a research project of their choosing related to one of the sites they had visited and followed a cycle of research from the development of a scientific question to the presentation of results. Teachers were responsible for directing students in their group, with university researchers providing demonstration and explanation as needed.

Teams had one day to examine their data and develop a PowerPoint presentation on their research problem, working hypothesis, data collection and analysis, and final conclusions. With students taking the lead, each group presented its work to peers, university staff, and parents, on the final day of the program.

3.3.3 Findings from the Cohort 1 Summer Research Institutes

Throughout the institutes, project staff observed that some teachers were becoming stressed both physically and emotionally. Field conditions were far more strenuous than many participants were accustomed to. Several groups appeared to have had a difficult time defining a scientific question without more background knowledge regarding the topics and study sites. Some teachers expressed concern about what was expected for their projects and how they would affect their course grade. Several groups were able to use Google Earth in their analysis, but the time and computer facilities available were insufficient to include much GIS. Consequently, the PowerPoint presentations varied in depth and quality.

Twenty-four teachers responded to the Cohort 1 summer institute exit survey. The hands-on nature of the experience and working with students in an out-of-school environment were highly praised. When asked about program weaknesses, two teachers mentioned needing more background information on geology and three expressed disappointment that GIS was not emphasized enough. Other comments centered on minor logistical issues.

Six randomly selected teachers were interviewed by an external evaluator. These interviews probed more deeply into the nature of the summer institute's impact on teachers' understanding of the nature of science. According to the evaluators, "All of the teachers saw themselves 'doing science' and asking scientific questions. A few commented that they were still learning about asking scientific questions. They learned that asking focused questions based upon the data was not simple. A variety of questions could be asked and that knowing which ones to follow up on, especially with limited time, was not easy". One teacher commented that they kept changing the hypotheses they had as they dug and found new plant fossils; "Some people spend 15–20 years studying a lot simpler system than this, …tons simpler." Another commented that they were "prepared for the students so that we could recognize good science questions when they arrived."

An important consideration was learning if the teachers felt that they had enough background to answer the scientific questions they were asking. The general answers were "yes," but, as described previously, it was clear to the teachers that some of their questions were complex and would take much more research to answer. Also, some teachers felt they did not have enough training in Google Earth, for example, to use it to answer their question or to analyze the data.

In terms of fieldwork, most felt that they were able to use the technology needed during the work and in their basic data analysis. One area of concern was expressed with the complexity of GIS systems in general and entering data into these systems.

A series of questions were asked on what teachers learned about designing research (sampling) strategies, preparing for fieldwork, collecting and recording data, analyzing results, and presenting and interpreting results. The teachers were given a "crash course" on multiple topics and enjoyed it. They realized that there were many things that they did not know, but that they were able to conduct scientific research in the field and were able to support the students in their group. Teachers were impressed with how the technology, including the total stations, GIS, and GPS, supported the research.

The teachers felt that they were prepared to collect and record data and that the students were also trained in the importance of this aspect of conducting research. In analyzing data, the comments were very specific to tasks their groups were working on. Some commented on the complexity of their specific site and task and the need to conduct more fieldwork to have a better understanding of their data. The teachers' thoughts on presenting and interpreting results were mixed. This resulted from the complexity of some of the sites, using Google Earth and GIS, and in the amount of available data, which ranged from a great deal to not enough to answer their questions.

All of the teachers felt that they would be able to take something back to the classroom. The evaluator found that in a variety of conversations (i.e., beyond the formal interviews) with the teachers, they said they would be able to adapt and use what they had learned, although for many of them paleontology was not the vehicle they would use to teach inquiry or use the technology they had learned to collect and analyze results. They were clear that this experience was positive and would affect their teaching and their students' learning. Some of the teachers discussed that some of their own students were attending one of the two summer institutes and that the students were an additional resource they could use in their classrooms and in their schools.

During conversations the evaluator had with the teachers during 3 days onsite, a number of recommendations were made. Many of them revolved around the actual organization and schedule of the summer research institute and where possible and appropriate, the project staff made those changes. Regarding the program curriculum, teachers noted that ArcView, and to a lesser extent Google Earth, requires a great deal of time and training for teachers to learn to use. Most of the teachers did not feel that they had had enough training in them to actually use them. A couple of teachers suggested additional training and/or tutorials be made available.

3.3.4 Cohort 1 Final Workshop

A final weekend workshop for Cohort 1 teachers was held in Missoula, Montana, in August 2007. Teachers spent one day touring the University of Montana Paleontology Center fossil collections, research database, and fossil preparation facilities and one day receiving technical assistance in planning their classroom projects. Unfortunately, local forest fires made it impossible for key PEP staff to attend the meetings. The post-workshop survey revealed that teachers gained little from these activities and travelling 6–10 h to attend a workshop was not well received.

3.3.5 Cohort 1 Classroom Projects

During the following academic year, teachers created learning activities for their own classrooms using an online template. The template included essential, unit, and content questions, unit summary, subjects and grades covered, description of target class, student learning objectives, educational standards addressed, instructional procedures, resource materials, prerequisite skills, student assessment, and teacher reflections. Teachers were encouraged to work together on projects as appropriate, in order to promote peer-to-peer mentoring and support. Each teacher or group of teachers submitted a draft activity and received feedback from project staff. Following these reviews, the teachers revised and submitted their units for grading.

During the unit development process, some teachers expressed uncertainty about how to use the template; that is, they did not understand what they should be writing in the various sections. Others had difficulty with the online environment and several requested assistance in identifying and/or downloading data sets. All but two of the teachers successfully created projects. Of those, all but one, which was developed by a teacher who moved to a new school, were implemented. Of the 15 projects completed, 14 used GPS, 13 used Google Earth, and 10 used GIS. When asked how frequently they would use the tools, knowledge, and concepts acquired from PEP, 75 % of the teachers stated they would frequently use them or integrate them throughout their teaching, while 25 % stated they would use them infrequently or not at all.

3.4 Summary of Design Adaptations

Following the design experiment approach, data collected during implementation of the Cohort 1 program were used to make adjustments in Cohort 2 activities. Both teachers' self-reported impressions and objective analysis of teachers' work refuted some of the project leaders' initial conjectures about teacher readiness to conduct graduate-level academic work. Results clearly indicated that PEP teachers needed much more remedial training in computer technologies and more elementary introductions to spatial technologies in order to feel comfortable with them. Many were hesitant to use GIS in their classrooms; they gravitated toward the simpler technologies.

Further, the conjecture that teachers would be able to "absorb" understandings about science simply from working alongside research scientists for a short period

Table 3.1 Key project objectives and related design adaptations

1. Increase teacher skill and comfort level with geospatial technologies
Expand introduction of more intuitive technologies (Google Earth and GPS) prior to initiating geospatial training with GIS
Provide increased hands-on practice, through GPS units to take home after Workshop 1, and step-by-step instructions for later use
Provide a more seamless integration of the geospatial training experiences with the project's geological research agenda, by crafting GIS exercises around analyzing relevant geospatial data to help select potential study sites for summer research activities
Improve computer facilities at the summer institutes, including a large-format plotter for making professional quality maps of research sites
Increase time during institutes for data analysis and map making
2. Increase teacher understanding of the nature of science and inquiry
Add a third teacher weekend workshop to prepare for the summer institute
Shift summer research activities toward guided, rather than open-ended, inquiry
Provide suggestions for potential summer research projects to allow teachers to collect background information prior to the institutes
Shorten summer institutes from 8 to 7 days each to avoid teacher burnout
3. Better prepare teachers to introduce new approaches in the classroom
Shift course emphasis from paleontology techniques to geographic analysis.
Add a new course book: "*Understanding place: GIS and mapping across the curriculum*" (2006) by Sinton & Lund to demonstrate GIS applications across range of disciplines
Initiate teachers' development of learning activities immediately following the first workshop
Provide a simplified online template for lesson plans with embedded examples
Increase time allotted for teachers to collaboratively develop teaching modules for use with the students during the summer institute, and place teachers in charge of conducting the activities they developed
Include teachers' written reflections on their individual and groups' experiences teaching the student orientation and conducting field-based research projects
Provide a host of online resources for classroom use
Increase individualized critique of classroom project plans and assistance with identifying data resources
4. Strengthen the PEP community of learners
Increase group work at workshops and institutes and further encourage collaborative classroom projects.
Replace August workshop at UM with a spring 2009 teachers' symposium in eastern Montana to share classroom projects and experiences.
Increase time allotted throughout the program for teacher networking

of time was unrealistic. Many struggled with open-ended scientific inquiry, finding it difficult to formulate viable scientific questions. A more guided approach to the research would be required. On the positive side, the hands-on nature of the course activities, including working with students as part of the professional development experience, had clearly boosted PEP teachers' perceived abilities and self-confidence in using geospatial technologies and inquiry approaches in the classroom. Still, adaptations were sought to increase these benefits. Table 3.1 outlines four improvements that PEP leaders wanted to make and the adaptations implemented in the Cohort 2 program to achieve these objectives.

3.5 The PEP Cohort 2 Program

The design adaptations listed above were systematically integrated into the PEP Cohort 2 curriculum.

3.5.1 Cohort 2 Spring Teacher Workshops

During Workshop 1, teachers received content instruction in the paleogeography, geologic formations, and fossil assemblages of eastern Montana. They examined typical fossils, arranged by geologic formation, to begin familiarizing themselves with what they might see in the field. They were introduced to Google Earth (GE) in the context of locating and mapping facilities that they would be using during the summer institutes (e.g., the computer and science laboratories, residences, and lecture hall). They were introduced to GPS receivers through a hands-on geocache activity, learned how to upload GPS data into Google Earth, and created and formatted placemarks of the local sites they had visited. For their first assignment, teachers were asked to create a sample learning unit for their students using Google Earth and an inquiry approach. All were able to accomplish this, submitting projects on a broad array of topics.

Post-workshop surveys indicated that teachers were very happy with the hands-on activities using the technology as well as with the prepared instructions and classroom resources made available to them. Only four of 24 respondents expressed concern over the pace and level of the instruction, and several were concerned about finding adequate time outside of class to practice what they had learned.

In Workshop 2, project leaders introduced ESRI ArcGIS 9 (ArcMap Version 9.2 and ArcCatalog; Gorr and Kurland, 2007). They demonstrated how spatial data can be found or created, added to a GIS, edited, and analyzed. Teachers explored essential map elements and design considerations and were tasked with analyzing GIS layers of geology, topography, land ownership, and road access to create maps of geologic formations for the summer research area and to predict where specific types of fossils might be found. In this manner, GIS was introduced as an analytical tool in the actual planning of the summer research activities.

All teachers were able to produce a reasonable map. These were shared and discussed among participants. In the post-workshop surveys, teachers praised the hands-on activities with GIS and the competence and patience of the instructors. They especially liked being able to produce a useful product at the end of the workshop. Yet, almost half expressed frustration about feeling rushed through the mapping exercise.

Workshop 3 was used to reinforce concepts and skills required for the summer field sessions. Project leaders modeled how to measure sediment stratigraphy, survey and identify fossils, use digital cameras and field notebooks, mark waypoints and tracks with GPS receivers, operate a total station, and upload data into ArcGIS 9.2. Project staff also reported on a recent expedition to the research area, in which they had narrowed down the teachers' prospective study sites based on field reconnaissance.

Teachers also collaboratively developed lessons to introduce students attending the summer institutes to relevant concepts and skills. Topics included the rock cycle and rock classification, the fossilization process and various types of fossils, GPS and how to use a GPS receiver, and GIS and types of maps that can be generated. The intent of this design component was to consolidate the teachers' content knowledge and build confidence in their newly acquired geospatial technology skills.

Post-workshop surveys results showed that time spent preparing for the summer institute, hands-on activities, and group work were well received by teachers. Several expressed desire for more time to do the activities and a few stated they were anxious to test their skills on actual field sites.

3.5.2 Cohort 2 Summer Research Institutes

The Cohort 2 summer research institutes were held in July 2008. On Day 1 teachers attended an orientation led by project staff covering a technology review and preparation for the student orientation. On Day 2 students arrived and attended an orientation in which teachers presented the mini-lessons that they had prepared during Workshop 3 and gave students a tour of the research facilities. Days 3–7 consisted of field- and laboratory-based researches. Each team partnered with a different research scientist each day, rotating through a series of activities, including (1) examining outcrops of local geological formations, each of which represented a different paleoenvironment evidenced by diagnostic sediment structures and fossils, and determining the environments and ages of the formations based on observations; (2) helping to excavate a *Triceratops* head shield and attendant plant fossils, including jacketing the shield with plaster and burlap for removal from the site; and (3) mapping and interpreting sediment stratigraphy of an ancient river deposit in an exposed bluff using total stations, GPS, and sedimentological data.

Each team also spent two mornings and two afternoons in a GIS laboratory, which was equipped with a computer for each student and ample table space to sort out fossils. There, students analyzed data, developed PowerPoint presentations, and produced GIS maps illustrating the spatial extent of the various formations and study sites of interest using the large-format plotter. Presentations were conducted on the final day of the program.

3.5.3 Findings from the Cohort 2 Summer Research Institutes

Toward the end of the first session of the institute, 11 teachers were interviewed by an external evaluator. In addition, 14 of the 25 teachers responded to the post-institute survey.

Cohort 2 teachers were very positive about the institutes. In the interviews, they talked about hands-on experiences, technology training and use, interactions with the scientists, and using their acquired knowledge and skills with students. According to the evaluators, "the issues from the first summer institutes were not apparent" for Cohort 2 participants, suggesting that the changes made, including both teacher preparation for the institutes and the specific study sites, activities, and schedule during the institutes, created a superior learning environment. Nevertheless, post-institute survey results show that for some teachers, more time to complete the activities and after-hours computer access could have further improved the experience.

Teachers completed reflections on their experiences teaching the student orientation activities that they had designed, as well as their group's research project. All teachers reported success in their teaching efforts but almost all also reported unforeseen situations in the activities that they would adjust for in the future. Teachers overwhelmingly reported that students had benefited from the learning activities and that the final PowerPoint presentations were unable to fully convey the breadth and depth of student learning. Affective aspects of the program that teachers felt were not reflected in the final projects included (1) experience with fieldwork, including actual application of field techniques and technology, (2) working as a research team, (3) role models and what it is like to be a scientist, and (4) friendships the students made. The following excerpt from one group's final reflections is fairly typical:

1. **How well do the materials you are presenting depict student learning?**
   Our projects were generated with collaborative efforts of both students and teachers. The students' thoughts and efforts were foremost considered. The students' knowledge of the programs used to produce the map and PowerPoint was diverse. Therefore, we utilized their abilities and encouraged growth through hands on experience with each program. Adjustments were constantly made to reflect their abilities. We wanted these projects to belong to them and for each student to take pride and ownership of the finished product.
2. **If you wanted someone else to understand your experience, is there anything these materials do not reveal about your experience that you would want to include?**
   The projects definitely reflect our knowledge of the programs used and the research that we did. However, they do not include the personal growth that we gained through staff, teacher and student interactions. These personal interactions were definitely a learning experience also. Our projects cannot express the experiences we had out in the field, nor the valuable lessons we learned from the students. The time spent with the students, both in the field and out was a learning experience that cannot be reflected in a map or PowerPoint.

Thus, the incorporation of students into the teacher training experience appears to have been particularly significant for many teachers, allowing them the opportunity to experiment with their own ideas and determine those things to which students would respond best.

In comparing the summer institute learning activities with their typical instruction, all teachers reported significant departures in at least one area (i.e., technology use, hands-on approaches, outdoor activities, group work, inquiry approaches). When asked what, if anything, from these activities would they want to bring back to their own classrooms, all teachers noted wanting to include one or more aspects of the program, with most teachers mentioning geospatial technologies and science content.

However, many teachers foresaw specific barriers to implementing their classroom projects. Teachers anticipated that technology, including access to computers, adequate bandwidth, and technical support, would pose a significant barrier to implementations. Time to teach new skills and to engage students in longer-term projects was also reported as a concern. In addition, several teachers expressed a need to practice more with ArcView, and a few teachers discussed school- or class-specific barriers.

These results contrasted with information provided by the teachers in their program applications, in which both Cohorts reported that access to software and training, followed by access to GPS units, were the biggest limitations for participating teachers in the infusion of GIS into their teaching. Almost all teacher participants reported having access to computers and internet at school. One explanation for this discrepancy is that prior to participating in the program, teachers were likely unaware of how computer-intensive geospatial technologies are and overestimated their school's capacity to meet these needs.

3.5.4 Cohort 2 Classroom Projects

All Cohort 2 teachers are able to develop their own technology-embedded, inquiry-based lessons for their classrooms. They were provided a simplified online template and many sought advice from project staff and were able to enhance their projects through several iterations. Of 18 projects created, 15 incorporated GPS, 8 used Google Earth, and 15 used GIS technology. Despite the teachers' concerns, most were able to implement their units effectively, either as replacement, supplemental, or after-school curriculum.

3.5.5 Cohort 2 Teachers' Spring Symposium

A fourth weekend workshop was held in the April 2009. PEP teachers formally presented their curriculum implementation projects, shared successes and challenges, and offered each other advice. This additional workshop was identified by teachers as playing an important role in advancing their curriculum work and solidifying their commitment to maintaining a community of learners beyond the life of the PEP project.

3.6 Outcomes

The primary goal of PEP was for participating teachers to understand how to use geospatial technologies and inquiry approaches and to demonstrate the ability and willingness to meaningfully integrate these technologies and approaches into their teaching.

3.6.1 Skill and Confidence Using Geospatial Technologies

This was accomplished at some level for almost all PEP teachers. Their curriculum projects spanned grades 3–12 and included life, physical, earth or environmental sciences, and social sciences, as well as math. It is notable that the majority of the curriculum projects moved students beyond making maps to using spatial data to analyze and interpret patterns. This is a significant indication that teachers not only developed students' geospatial technology skills but were also able to create opportunities for students to apply these tools in making data-driven decisions.

Further, PEP project leaders' improved understanding of teachers' needs, and subsequent program design adaptations resulted in measurable differences in teachers' capacity to design and implement geospatial learning activities for their students. Table 3.2 summarizes the percentage of projects incorporating the various geospatial technologies for each cohort.

These results demonstrate a shift from a heavy dependence on GPS and GE by Cohort 1 to an equal distribution of GPS and GIS in Cohort 2 projects and a much greater integration of GIS, suggesting that the design iterations did help facilitate teachers' ability to incorporate more sophisticated geospatial technologies such as GIS into their teaching. These results are particularly notable when looking at the grade bands represented for each year. A majority of the Cohort 1 teachers taught 7–12th grade, whereas Cohort 2 included a heavy representation of elementary teachers. In Cohort 1, there was only one project below the middle-school level (grade 5), and it was developed by a technology teacher. In Cohort 2, seven of the projects were in grades 3 through 5 and all but one of these used GIS. The following are outlines of typical examples of Cohort 1 and 2 projects, both developed for 8th grade science classes.

Cohort 1: Students use GPS receivers to mark the school bus routes for their school. They then download the GPS information into Google Earth and create a map of the routes, adding placemarks with appropriate information. Using the map route feature in Google Earth, students test to see whether alternative routes might save driving time. They present their final maps and recommendations to the school bus supervisor and school administration.

Cohort 2: Using ArcMap, students track historical changes in a local wetland and surrounding uplands using historical maps and photographs, National Wetlands Inventory maps, and original data collected by students. Potential causes of changes in the lateral extent of the wetland, including local land-use practices and irrigation, invasive species, and regional climate change, are considered.

Table 3.2 Percentage of classroom projects incorporating GPS, GE, and GIS by cohort

	GPS (%)	GE (%)	GIS (%)
Cohort 1 (15 projects)	93	86	67
Cohort 2 (18 projects)	83	44	83

3.6.2 Understandings About the Nature of Science and Inquiry

The previous examples also point to an increase in sophistication of the "scientific questions" being asked. Cohort 1 teachers tended to frame their learning activities around questions related to the technology itself, rather than questions exploring content (e.g., "How can technology be used in mapping?"). Others asked content-driven but unscientific questions (e.g., "How can students learn about community history in a meaningful way?"). Others asked more scientific questions but failed to relate their significance (e.g., "Are the fossils in [X] County found in the same stratigraphic layer?"). Only three Cohort 1 projects were prefaced with what the project leaders considered sound scientific questions (e.g., "What are the primary factors affecting the spread of noxious weeds in [X] County?").

In contrast, half of the Cohort 2 projects stemmed from sound scientific questions (e.g., "What is the relationship between geologic formation and soil type?" "Do land use practices in [X] County differentially affect field use by mule deer and white tailed deer?" "Does European Buckthorn adversely affect riparian habitat in Montana?" "What impact, if any, do a water treatment plant and municipal golf course have on [X] Creek?" "How does soil type affect septic system function?" "How does population density affect presidential election outcomes?"). This outcome is especially notable given that many Cohort 2 teachers taught lower grades and needed to use age-appropriate questions. For example, a 3rd grade class explored "How big is our town? Is it bigger than [X] City?" and a combined grades 2–5 class asked: "What data or artifacts would explorers need to collect and record to provide a comprehensive understanding of the area of exploration?" These results likely point to the success of the design adaptations implemented for Cohort 2, although true cause and affect cannot be determined given teacher variability within a small sample size.

3.7 Conclusions and Recommendations

The use of a design experiment theoretical framework allowed project leaders to systematically identify deeper understandings of the range and diversity of teachers' needs and to implement appropriate project adaptations. Significant programmatic changes were made between Cohort 1 and Cohort 2. The effects of these changes are evidenced in the level of GIS integration and sophistication of science questions in the curriculum developed by teachers. Another set of design adaptations, including (1) additional hands-on practice with the technologies, (2) a curriculum component targeted more directly on scientific inquiry, and (3) more practice with project design, would almost certainly improve outcomes further. However, such adaptations would be nearly impossible to realize given the time pressures already faced by teachers in this educational landscape of small, isolated, rural schools.

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Chapter 4
Meeting Teachers Where They Are and Helping Them Achieve Their Geospatial Goals

Nancy Trautmann and James MaKinster

Keywords Technological pedagogical content knowledge • Learning community • Flexibility • Self-confidence

4.1 Introduction

The purpose of using GIS or other geospatial technology in science teaching is not simply to train students in how to use the software but rather to enable them to learn science through analysis and synthesis of complex spatially oriented datasets. Teacher professional development focusing on this type of learning needs to provide not only training in how to use relevant hardware and software but also ample opportunity for teachers to explore how best to use geospatial technology to enhance the ways in which their students learn desired content (Coulter & Polman, 2004; McClurg & Buss, 2007).

GIT Ahead was a 3-year project funded through the National Science Foundation's Advanced Technological Education program. (GIT stands for geospatial information technology). The project focused on equipping secondary teachers with technological skills and helping them to develop and implement plans for incorporating geospatial technologies into their science teaching. Unlike professional development aimed at preparing teachers to use a specified curriculum, GIT Ahead aimed to meet teachers

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where they were and assist them in developing the technological competencies, resources, and confidence needed to attain their individualized curricular goals. Each year, up to 20 secondary teachers were recruited from the 15-county Finger Lakes Region in central New York State. Each cohort of teachers had a broad range of teaching responsibilities, ranging from 6th through 12th grades, remedial through advanced placement levels, and subjects including earth science, biology, environmental science, and a variety of electives. GIT Ahead teachers not only taught a wide range of students, they also brought to the program a diverse range of expertise with regard to geospatial technology. While some had had no prior experience using such technology, others had various skill levels and joined the project for the opportunity to focus on technology-enhanced curriculum development within a supportive environment. Because GIT Ahead aimed to meet a broad range of interests and needs, geospatial lessons representing a variety of content areas were introduced during professional development sessions. Teachers selected from these lesson plans and adapted them to suit the level of conceptual understanding and technical analysis appropriate for their courses and students.

GIT Ahead began each year with an 8-day summer institute, during which secondary science teachers learned how to investigate local and regional environmental issues using global visualization tools, GPS, GIS, and related technologies. The teachers were provided with GPS units, GIS software, and a variety of print and electronic curricular resources. Ongoing support was provided through 6 Saturday workshops throughout the academic year, along with virtual office hours and individualized assistance as needed. For some of the winter workshops, connecting via web conferencing was offered as an option to reduce the need to travel in potentially inclement weather. The summer institute and Saturday workshops introduced the teachers to examples of technology-enhanced activities through which specific scientific topics could be taught. Some of these lessons were selected from published resources (e.g., Malone, Palmer, Voigt, Napoleon, & Feaster, 2005), and others were developed by project staff (Wilson & MaKinster, 2008). Roughly one third of the summer institute and half of each 6-h Saturday workshop were reserved for teachers to plan and prepare their individualized curriculum projects, with individualized technical and curricular guidance as needed.

One incentive for ongoing participation throughout the school year was the option for teachers to earn graduate credit for preparing, implementing, and reflecting on GIT Ahead curriculum projects. Another incentive that teachers reported valuing highly was the chance to continue reconnecting with supportive colleagues and project staff. Each Saturday workshop included time for group reflection on successes and challenges the teachers were experiencing in implementing their projects. These frank and supportive discussions helped to build a tightly knit professional learning community. Despite wide variance in the teachers' technical skill and teaching responsibilities, they faced similar challenges in learning complex technologies and striving to fit new ideas into the highly constrained environments of secondary science classes. Major challenges extended beyond the large amount of time required for development and implementation of new curriculum projects, for example, also including school-specific hardware and software limitations, regulations, and scheduling difficulties. Successes that the teachers shared included satisfaction with finding ways to work around obstacles and excitement about seeing their students' reactions to learning science in new ways.

Anonymous web-based questionnaires elicited feedback from teachers at intervals throughout the summer institute and at the conclusion of each Saturday workshop. These questionnaires helped the project 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 their secondary science courses.

4.2 Theoretical Frameworks

4.2.1 Technological Pedagogical Content Knowledge (TPACK)

Defined by Mishra and Koehler (2006), TPACK refers to the ability of a teacher to integrate technological understandings and skills with knowledge of how to teach specific subject matter. This specialized form of knowledge is represented by the area formed through intersection of three circles representing pedagogical knowledge, content knowledge, and technical knowledge (Fig. 4.1a). The goal of GIT Ahead was to expand each teacher's TPACK through expanding both the extent of his or her technological knowledge and the extent to which this domain became integrated with the other two domains (Fig. 4.1b; MaKinster and Trautmann, Chap. 16).

Unlike most professional development programs, GIT Ahead did not specifically aim to expand teachers' pedagogical knowledge or content knowledge. For example, although project staff modeled inquiry and problem-based learning in curriculum produced and presented to teachers, workshops did not specifically focus on how to teach using these pedagogies. Similarly, although all of the activities presented during the summer institute and school-year workshops addressed specific science and/or environmental topics, these were presented as examples of potential classroom application of geospatial technology rather than as new content knowledge relevant to all teachers. Because the teachers taught a diverse range of courses, each lesson was directly usable by only a few, but the new tool or technique that it introduced was potentially adaptable for use by all. For example, the teachers learned how to overlay GIS layers in Google Earth in a lesson exploring the relationships between surface water acidification and bedrock geology. Although this topic was of direct relevance only to earth science teachers, biology teachers were able to apply the same overlay techniques to topics of relevance in their curricula.

Exposing teachers to multiple models of technology use enabled them to choose and adapt those they deemed best for meeting their classroom needs. In making such choices, teachers balanced personal interests with the curricular objectives of their department, district, or the state. Some chose to use provided lessons intact

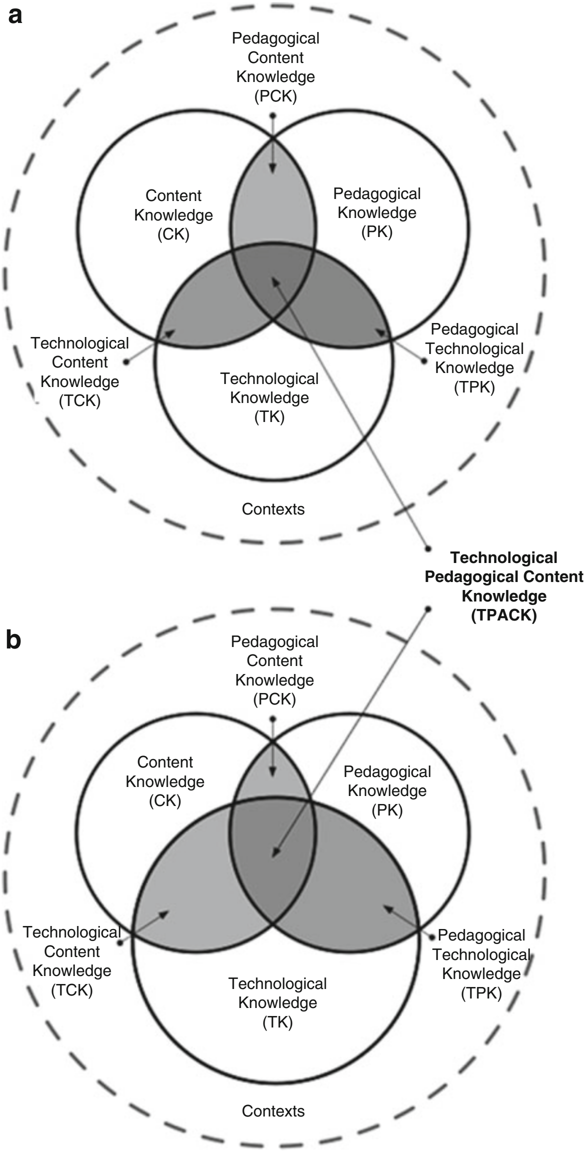

Fig. 4.1 (**a** and **b**) Technological pedagogical content knowledge with the three *circles* representing knowledge of technology, pedagogy, and content overlap to form a triangle representing TPACK

while others applied the demonstrated technological tool or technique to a different topic. For example, after seeing a Google Earth tour demonstrating local geologic features, GIT Ahead teachers created their own tours with which students explored everything from constellations in the night sky to biomes around the world.

4.2.2 Flexibly Adaptive Professional Development

In GIT Ahead, professional development was designed to meet the needs of a disparate group of teachers, providing each with the training, support, and resources necessary for success. Knowing that science teachers are likely to adapt curricula to fit the culture and context of their classrooms (Barab & Luehmann, 2003; Squire, MaKinster, Barnett, Leuhmann, & Barab, 2003), GIT Ahead supported teachers in a manner that enabled them to adapt their experiences and curricular goals to their individual needs and classroom contexts. The teachers were exposed to a broad range of technological tools and examples of curricular applications, and each teacher selected from a wide selection of options when deciding how best to integrate geospatial technology into his or her teaching. Teachers brought their talents, experiences, needs, and expectations to the program, and the project team strove to create opportunities that would enable each to design and implement lessons and units that entailed appropriate, context-specific strategies for integrating technology into their teaching. Each teacher identified a set of science concepts to teach using geospatial technology while also considering the time available for such efforts. Teachers then worked with GIT Ahead staff to articulate achievable objectives and create a unit outline, mapping a suitable structure and time line to meet their curricular goals. Projects created by the teachers ranged from choosing the optimal site for a wind farm in New York State to following the route of Charles Darwin's voyage.

Flexibility is a feature that we found crucial for supporting the needs of teachers with varying backgrounds and curricular mandates. In GIT Ahead, this flexibility took three forms: (1) we encouraged teachers to design their own implementation strategies rather than expecting uniform execution of a specified plan, (2) we provided individualized support to scaffold teachers' creation and implementation of technology-enhanced curriculum projects, and (3) we were willing to continually change the program based on feedback from participants. As discussed in Trautmann and MaKinster (2010), we coined the term "flexibly adaptive" to describe this approach to professional development. This term was built on the idea forwarded by Squire et al. (2003) of *flexibly adaptive curricula* as open-ended curricula with an easily adaptable structure that enables each teacher to tailor implementation in a unique way that responds to local needs. Extending this definition, *flexibly adaptive professional development* enables professional development providers to meet the individual needs of teachers from multiple grade levels and subject areas who are teaching a variety of classes. In place of a more standardized approach to building teachers' skills in teaching with technology, our approach is to meet the needs of teachers with widely ranging teaching responsibilities, curricular interests, and technological skills.

Effective professional development in support of teacher-designed geospatial curriculum projects must be flexible in the same manner that Brown (1992) outlines for "design experiments." According to Brown, effective projects focused on enhancing student learning involve carrying out design work, researching its implementation, cycling the findings into future design iterations, and then reexamining how these innovations affect the learning process. Extending this approach from student learning to teacher professional development requires willingness to change the nature, structure, and even the assumptions of professional development projects in response to cyclic evaluation data and ongoing experiences and reflections.

Note that our definition of flexibly adaptive professional development extends beyond the design of experiences for teachers to also include flexibility in expectations for implementation. Contrary to professional development approaches that call for implementation fidelity (Loucks, 1983; Penuel & Means, 2004), flexibly adaptive approaches support teachers in adapting curricular resources, materials, and technology to their individual needs and classroom context. Providing multiple tools and resources along with ongoing support enables teachers to develop ownership over the technology, the integration of new types of activities into their existing curricula, and the resulting student learning outcomes.

4.3 Developing a Professional Development Model Over Time

In GIT Ahead, the flexibly adaptive approach to professional development evolved over the course of the first summer institute. This first institute began with heavy emphasis on developing teachers' ability to make GIS maps and import various types of data. While the focus was not solely on the technology, the goal was to help the teachers become more adept in using ArcMap. Although most of the teachers persevered and successfully implemented geospatial projects in their teaching, the daunting challenge of mastering ArcMap initially made it difficult for them to integrate what they were learning with their pedagogical goals. As the first week of the summer 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. This new model was implemented throughout the remainder of the summer institute and subsequent school-year workshops, and it was refined considerably prior to the second year of the project.

In the second year of the project, the 8-day summer institute was split into two sessions, with 5 days in July and three in August. This gave teachers time over the summer to practice their technological skills if they so desired and to develop ideas for classroom implementation. Gathering for 3 days shortly before the fall semester gave them a chance to renew their skills, build their confidence, get help with questions, and spend time creating classroom-specific implementation plans.

In the second and third years, the project introduced new cohorts of teachers to teaching with geospatial technology by setting technological considerations aside and focusing first on potential applications of spatial data in science teaching and learning. Teachers worked in groups during the first morning of the summer institute to discuss an intriguing collection of paper maps and aerial images, collectively generating ideas for potential applications in their science classes. Rather than launching directly into learning how to manipulate complex geospatial software to make and use maps, the first software applications to which the second and third cohorts of teachers were exposed consisted of prepared curriculum units with straightforward directions. This approach modeled effective use of geospatial technology in science teaching by focusing primarily on subject matter rather than on the technology itself. Exploration of science-focused Google Earth tours provided another effective entry point helping teachers to envision potential applications of geospatial technology in their science teaching. Building on these initial experiences with user-friendly applications, teachers progressed to use of ArcExplorer Java Edition for Education (AEJEE) and ArcMap GIS software. These applications required greater technical skill but afforded greater capacity for analysis of user-entered data. Project staff helped teachers to place each software tool along a continuum representing complexity of use and ability to incorporate local data. Throughout the summer institute and school-year workshops, time was provided for sharing of ideas about possibilities for curricular implementation of each new tool or resource.

4.4 Evidence of Success

GIT Ahead's "flexibly adaptive" professional development model successfully met the needs of 6th–12th grade teachers with widely ranging technological skills and curricular responsibilities. Success of this approach was evident in growing commitment, skill, and pride of accomplishment on the part of teachers who made breakthroughs in use of the technology and applications to their teaching. Curricular mandates created widespread differences in the extent and manner in which geospatial technology could be integrated into various courses, but even under the most constrained circumstances, teachers managed to implement small projects. For some teachers, increased confidence and skill led to an increase in the extent to which they have been able to weave technological applications into their teaching. Several have become geospatial technology leaders in their schools or districts, and others have designed new science courses focusing specifically on use of GIS.

GIT Ahead teachers representing a broad range of backgrounds designed and taught technology-enhanced lessons and units for remedial through advanced secondary science courses. Not all overcame the inevitable hurdles and stuck with the program throughout the school year. However, those who did tended to grow in enthusiasm as they saw their students rise to the challenge of applying geospatial technology to analysis of relevant environmental issues. Most teachers applied geospatial technology in lessons lasting one month or less in the school year immediately following their participation in the summer institute (Fig. 4.2). Over the course of the 3-year project, declining numbers of teachers fell into the low-use

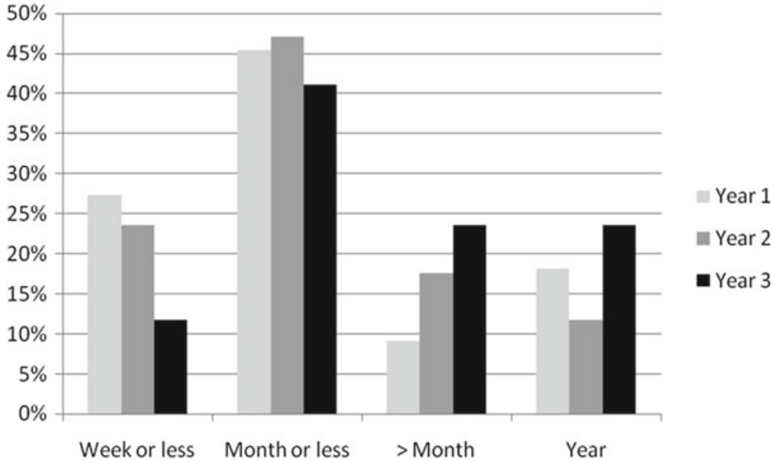

Fig. 4.2 Teacher end-of-year responses to the question, "How extensively have you used geospatial technologies in your instruction this year? (If you teach more than one type of course, please answer for the course in which you have made most extensive use of GIT)." *N*=45 teachers in Years 1–3

group who used the technology for a single week or less, and increasing numbers wove the technology into their teaching for a month or for the entire school year.

Anonymous questionnaires administered throughout each summer institute and at the end of each Saturday workshop indicated high levels of teacher satisfaction with GIT Ahead as a professional development experience. One of the features valued most highly was the ongoing opportunity to receive technical assistance, advice, and inspiration in a supportive community of colleagues. Most of the teachers consistently praised the project in terms of its nature, structure, and focus. For example, one stated in the anonymous end-of-year questionnaire:

> This program is by far the best and most extensive training I have received in new technologies. The format of having conferences throughout the year to work on issues as they came up with guided help was particularly helpful. I am hoping to continue learning more!

Another stated:

> This was the most invigorating series of workshops I've ever attended. It was refreshing to attend workshops where I can immediately implement the ideas and feel as though I truly received professional development…I looked forward to and enjoyed every minute we worked together. Thank you for your guidance, support and encouragement.

Many of the teachers expressed interest in making more extensive use of geospatial technology than had been possible during their initial year. For those teaching New York State Regents courses, a major barrier was the intense pressure for student performance on high-stake standardized tests. Technological glitches presented another challenge. As in other technology-intensive projects, some GIT Ahead teachers faced considerable challenges in getting needed software installed on school computers on

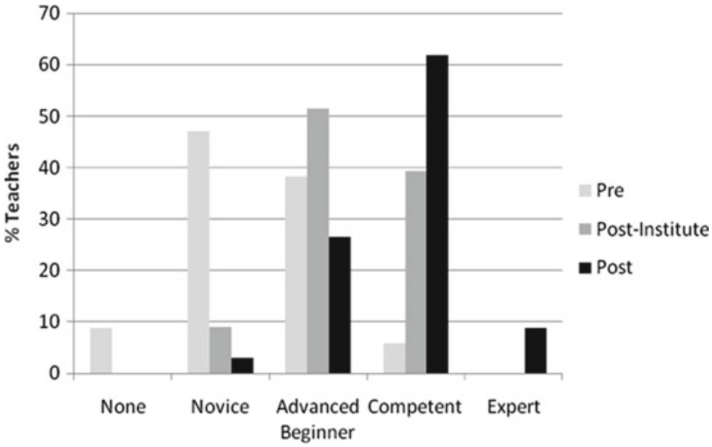

Fig. 4.3 Teacher beginning- and end-of-year responses to the request, "Please rate your expertise in using one or more web-based geospatial programs (such as Google Earth or World Wind)." *N*=34 teachers in years 2 and 3 (Scale: None – I have no experience or expertise using this sort of program, Novice – I have tried using this sort of program but need a lot of help, Advanced Beginner – I have some experience and comfort with this sort of program but need help to use it well, Competent – I generally feel comfortable using this sort of program, Expert – I feel very comfortable and confident using this sort of program)

a timely basis. A common theme in the reflections that teachers wrote at the end of each year was interest in expanding their use of geospatial technology in upcoming years. This was based on two factors: growing confidence in their own abilities, coupled with perceptions of enhanced student motivation, and learning through the activities they had implemented to date. For example, in the anonymous end-of-year questionnaire, one teacher wrote, "I have a new confidence with GIT technology and look forward to creating more projects." Another stated, "Next year I hope to build on what we accomplished this year. Many of the 'bugs' that I encountered this year have been worked out and knowing that support in the form of other teachers and the GIT Ahead instructors is available, I am confident that more can be done in the future. Many, many thanks for an incredible experience!"

Responses to signed questionnaires administered before and after the summer institute and at the end of Years 2 and 3 showed progressive growth in the teachers' perceived ability to use web-based geospatial programs such as Google Earth and Google Maps and their ability to make and use GIS maps with either ArcMap or AEJEE (Figs. 4.3 and 4.4) (Year 1 is not included here because we posed different questions at the beginning of the project).

Growth in teachers' GIT skills was accompanied by corresponding growth in their perceived ability to apply GIT in their science teaching (Fig. 4.5).

The extent of GIT Ahead teachers' ideas about ways in which they could use geospatial technology in their science teaching similarly shifted to the higher end of the scale over the course of the year (Fig. 4.6).

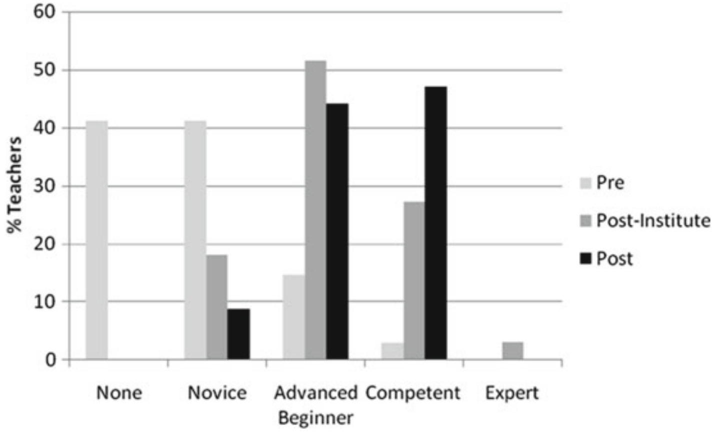

Fig. 4.4 Teacher beginning- and end-of-year responses to the request, “Please rate your expertise in making and using maps with geospatial technologies such as GIS and GPS.” *N*=34 teachers in years 2 and 3 (Scale: None – I have no experience or expertise making and using maps, Novice – I have tried making and using maps but need a lot of help, Advanced Beginner – I have some experience making and using maps but need help to do it well, Competent – I generally feel comfortable making and using maps, Expert – I feel very comfortable and confident making and using maps)

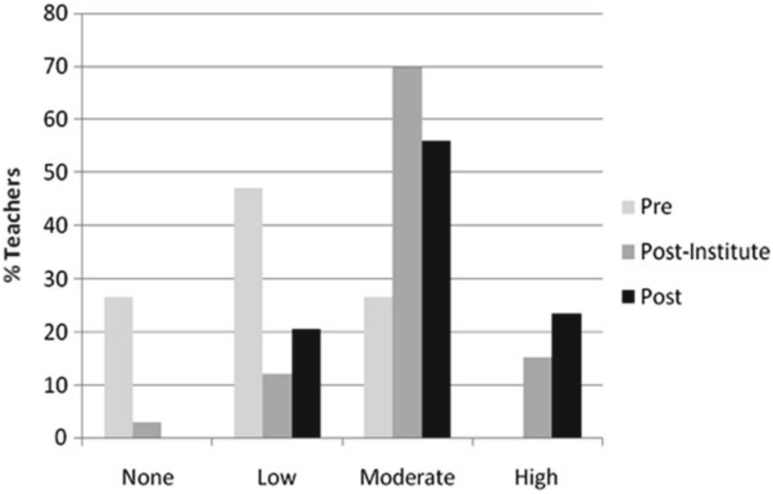

Fig. 4.5 Teacher beginning- and end-of-year responses to the request, “Please rate your current ability to apply geospatial technologies (GIT) in your science teaching.” *N*=34 teachers in years 2 and 3 (Scale: None – I currently have no ability to apply GIT in my science teaching, Low – I currently have very limited ability to apply GIT in my science teaching, Moderate – I am fairly confident in my current ability to apply GIT in my science teaching but will need some help, High – I am quite confident in my current ability to apply GIT in my science teaching)

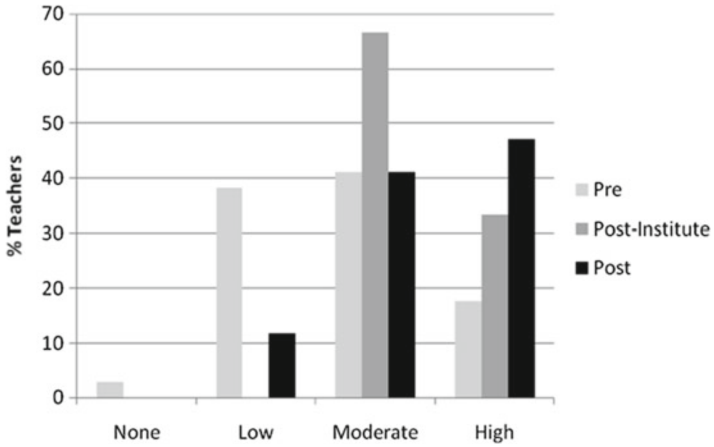

Fig. 4.6 Teacher beginning- and end-of-year responses to the request, "Please rate the current extent of your ideas about how you might use geospatial analysis in your science teaching." *N*=34 teachers in years 2 and 3 (Scale: None – So far I have no idea how I might apply geospatial analysis in my science teaching, Low – So far I have few ideas about how I might apply geospatial analysis in my science teaching, Moderate – I have several ideas I would like to try with regard to applying geospatial analysis in my science teaching, High – I have many ideas I would like to try with regard to applying geospatial analysis in my science teaching)

The end-of-year questionnaire asked teachers to judge the impacts of geospatial projects on various aspects of their students' learning (Table 4.1). The results were positive or neutral for all items, indicating teacher satisfaction with use of geospatial technology for a wide range of reasons. The largest impact was attributed to improvement in students' spatial thinking, critical thinking skills, science content knowledge, and awareness of the relevance of science. Other aspects receiving high scores included student interest in the course and understanding of environmental issues. Smaller percentages of teachers attributed to the project increases in student interest in going on in science, motivation to go into geospatial-related careers, or motivation to succeed in school. When asked to extrapolate and predict likely effects if students were exposed to expanded use of GIT in their science classes, most of the teachers predicted further enhancement of student knowledge and skills (Table 4.1).

Saturday workshop discussions and year-end written reflections provided additional evidence of teacher confidence in the positive student learning outcomes derived from use of geospatial technology in science classes. The primary impact that consistently emerged from these sources was the teachers' perception that use of geospatial technology was increasing their students' level of motivation, engagement, and interest in learning. Interviews of students in three participating classrooms likewise revealed a high level of student enthusiasm for the GIT Ahead projects in which they had engaged (Morgan, MaKinster, & Trautmann, 2009). These students stated that they were able to explore and understand scientific

Table 4.1 Teacher responses to the end-of-year 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)?"

Item	Estimated effect of GIT-related projects[a]	Projected effect of expanded use of GIT[b]
Capability to use geospatial technologies	91	100
Ability to think spatially	91	100
Awareness of the relevance of science	89	82
Science content knowledge	84	96
Critical thinking skills	84	96
Interest in this particular course	82	84
Understanding of environmental issues	78	96
Interest in going on in science	60	84
Motivation to go into GIT-related careers	49	89
Motivation to succeed in school	44	69

$N = 45$ teachers in Years 1–3

[a] % of teachers responding "Increased moderately" or "Increased to a great extent" to "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)?"

[b] % of teachers responding "Would be further enhanced" to "If you were to expand your use of GIT in this course in future years, how *do you predict that the extent of these same student outcomes would change?*"

concepts more easily with geospatial technologies, in part because the interactive nature of the software provided them control over their learning and kept them engaged throughout the lesson or unit.

4.5 Implications for Practice

GIT Ahead project evaluation indicated tremendous potential for integrating geospatial technology into science teaching. Each year, participating teachers became comfortable using ArcGIS and related GIS software, GPS, and Google Earth, and they worked to integrate geospatial technology into their teaching in various ways according to their individual interests and curricular plans. Many of the teachers found that their visions of potential applications grew as they gained familiarity with technological applications, overcame implementation hurdles, and saw the resulting impacts on student motivation, interest, and learning.

Based on our experience in GIT Ahead, key aspects of geospatial technology-focused professional development include:

- Intensive summer training
- Time for individualized curricular planning
- Ongoing technological and curricular support throughout the school year
- Promotion of a supportive learning community

A common theme in this book is that professional development should focus on how to enhance student learning through use of geospatial technology, rather than how to use the technology per se (cite other chapters here). GIT Ahead followed this theme, providing teachers with a variety of technological options but introducing each only to the extent needed to meet the goals of a particular lesson. As a result, all software applications were introduced within a specific context that helped teachers to envision using similar approaches with their students.

4.6 Implications for Research

GIT Ahead, like most of the projects described in this book, had a relatively small budget for evaluation and no budget for research into teacher or student learning gains and related causal mechanisms. With growth in the number of projects supporting this sort of professional development, demand is growing for creation and validation of an instrument designed to measure self-efficacy for teaching with geospatial technology. Essentially, this would provide a way of quantifying the impact that this type of experience has on the ability of teachers to integrate this sort of technology into their teaching. Use of a common instrument across a variety of projects would help to identify and verify key features of professional development designed not only to impart technological skills but to equip teachers with the full range of TPACK needed for effective integration of geospatial technology into their teaching within specific content areas.

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Chapter 5
Spatial Sci: Forwarding Geospatial Technology Innovations in the Classroom

Lisa M. Blank, Jeffrey W. Crews, and Randy Knuth

Keywords Curriculum design • Adoption • Learning community • Practitioner-led innovation

5.1 Introduction

This chapter describes geospatial technology professional development efforts initiated by the PJW College of Education and Human Sciences. Using the Next Practice Innovation Model, the Spatial Sci Project stimulated classroom innovation in the use of geospatial technologies, identified system supports for teachers, empowered motivated early adopters, modeled effective and developmentally appropriate uses of emerging geospatial technologies, and promoted learning communities within and across school districts to accelerate the possibilities of geospatial technologies.

5.2 Next Practice: A Theoretical Framework for Practitioner-Led Innovation

The Next Practice Innovation Model is a theoretical framework developed by England's Department for Education and Skills (DfES) and launched in 2002 as an effort to "forward an agenda for teachers to lead change in schools" (DfES 2002, p. 2).

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The Innovation Model consists of three phases: stimulate, incubate, and accelerate. In phase 1, the goal is to *stimulate* innovation by identifying system needs and innovators. In phase 2, the goal is to *incubate* innovative strategies through the creation of communities of practice. In phase 3, the goal is to *accelerate* innovations by promoting broader adoption and/or adaptation of pedagogies (Barber, 2002; Hannon 2006).

5.3 Stimulating Professional Imagination

The beginnings of the Spatial Sci project can be traced back to The University of Montana's College of Forestry Numerical Terradynamic Simulation Group (NTSG), which created the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite software, designed primarily to measure global vegetation. In 1999 and 2002, the National Aeronautics and Space Administration (NASA) launched two new satellites, known as Terra and Aqua, which used the software developed by NTSG. The satellite imagery produced from Terra and Aqua provided scientists with new views of Earth dynamics. In an effort to make this new technology accessible to the public, NASA provided $1.75 million dollars in seed money to the University of Montana to initiate the NASA Earth Observing System (EOS) Education Project.

The mission of EOS was to broaden public exposure beyond the Terra and Aqua satellites to all the Earth Observing System satellites and begin providing professional development support to educators who wished to incorporate geospatial technologies into their learning environments. To begin this work, EOS purchased 30 wireless laptop PC computers and took to the road, visiting schools across Montana in an attempt to stimulate the imagination of Montana teachers and students regarding the possibilities of using satellite imagery in their classrooms.

5.4 Identifying System Needs: GIS4MT

Quickly, EOS staff and participating teachers realized that the real power of the imagery lay in being able to look at relationships between different sets of geospatial data. This led to the launch of the Geospatial Information Systems for Montana (GIS4MT) program. First, ESRI, Redlands, CA, and EOS negotiated a joint venture to provide professional GIS software to every Montana public school student and teacher in grades K–12. The GIS4MT project leveraged the ESRI GIS software opportunity by providing onsite geospatial teacher training to 227 participating Montana schools and 120 University of Montana preservice teachers annually. Unfortunately, in follow-up program evaluation studies of the geospatial training, it was found that teachers struggled to fully implement geospatial technologies into their classrooms, citing a lack of access to spatial data sets situated in their local geography and appropriate for school-aged audiences and a lack of ongoing, onsite technology support. As one teacher related, "Locally relevant spatial data sets are essential if I'm going to get my students to invest the time and energy to learn science content using GIS."

In response to the teacher feedback outlined above, GIS4MT project leaders decided to pursue funding to develop place-based spatial data sets and curriculum that would work to increase students' motivation to use GIS as a tool to understand local community issues. Place-based education posits that a student's community should be the primary resource for learning and that using a pedagogy of place increases students' science understanding and motivation to learn (Athman & Monroe, 2004; Semken & Freeman, 2007). Given that Montana is such a large and geographically diverse state, it was decided that GIS4MT teachers were uniquely positioned to identify compelling, locally relevant spatial data sets and act as co-developers of curriculum where Montana students learned to use GIS to explore their place.

5.5 Incubating Geospatial Technology Innovation: The Geospatial Technologies in the Classroom Project

In 2006, a Toyota USA Foundation grant ($300,000.00) was secured to initiate the Geospatial Technologies in the Classroom Project (GTEC). For this project, a teacher training model was proposed that would sustain the use of geospatial technologies within Montana classrooms and position Montana science classrooms as emerging leaders in geospatial technology education. Four project activities were identified:

1. Recruit leading geospatial technology educators and mobilize leadership teams into effective communities of practice.
2. Generate place-based spatial data sets appropriate for use with school-aged audiences and aligned with national education standards.
3. Establish a network of system supports for acceleration of geospatial applications into the 5–12 classroom including interactive website, spatial data portal, help desk, and biannual video conferencing.
4. Found a statewide geospatial technology competition to promote wider adoption and adaptation of geospatial technologies.

Applications for participation in the GTEC program were sent only to GIS4MT teacher participants as their completion of the GIS4MT trainings indicated a strong interest in geospatial technologies, a growing competency in the use of geospatial technologies, and a willingness to take risks that are inherent in implementing emergent teaching practices.

The goal of the teacher recruitment process was to select a geographically diverse set of Montana teachers who were identified as leaders within their school communities in the use of geospatial technologies. From 227 GIS4MT teacher candidates, 20 teachers were selected for participation in the GTEC project based on the following criteria: number of years as a classroom teacher, amount and depth of training in the use of geospatial technologies, evidence of successful use of geospatial technologies with students, and support and recognition by school administration of creative and innovative use of geospatial technologies. Ten of these 20 teachers were GTEC fellows during the 2006–2007 academic year (Cohort 1), and the remaining 10 teachers were GTEC fellows during the 2007–2008 academic year (Cohort 2).

Each teacher cohort participated in a week-long geospatial technology summer institute designed to (1) stimulate teachers' imagination by exposing participating teachers to the depth and variety of spatial data sets produced and in use by university, agency (e.g., United States Forest Service), and agricultural GIS users across Montana; (2) incubate and cultivate a community of geospatial technology practitioners; and (3) challenge each teacher to develop a curriculum module and spatial data set that was unique to their geographic setting and community. Teachers would then pilot their GIS curriculum module and accompanying spatial data sets in their classrooms in the upcoming academic year.

To support teachers in the development and implementation of their spatial data sets and curriculum throughout the academic year, GTEC project leaders created several system supports. First, an interactive website and spatial data portal for teachers was developed. Second, synchronous chats were held four times a year for all GTEC teachers and project staff for the purposes of monitoring classroom implementation, introducing new teaching strategies and resources, and facilitating teacher communication across project sites and cohorts. Third, GTEC staff piloted new, interactive teaching software for tutorial animation to enhance student understanding and retention. Fourth, GTEC project staff held regularly scheduled help desk hours to provide answers to questions and further ideas for curriculum development. Fifth, teachers were provided with a substantial incentive to participate fully in the program. Each teacher received $1,000.00 for attending the summer institute and a $500.00 classroom mini-grant for the purchase of geospatial technology-related classroom supplies. A final $1,000.00 stipend was received by each teacher once the following program components were completed: (1) development, implementation, and submission of a place-based GIS curriculum module and (2) completion of all program evaluation instruments.

5.6 System Supports for Implementing Geospatial Technologies

5.6.1 Interactive Website and Spatial Data Portal (www.spatialsci.net)

During the development of the program website, the GTEC project was envisioned to be one that would expand in scope and depth as teachers' geospatial technology needs evolved. Consequently, the entry page to the website is entitled *Spatial Sci,* the parent program for multiple geospatial technology resources within the site. The GTEC project has its own set of pages within the parent Spatial Sci website.

Some of the most important features of the website are the data and image portals. Five categories of spatial data can be found in the data portal: *demography,* *physical science, life science, earth science, and Google Earth* data layers. These categories, designed to complement established classroom content domain areas, were developed based on focus groups held with teachers across Montana who regularly and successfully incorporate geospatial technologies into their teaching.

When a user clicks on one of data category tabs, all of the spatial data layers available for that content domain are displayed using consistent data formats and map projections. With the exception of Google Earth data layers, which are specific to that software platform, all other data layers are designed to be used with ESRI's ArcMap GIS and mapping software platform (www.esri.com). Under the **Curriculum** tab, users can access the curricula developed and implemented by GTEC participants and staff and other geospatial technology efforts under the direction of GTEC project leaders.

5.6.2 GTEC Help Desk

In an effort to minimize implementation barriers, GTEC teachers could contact GTEC project staff via phone or email at regularly scheduled hours and expect an immediate and knowledgeable response to their geospatial technology questions. Direct feedback from GTEC teachers allowed project leaders to structure future workshops and activities to address training needs and improve integration of geospatial technologies into the classroom. For example:

1. Help desk questions and comments enhanced GTEC spatial data and curriculum warehousing activities through integration of new data sets and materials that then were made available to the wider geospatial user community via the GTEC website portal. These data sets are freely available for download and provide examples of the types of data useful for teachers in classroom settings.
2. Several GIS skill builders were created in response to teacher questions – these are unique geospatial tutorials available for download from the GTEC website, tailored to the needs of teachers who implement geospatial lessons in the classroom.
3. GTEC staff also piloted new, interactive teaching software (Camtasia) that added animation to tutorials to enhance understanding and retention for teachers and students.

5.6.3 Synchronous Chats

In the original grant proposal, the GTEC project proposed to have teachers meet during the school year via video conferencing using the Vision Net infrastructure. Unfortunately, many of the Vision Net sites at the participating Montana schools were unavailable due to scheduling conflicts and lack of school funding for Vision Net connections. Because the distances were so large, and travel time and costs were prohibitive between school sites, a distance technology was still needed to facilitate communication between GTEC teachers and project staff. In response, GTEC project staff developed a synchronous chat feature as part of the interactive website. This consistent and regular contact helped maintain the communities of practice across the academic year.

5.7 Accelerating Innovation: GIS Competition and Online GIS Courses

5.7.1 GIS Competition

One of the strategies for scaling up the GTEC project goals was the development of a statewide GIS competition. The theme for the first annual GIS competition (2006) was *Montana's Changing Snowpack and What it Means for your Community*. The 2007 GIS Competition was entitled *Mapping Montana's Energy Alternatives*. While this project idea was well-received by GTEC teachers given their broad participation and numbers of student entries, the competition required an annual funding source for awardees that project leaders have yet to successfully identify. An acceleration avenue with a steady and self-sustaining source of funding emerged as an essential project need.

Online GIS courses developed specifically for educators were identified as a potentially more effective route for advancing GIS innovations.

5.7.2 Online GIS Courses

Spatial Sci is currently developing a series of three online GIS courses that are designed primarily for K–12 school teachers but are open to and can benefit a wide variety of users both in and outside Montana. The overarching goal of these courses is to provide a solid foundation in essential GIS concepts, software, and available data types. Each class is instructor led, not self-paced, and lasts 10 weeks. Class size is limited so participants have the opportunity for ample interaction with the instructor and other students. The introductory course was launched in the spring of 2009, the Intermediate in 2010, and the Advanced in 2012. All courses are now offered once per year for three credits (undergraduate and graduate are co-convened).

5.8 Project Evaluation and Outcomes

The project evaluation presented here focuses on the teacher outcomes of the GTEC professional development effort. The evaluation was completed by an outside evaluator (Knuth Research, Inc.) and investigated how a teacher geospatial

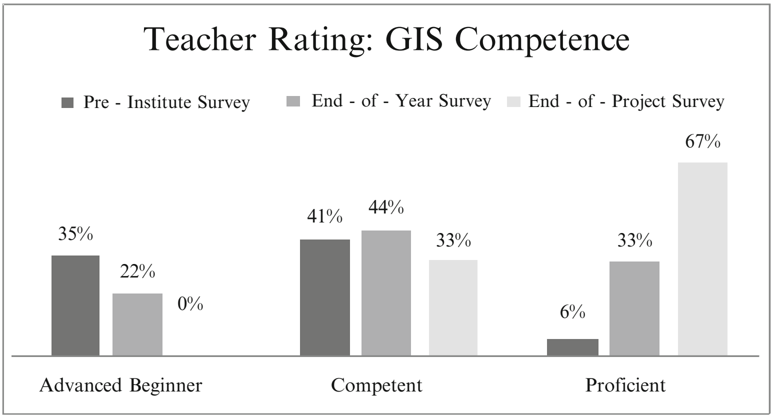

Fig. 5.1 Teacher GIS competence

technologies professional development project influenced teachers' GIS competencies and facilitated innovation, implementation, and adaptations of GIS into their classrooms (Sandholtz, Riongstaff, & Dwyers, 1997).

5.8.1 Pre-institute and End-of-Project Surveys

Participating GTEC teachers were asked to fill out a pre-institute survey as well as end-of-year and end-of-project surveys. The pre-survey contained goal questions in addition to eleven questions found on the end-of-year and end-of-project surveys that dealt with teacher perceptions of GIS competency, ability to locate data sets, ability to create data sets, and extent of GIS implementation and geospatial career development in the classroom. Survey items rated teacher's abilities in these areas along a continuum of novice, advanced beginner, competent, proficient, and expert.

Sixty-seven percent of teachers on the end-of-project survey assessed themselves as proficient in using GIS in their instruction as compared to 33 % on the pre-institute surveys (Fig. 5.1).

Locating GIS datasets is a frequent stumbling block for many first time GIS users in the classroom. Less than half of GTEC teachers came into the project competent or proficient in this task. Almost 90 % on the end-of-year and end-of-project surveys indicated that they were either competent or proficient at this task (Fig. 5.2). No participant rated him/herself as novices or experts after attending the institute. Competency in creating data sets also increased from pre-institute to end-of-year to end-of-project surveys. While two-thirds of participants indicated that they were competent in creating data sets at the end of the first school year of participation, at the end of the project, about a third of the competent teachers became proficient at this task (Fig. 5.3).

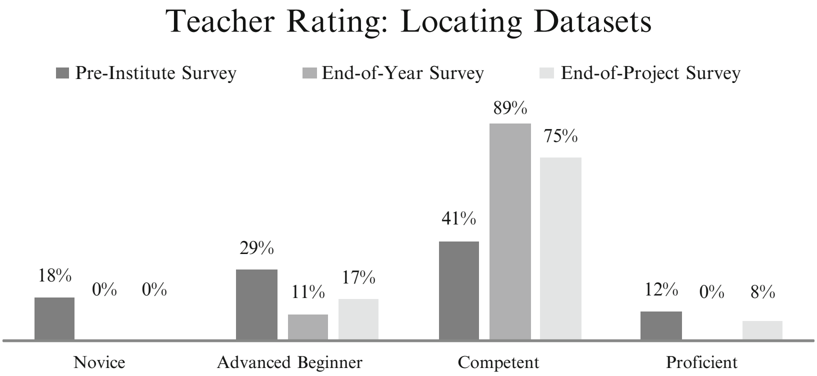

Fig. 5.2 Teacher ability to locate datasets

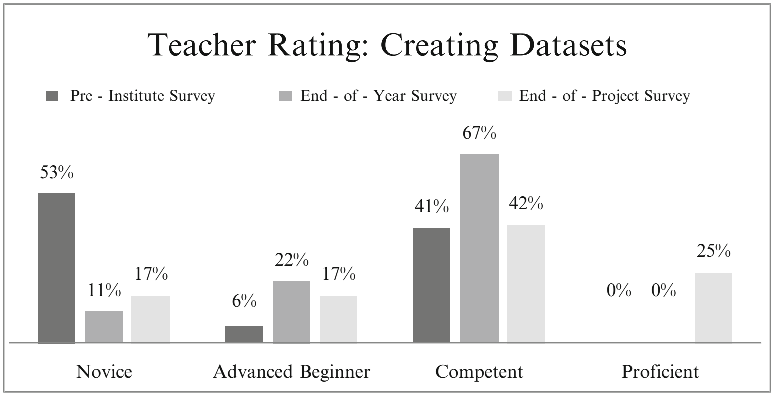

Fig. 5.3 Teacher ability to create datasets

In terms of classroom implementation, 67 % of teachers after the first year of participation indicated that they “have used geospatial technologies in more than one unit of instruction and in different topical areas but at only one grade level (e.g., two or more different units in 9th grade earth science, one about stream management, another about city planning),” while only one teacher implemented GIS more extensively. In contrast, 27 % of the teachers on the end-of-project survey reported that they “have used geospatial technologies in several subjects and across several grade levels (e.g., several units in 9th grade earth science and 10th grade biology).” This result suggests that a combination of time, practice, and commitment to the instructional use of GIS technology is needed to foster and advance the implementation of GIS in the classroom (Fig. 5.4).

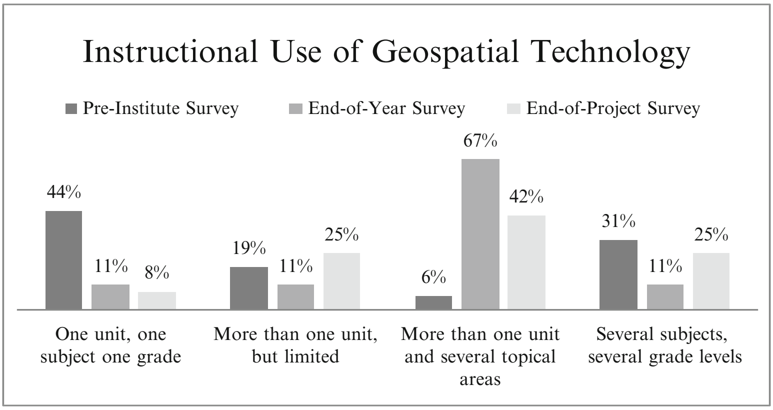

Fig. 5.4 Teacher instructional use of geospatial technology

5.8.2 *End-of-Project Interviews*

In addition to the pre-institute, end-of-year, and end-of-project surveys, end-of-project interviews were conducted by telephone for 14 of the participating GTEC teachers. At the beginning of each telephone conference, the evaluator read aloud the participant's project goals which they had set during the GTEC Summer Institute. The participant was then asked the following questions:

1. How often and to what extent did you and your students use GIS in the years following the summer institute you attended?
2. How has your teaching changed as a result of this project?
3. Did you achieve what you had hoped for? Why/why not?
4. What changes in student knowledge and student interest have you noticed?
5. To what extent did you use the Spatial Sci Website? Did you use any other support from the GTEC team?

The following is a list of project outcome themes that are common for most, if not all, of the teachers involved in the final phase of the GTEC project:

- Utilizing available resources and requesting additional resources when needed (i.e., data, digital images, computers, GPS units, etc.)
- Incorporating GIS technology into the curriculum (i.e., ArcView, ArcMap, Google Earth, GPS units, other visual technologies)
- Creating GIS lessons/units that are environmentally based and relevant to the lives of students in Montana
- Adapting GIS to fit varying teaching situations (i.e., subject, grade level, varying student ability, etc.)
- Helping students learn how to analyze data and draw conclusions

Table 5.1 Use of GIS and depth of learning

	Infrequent implementation – irregular use of GIS or total GIS time is equal to or less than 1 week	*Frequent implementation* – regular use of GIS (or a unit study) or total GIS time is equal to or greater than 1 week
Shallow learning – student responsibility and research is minimal (e.g., worksheets, direct instruction)	Teacher 4	Teacher 6 Teacher11 Teacher 13
	Years of teaching: 14	Mean years of teaching: 9
In-depth learning – student responsibility and research is extensive (hands-on, student research, fieldwork, etc.)	Teacher 1 Teacher 12	Teacher 2 Teacher 3 Teacher 5 Teacher 7 Teacher 8 Teacher 9 Teacher 10 Teacher 14
	Mean years of teaching: 11	Mean years of teaching: 12

Although there were several overarching themes that were consistent for most teachers, there were also several elements that varied from teacher to teacher. These elements include frequency and length of GIS lessons/units, depth of student responsibility and learning, effect on teaching method and style, and effect on student knowledge and interest.

The end-of-project interviews helped identify the extent to which participating teachers were using GIS in their classrooms. The grid below (Table 5.1) was created for categorizing teachers (based on their interview responses) on two dimensions: (1) the extent of active student learning (shallow or in-depth) and (2) frequency of GIS implementation (irregular or regular use of GIS). Two outside evaluators independently placed teachers in a cell in Table 5.1 with high inter-rater agreement (11 of 14 matched; the remaining were discussed and mutually agreed upon placement). In the grid the teacher numbers refer to the specific interview results presented later in this chapter.

As can be seen, the majority of participating teachers fell into the “in-depth learning and frequent GIS implementation” cell. The mean years of teaching experience for each quadrant is reported in Table 5.1. Based on personal work during the institutes with each of these teachers, the outside evaluator found each participant to be highly skilled and dedicated to making learning as meaningful as possible for their students. While teaching ability or experience was not identified as a consistent predictor of the level of GIS implementation, the following contextual factors were identified from interview coding as consistently influencing the extent of instructional integration:

1. Adequate time for supported practice with GIS.
2. High level of teacher commitment to the instructional use of GIS technology.

3. Adequate system supports including administrative support, technology infrastructure, and a consistent, regularly available technology help desk for teachers.
4. GIS databases and accompanying curricula that were local and relevant to students' lives and communities to justify the investment of time and energy required to learn GIS.
5. Regular use of GIS and increasing levels of student responsibility, rather than one long, in-depth GIS unit, was preferable for maintaining student interest and developing students' skill sets.

5.9 Teacher Impact and Practice

The representative teacher synopses below provide a glimpse into the classrooms of participating teachers. Each teacher was contacted during the final phase of the project to determine the extent to which geospatial technologies had been implemented in his or her classroom in order to help improve science teaching and learning. Summaries of a teacher interview from each quadrant and cohort are presented below. Because a larger number of teachers were identified for the frequent implementation/in-depth learning quadrant than any other quadrant, two teacher summaries are included from that quadrant.

5.9.1 Teacher 4 (Infrequent Implementation/ Shallow Learning)

Teacher 4 currently teaches science at a high school in eastern Montana. He was a part of the first cohort and attended the GTEC institute during the summer of 2006. During the school year (2006–2007), this teacher used GIS 2–3 h per month. He went through the basic operations of ArcMap and taught his students how to use it. He then did some of the same activities from the summer institute with his physics students. The students worked in small groups and used GIS tools to answer questions about oil deposits in eastern Montana. This teacher said that he has a difficult time connecting GIS with his chemistry class.

In terms of changes that he made in his teaching as a result of the GTEC project, this teacher said that he learned some new things that he could pass along to his students. When asked to elaborate, this teacher said that when the rancher shared at the summer institute, this teacher was able to "take that back to his students." In terms of changes in student knowledge and interest, he mentioned that his students' interest was piqued with a local TV show about mapping, but that when the TV show ended, their interest dwindled.

When the evaluator asked whether or not this teacher achieved what he had hoped for, he said "Physics, yes, but not for chemistry." This teacher said that he received some projects and data from the Spatial Sci website and contacted the GTEC team when a need arose which he found helpful. He had a couple of students who were working on the GIS competition but that it didn't work out for them to participate because of technology limitations at the school. This teacher identified the lack of technology as a continual barrier for him in terms of implementing more GIS in his teaching.

5.9.2 Teacher 1 (Infrequent Implementation/ In-Depth Learning)

Teacher 1 currently teaches science in northwestern Montana. He was a part of the second cohort and attended the GTEC institute during the summer of 2007. During the school year (2007–2008) following the summer institute this teacher attended, this teacher wanted to do a project with his students on water quality but was "too far away" and didn't think there was enough GIS data related to that topic. Because his is a rural school, this teacher said that he and his students were able to use GIS to plot the loss of agricultural land to urban development. This teacher said he felt the project went well. As a part of the GIS Competition, he and his students obtained a basic layer county map along with a transparent Google Earth water drainage map and looked at the transition of the loss of agricultural land by year. Students looked into how many tons of grain were lost due to development. This teacher also mentioned that he had a "GIS Day" during which students took GPS readings on poorly located wells and then entered and validated the raw data. This teacher said that the GIS day also included talking about careers in this field of study. They are also working with GIS alongside a sister school this year.

In terms of changes that he has made in his teaching as a result of the GTEC project, this teacher said that he has access to more map systems, such as mapping systems in other countries. Because of this, this teacher said he and his students are able to look at migration routes in different parts of the world. This teacher also felt that he was able to support other teachers because of his involvement in the project. In terms of changes in student knowledge and interest, he indicated that because he only has a few computer stations, it didn't have the impact on his students that he had hoped. He does think, however, that his students' working knowledge of the way GIS works has improved. He suggested that GIS creates "a new avenue of learning." "Because we teach GIS in high school," this teacher stated, "our students get a head start."

When the evaluator asked whether or not this teacher achieved what he had hoped for, this teacher responded that he modified his original goals and that they were a "good success." He mentioned that he felt that his research skills improved, he was able to integrate more, and that he "realized how much more there is out there." This teacher also mentioned that he used extensive support from the GTEC team including some resources. "We've been competing in the Competition for the past 2 years, and we couldn't have done as near a good of a job without them."

5.9.3 Teacher 6 (Frequent Implementation/Shallow Learning)

Teacher 6 currently teaches seventh grade science in western Montana. He was a part of the first cohort and attended the GTEC institute during the summer of 2006. After attending the 2006 summer institute, this teacher developed two GIS units. The first unit is on Plate Tectonics lasting about 1 week and 2 days. The second unit is a Habitat Analysis that lasts about 3 days. During the Plate Tectonics unit, this teacher's students look at GIS maps that show volcano locations and earthquake locations and depths. His students also look at paper topographical maps and create their own paper maps that show 3–4 categories of plate boundaries based on the information that they have looked at. This teacher said that he then has his students make connections between the maps and then construct boundaries based on those connections. For the Habitat Analysis unit, this teacher stated that his students use GIS to determine the tolerance range for elevation and precipitation for a Wyoming animal. They then look for areas in Missoula, Montana, that would fit the tolerance range of the animal and could possibly serve as a relocation site. This teacher also talked about another unit, which "comes and goes," that is on Asteroid Crater Analysis in Montana.

In terms of changes that he has made in his teaching as a result of the GTEC project, this teacher said that his students do inquiry work with data, and he tries to incorporate inquiry more and more. He is currently looking into opportunities to become more comfortable with GIS. In addition, he wants to use data from the Chinese earthquake and turn it into a relevant lesson for his students. In terms of changes in student knowledge and interest, this teacher is able to get some data from his pretests, post-interviews, and other anecdotal notes. "Some kids struggle. It's such intense software that kids can get lost." He said that other kids are able to go onto the computer and get GIS information, but they view the computer as a toy rather than a tool.

When the evaluator asked whether or not this teacher achieved what he had hoped for, this teacher answered "Yeah." He said that he was able to develop his Plate Tectonics unit. He also mentioned his master's project through Montana State University on the effect of GIS on attitudes and comprehension levels in students. This teacher said that he was able to use and still does use the Spatial Sci website, data, and articles. He mentioned that he was able to look at another participant's lessons on bears and he occasionally asked other participants questions.

5.9.4 Teacher 14 (Frequent Implementation/In-Depth Learning)

Teacher 14 currently teaches environmental science and biology at the high school level. She was a part of the second cohort and attended the GTEC institute during the summer of 2007. After attending the 2007 Summer Institute, this teacher said that she continued to use ArcView instead of ArcMap because it took up less space. She attempted to convert old lessons to ArcMap over the summer but was unsuccessful when attempting to load them. As a result, she continued to use older ArcView lessons. This year (2008–2009) she has created four new ArcMap lessons to use with her students. This teacher described each lesson in detail and was very excited when talking about the work she and her students were doing. She created analysis and evaluation questions for her students to answer as they worked through each lesson. Lesson topics included analyzing the effects of lycee shrimp on the ecosystem at Flathead Lake, studying fire ecology and bird population at Glacier National Park, and analyzing chemical levels of the water in Berkeley Pit in Butte, Montana. This teacher utilized many technology resources including Google Earth Tours, 3-D Analyst, graphs, digital images, and satellite images.

In terms of changes that she has made in her teaching as a result of the GTEC project, this teacher said "kids need to develop the spatial part of their brain. They need to be active learners, move at their own pace, and they need to be actively drawing conclusions." With this philosophy in mind, this teacher said she is trying to incorporate more lessons that use spatial technology in order to help her students learn science. In terms of possible changes in student knowledge and interest, this teacher stated that "it's hard to know whether or not they have developed spatial skills. It's hard to assess." Despite this, this teacher noticed that a few of her students are good at this type of science and has made attempts to encourage them. This teacher also mentioned that a few of her students have stated an interest in pursuing environmental careers.

This teacher said that she achieved what she hoped for when she began this project. She created new lessons and continues to incorporate technology tools in order to teach those lessons. She also utilized the full extent of the GTEC resources available to her. She used the Spatial Sci site to look up information for the competition, browsed data sets, looked at what other teachers were doing, and emailed the help desk when she was having issues. This teacher said that she felt supported and that [ ] was more than willing to help her. Overall, this teacher stated that the GTEC Institute was very helpful in that she was able to work on her own stuff during the classes and was, therefore, able to get local data and new technologies for her classroom.

5.9.5 Teacher 5 (Frequent Implementation/In-Depth Learning)

Teacher 5 currently teaches science at a school in northwest Montana. He was a part of the first cohort and attended the GTEC institute during the summer of 2006. The evaluator contacted this teacher during the final phase of the project to determine the extent to which geospatial technologies have been implemented in his classroom in order to help improve science teaching and learning.

Since this teacher's involvement in the 2006 GTEC summer institute, he and his students use GIS on a daily basis (4 ninety-minute periods). They are currently in the middle of a project dealing with asbestos and its possible link to lung abnormalities in Montana. This teacher and his students have identified 236 addresses that received shipments of asbestos and are identifying abnormalities in those areas. They have been in conversation with the Center for Disease Control (CDC) about the data they have come up with and are currently waiting to hear back about the verification of their data. This teacher stated that his students have been talking with people about this, taking notes, and making connections. At the start of each of his classes, the teacher said that he created GIS tutorials to start with, which gives his students the base knowledge for the work that they are now doing. Teacher 5 has been working with Dr. White from Montana State University and other teachers to get a GIS laptop that is equipped with data bundles within a 20-mile radius of Libby. This teacher said that he and his students have also been going through some data about lung abnormalities from the Agency for Toxic Substances and Disease Registry (ATSDR).

5.10 Conclusions and Recommendations

Consistent with Trautmann and MaKinster (2010), McClurg and Bass (2007), Hewson (2007), and Loucks-Horsley et al. (2003), the GTEC project confirmed crucial aspects needed for successful professional development experiences including time, ongoing technological and curricular support throughout the year, the promotion of a supportive learning community, assistance in the development and implementation of individualized curriculum plans, and program flexibility to meet teachers' interests and needs.

In addition, project leaders identified five essential features of geospatial professional development that GTEC teachers needed to initiate and maintain geospatial innovations within their classrooms and to accelerate innovations across their schools, communities, and beyond:

1. Time for supported practice with GIS, continuous learning opportunities, and teacher commitment to the instructional use of GIS technology are needed for successful classroom integration.
2. Adequate system supports are necessary for sustained integration of GIS into the classroom. These include administrative support, technology infrastructure, and a consistent, regularly available technology help desk for teachers.
3. GIS databases and accompanying curricula must be local and relevant to students' and teachers' lives and communities to justify the investment of time and energy required to learn GIS.
4. Professional development must be specific to the needs of the teacher's developmental technology skills and classroom curriculum.
5. Regular use of GIS and increasing levels of student responsibility, rather than one long, in-depth GIS unit, is preferable for maintaining student interest

and developing students' skill sets; consequently, models for this must be provided for teachers.

The good news of the GTEC project is that a majority of the teachers now regularly use GIS in their classrooms and students are extensively involved in the learning process and motivated to use GIS to examine community issues. The challenge is in identifying a way to scale up the GTEC project. Recall that the GIS4MT project served over 200 teachers, but teachers struggled to fully implement geospatial technologies into their classroom because of a lack of access to locally relevant curriculum and data sets and ongoing, onsite technology support. While it appears that GTEC did increase teachers' adoption of geospatial technologies into the classroom by providing teachers technology support and time to practice GIS skills and develop geographically relevant spatial data sets and curriculum with a community of peers, the question is: Can a model serving 20 teachers be adapted to serve 200 teachers? How? Perhaps effective geospatial technology professional development requires small teacher cohorts. Is there an optimal number? If so, what is it?

Other questions remain. Project leaders observed that for the majority of teachers, Google Earth and GPS were more successful initial entry points than GIS for gaining comfort in using geospatial technologies and for the integration of geospatial technologies into the classroom. While this may be because of the ubiquitous use of GPS in commercial products and the intuitive interface of Google Earth, it suggests that a successful acceleration of innovative applications of geospatial technologies in the schools would benefit from a deliberate articulation and systematic instruction of GIS skills across the grades. When should GIS begin to be used? What skills should be taught first?

The chronicle of the Spatial Sci project shared in this chapter identifies teachers as effective geospatial technology innovators and points to locally relevant spatial data sets as an important avenue in accelerating the use of GIS in the classroom. The challenge of how to sustain these efforts remains.

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Chapter 6
Eyes in the Sky: Facilitating Classroom Research Using Geospatial Technology

Carla McAuliffe and Jeff Lockwood

Keywords Distance learning • Authentic science • Geospatial professionals • Geospatial careers

6.1 Introduction

Eyes in the Sky was a professional development program created by TERC with funding from the National Science Foundation's (NSF's) Innovative Technology Experiences for Students and Teachers (ITEST) program. From 2004 to 2008, three overlapping cohorts of teachers received 18 months of professional development that included distance learning and face-to-face components. Participating teachers used geospatial technologies (e.g., geographic information systems (GIS), image analysis, and global positioning systems (GPS)) to carry out community-based research projects with their students. Eyes in the Sky was a regional program, reaching 48 teachers from underserved rural and urban populations in Arizona, plus one teacher from New Mexico.

Major components of the Eyes in the Sky professional development program included (1) a 12-week distance learning course, (2) a 2-week summer workshop, (3) a classroom implementation phase, and (4) a culminating research showcase. Participating teachers received 136 h of professional development during the 18-month program, and ITEST funding provided each participant with four units of graduate credit, a $750 stipend, a digital camera, and a handheld GPS unit.

The primary goals of the Eyes in the Sky program were to have teachers and their students (1) study, practice, and apply geospatial technology to understand issues in environmental science; (2) use geospatial technology to conduct authentic community-based science research using an eyes-in-the-sky perspective; and

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(3) cultivate an awareness of careers that use geospatial technology by implementing inquiry-based activities crafted by geospatial professionals in collaboration with the Eyes in the Sky project team. This chapter describes the Eyes in the Sky program and offers recommendations for geospatial technology-based professional development.

6.2 Theoretical Framework

Three key ideas guided the design and development of the Eyes in the Sky program: (1) teachers and students should engage in authentic science inquiry; (2) workplace competencies and technology skills are best learned when taught within meaningful contexts in existing science, technology, engineering, and math (STEM) courses; and (3) environmental problems can be better understood using an eyes-in-the-sky perspective through the application of geospatial technology. Using these ideas, the authors created a professional development program in which teachers and students accessed and analyzed freely available satellite imagery and geospatial data to investigate local or regional environmental issues. These issues included light pollution, water use, the impact of recycling, and the effect of urban growth on native vegetation.

6.2.1 Teacher as Researcher Model of Professional Development

The overall professional development model of the Eyes in the Sky program was that of Teacher as Researcher. The Teacher as Researcher model has a long history of use by several professional development programs, including the National Oceanic and Atmospheric Administration's (NOAA's) Teacher at Sea (TAS) program, the National Optical Astronomy Observatory's (NOAO's) Research-Based Science Education (RBSE) program, and the Teachers Experiencing Antarctica and the Arctic (TAS) program, as well as many others. Loucks-Horsley, Love, Stiles, Hewson, and Mundry (2003) refer to this model as an immersion experience. The underlying assumption of the Teacher as Researcher model is that engaging teachers in scientific research experiences helps better prepare them to facilitate similar experiences for their students (Loucks-Horsley et al., 2003). In the Eyes in the Sky professional development program, mentor scientists worked with the project team to develop research experiences centered on environmental science issues within the local community. For example, in the Urban Saguaro Cactus project, teachers used GPS units and digital cameras to locate and photograph several cacti during a field excursion. Prior to photographing them, a one-meter strip of tape was placed on individual cacti for scale purposes (Fig. 6.1).

Fig. 6.1 Desert saguaro and an urban saguaro

Teachers used image analysis to measure the height of cacti and to locate and characterize the nesting sites of birds. Data were recorded in a spreadsheet and then mapped as part of a GIS unit. Teachers investigated these and other questions: (1) How do the features of an urban saguaro cactus differ from those in natural areas? (2) How do invasive species of birds affect the distribution and occupation of nesting sites in urban saguaros?

6.2.2 *Meaningful Contexts Plus Teacher as Pedagogical Expert*

The Eyes in the Sky professional development model assumes that teachers are pedagogical experts capable of adapting curricular materials to meet the needs of their students and capable of satisfying local and state standards (Penuel, Fishman, Yamaguchi, & Gallagher, 2007). The Eyes in the Sky program provided teachers with a range of activities and investigations that could be adapted for their own classroom use, increasing the likelihood of classroom implementation. When professional development models rely on teachers developing lessons, classroom implementation can fail, simply because teachers struggle to actually write the lessons (Dahlman, personal communication). For some teachers, becoming a curriculum developer is not easy. Add to that the challenges of learning a new data analysis tool, and the process of figuring out how to teach this new material to students can seem overwhelming. However, the same teachers might be able to easily teach from existing curricular materials. On the opposite end of the spectrum, when teachers are asked to enact prepared curriculums without adaptations, they will often be unreceptive unless the curriculums precisely meet the teachers' needs.

Rather than placing teachers in the role of curriculum developers or, alternatively, providing them with a prescribed set of curricular materials that they must use with students (Penuel et al., 2007), Eyes in the Sky exposed teachers to a range of potential activities and investigations. The program showcased the capabilities of geospatial data analysis as applied to unique environmental science scenarios. For example, in the distance learning course, teachers used GIS and image analysis to investigate the Aspen Fire on Mount Lemmon, near Tucson, AZ. This fire burned more than 80,000 acres in the summer of 2003, destroyed hundreds of homes and businesses and caused millions of dollars of damage. Using two key GIS analysis techniques – feature querying and spatial querying – teachers explored how the fire spread and determined the daily extent of damage during the 26 days the fire burned out of control. Participants compared infrared and true-color images of the fire, readily distinguishing burned areas from healthy vegetation. In the process, they learned how GIS is routinely used to help firefighters and other agencies create strategic plans when dealing with natural hazards, including locating resources and determining areas with the highest risk. Teachers in the Eyes in the Sky program were given the option of adapting this activity for use with their students if it met their curricular needs. Alternatively, they could apply the querying techniques to data more appropriate to their STEM content. Project staff helped teachers find and prepare any necessary additional data.

6.2.3 Understanding and Applying Geospatial Technology: *Thinking Through Geospatial Technology or Thinking Geospatially*

The Aspen Fire scenario highlights the Eyes in the Sky approach to using geospatial data analysis in teaching and learning contexts. Professional development specialists argue that teaching with rather than about an educational technology (such as GIS or image analysis) is the most effective way to introduce these tools to teachers and, in turn, students (Hall-Wallace & McAuliffe, 2002). "Teaching with" usually refers to situations in which students acquire content while using educational technology. Professional development specialists argue that the technology itself should be "transparent." Students should not need to know all the steps and procedures for data analysis (Edelson, 2004). However, the authors contend that learning data analysis techniques in a meaningful context can be very powerful and term this process "thinking through geospatial technology." During the Eyes in the Sky program, teachers and students engaged in scientific inquiry by using geospatial technology to ask and investigate research questions. The authors feel it is difficult to ask a geospatial question if one is not thinking geospatially. Thus, the Eyes in the Sky professional development program included activities and investigations that specifically highlighted geospatial data analysis techniques, such as measuring distance and area, constructing and deconstructing multispectral images, and performing queries. The suite of geospatial data analysis techniques explicitly taught during the Eyes in the Sky program could then be applied by teachers and students to many different investigations of environmental issues.

6.3 Professional Development Design

6.3.1 The Eyes in the Sky Program and Its Participants

The overall structure of the Eyes in the Sky professional development program is shown in Table 6.1 for Cohort 1.

This same structure was used for Cohorts 2 and 3, who began their programs in spring 2005 and spring 2006, respectively.

In fall 2003, Eyes in the Sky began by recruiting teachers and developing a distance learning course. The goal was to recruit 24 participants, targeting the Tucson metropolitan area since the summer workshop was to be held there. To locate potential teachers, project staff visited science departments, gave presentations at local and state science conferences, mailed flyers to individual schools, and distributed information via e-mail and listservs. By December 2003, 24 teachers had agreed to participate in Eyes in the Sky. By the time the distance learning course started in January 2004, five of those who had accepted decided not to participate. Nineteen teachers began the distance learning course. Four participants left the program during the distance learning course, resulting in 15 teachers attending the summer workshop (see Table 6.2). The participants who dropped out of the program cited technical difficulties, personal health issues, and a change of teaching assignment as reasons for departure. Similarly, with Cohort 2, two teachers dropped out of the program before the distance learning course began. An additional six dropped during the course, resulting in 22 teachers attending the summer workshop. The teachers who dropped the program cited the same reasons as Cohort 1, as well as family

Table 6.1 Eyes in the Sky Cohort 1 professional development activities

Professional development activity	Length and timing of activity
Distance learning course	12 weeks in spring 2004
Summer workshop	2 weeks in summer 2004
Classroom implementation and staff mentoring	School year from fall 2004 to spring 2005
Research showcase	Late spring 2005

Table 6.2 Number of teachers and students in the summer workshops by cohort

Cohort	Number of teachers recruited	Number of teachers in summer	Number of students in summer	Location of summer workshop
1	24	15	52	Tucson, AZ
2	30	22	48	Tempe, AZ
3	15	12	46	Tempe, AZ

issues and time limitations. Fifteen teachers were recruited for Cohort 3. Three dropped before the course began. The remaining 12 teachers stayed in the distance learning course and attended the summer workshop.

The first summer workshop was held in Tucson, AZ, while the second and third were held in Tempe, AZ. Eyes in the Sky targeted Arizona's two largest urban centers, drawing teachers from schools with high populations of traditionally underserved students. In addition, 16 % of the teachers came from schools in rural Arizona. Overall, teachers from 43 schools participated in the Eyes in the Sky program. Of those schools, five had 99–100 % Native American student populations and four had 80–87 % Caucasian student populations. All schools had at least a 13 % non-Caucasian student population. At 17 out of 43 of the schools, 50 % or more of the student population is eligible for free or reduced-price lunches. Using aggregate school profiles of participating teachers, the "average" Eyes in the Sky school had student populations that were 40 % Caucasian, 39 % Hispanic, 5 % African American, 2 % Asian, and 14 % Native American. The "average" Eyes in the Sky school was 60 % non-Caucasian with 40 % of students eligible for free or reduced-price lunches.

The 49 teachers who participated in the Eyes in the Sky program taught a variety of subjects, including math and technology and spanning the sciences from biology to chemistry to physics to earth science. Teaching experience ranged from 2 to 27 years, with an average of nearly12 years of teaching experience.

6.3.2 Distance Learning Course

Each cohort of participating teachers began the Eyes in the Sky program with a 12-week distance learning course. ITEST funding covered tuition for four graduate credits for each participant. Weekly lessons in the online course helped teachers become skilled users of two geospatial technologies: GIS and image analysis. GPS instruction occurred later during the summer workshop. Teachers learned to use ArcView GIS and ImageJ image analysis software. Teachers were asked to learn these two geospatial technologies well enough to use them as research tools and well enough to use them with students. Each week, the distance learning course began by stating goals identifying what participants should know and be able to do as a result of the planned activities. The course was explicitly designed to feature a variety of geospatial data analysis techniques (see Table 6.3). Each week, teachers learned one or two new data analysis techniques embedded within the context of environmental

Table 6.3 Weekly topics in the eyes in the sky distance learning course

Week	Topic
0	Introductions and Installations
1	What is Geospatial Information Technology (GIT)?
2	Eyes in the Sky: A Space-Based Perspective
3	Eyes in the Sky: A Map-Based Perspective
4	Topographic Tools: How High? How Low?
5	Image Stacks: Analyzing Motion, Visualizing Change
6	Eyes on Research: What is Authentic Scientific Inquiry?
7	Research Focus: Exploring GIT Datasets, Formulating Questions
8	Careers that use Geospatial Information Technology (GIT)
9	Eyes on Data: Deconstructing and Constructing Color Images
10	Eyes on Earth: Exploring Global Distributions
11	Eyes on Earth: Exploring Regional Distributions
12	Eyes on Our Community: Managing Local Resources

science. Learning activities focused on natural hazards such as flooding and fires, as well as the monitoring of changes in land use and water resources. There were 2 weeks during the online course when teachers did not use geospatial technology. During one of those weeks, they interviewed a geospatial professional and prepared a career profile of that individual. During the other week, participants read and discussed the research article, Epistemologically Authentic Inquiry in Schools: A Theoretical Framework for Evaluating Inquiry Tasks (Chinn & Malhotra, 2002), and reflected on the difference between authentic scientific inquiry and classroom inquiry.

The Eyes in the Sky project team built the weekly course materials from a combination of sources. In some weeks, new activities were created to feature local datasets. In other weeks, materials were adapted and modified from existing activities, relying heavily on two published sets of instructional materials: Exploring Water Resources: GIS Investigations for the Earth Sciences (Hall-Wallace, Walker, Kendall, & Schaller, 2003) and Discovering Image Processing: Fundamentals of Image Processing to Integrate Science, Mathematics and Technology (Dahlman & McAuliffe, 1998). Exploring Water Resources consists of four GIS-based units that present scientific content about water. Content begins at a global scale, progresses to a regional scale, and ends with a local-scale case study focused on the impact of aquifers and wildlife conservation in Tucson, AZ. Discovering Image Processing consists of ten image analysis-based lessons covering topics such as remote sensing, analysis of digital elevation data, and use of aerial photography.

Throughout the distance learning course, teachers investigated local and regional data to help them generate ideas for possible classroom research projects. They investigated material that included precipitation and water use data, vegetation and forest fire data, and population, transportation, and land use data. In addition, teachers were continually asked to describe how they would apply the skills they were learning to the science, technology, engineering, and math (STEM) content they

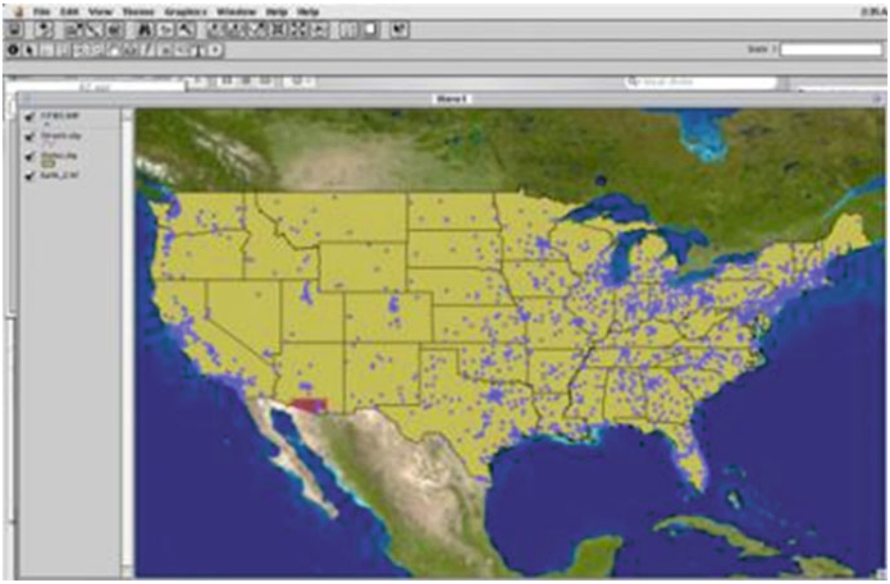

Fig. 6.2 Screenshot showing the locations of reservoirs in the USA

taught. Teachers documented their learning by posting screenshots showing key steps of their geospatial analysis procedures (see Fig. 6.2). They interacted with other teachers through a discussion board in which they reflected on the data analysis and its implications for their teaching, and they discussed their results by responding to at least two other teachers' posts.

The Eyes in the Sky distance learning course was designed using a modified model of asynchronous interaction. Each course week began on a Friday, with an initial posting required by the following Monday and additional ones by Thursday. Teachers could post at a time that was convenient to them but within the weekly constraints. While there were instances when a teacher might miss a week, the project team strongly encouraged teachers to stay current so they could benefit from the discussion with colleagues.

The project team facilitated the weekly discussions, probing teachers to think deeply about their analyses while providing technical support as needed. The project team guided questions and summarized key ideas. Course instructors used online learning strategies shown to be effective in this format (Collison, Erlbaum, Haavind, &Tinker, 2000; Matthews-DeNatale & Doubler, 2000), including establishing clear expectations and assuming the role of the "guide on the side," rather than the "sage on the stage." Instructors responded to teachers' questions on the online discussion board, even when they were emailed individually. This centralization tactic avoided numerous side conversations and enabled others to benefit from the exchange. Each week, course instructors sought to create the equivalent of a face-to-face large group discussion within a virtual environment.

6.3.3 Summer Workshop

The second component of the Eyes in the Sky program was a 2-week summer workshop. The summer workshop served two key purposes. It helped teachers prepare to carry out authentic community-based science research using geospatial technology, and it gave teachers the opportunity to introduce geospatial technology to students.

During the first week, teachers engaged in authentic science research and continued to build their geospatial technology skills. The summer workshop enabled teachers to gain firsthand experience collecting and analyzing field data using geospatial technology. Each teacher received a GPS unit and a digital camera to use during the workshop and take back to his or her own classroom at the end of the workshop. The research experiences of teachers were scaffolded; they collected and analyzed data for a series of authentic research projects. The projects served as exemplars for implementation in the teachers' own classrooms. Urban Saguaro Cactus and the Dark Skies: Making a Light Map in Your Community were two of the projects developed by the Eyes in the Sky team. The Urban Saguaro Cactus project was described earlier.

In Dark Skies, teachers used GPS units and a series of star charts representing the view of the sky at differing levels of "seeing" to gather data on sky darkness at multiple locations in the Tucson or Phoenix metropolitan areas. Teachers then imported the data into a GIS and created a contour map describing the regions in the city where the skies are darkest and the regions where light pollution blots out the most stars. Teachers investigated the following questions: (1) What features in the community are responsible for excessive light pollution? (2) How can light pollution be reduced?

In addition to carrying out geospatial research during this first week of the summer workshop, teachers were asked to develop and submit a research plan describing how they might implement a research project in their classrooms and how they might introduce students to geospatial technology careers. The first week also provided teachers with many opportunities to practice their geospatial technology skills, including previewing the activities that geospatial professionals would be using with students during the second week.

In the mornings of the second week of the summer workshop, teachers facilitated an Eyes in the Sky Summer Institute for between 46 and 52 students recruited from the school and/or district hosting the workshop (see Table 6.2). Pueblo High Magnet School, with a student population that is 89 % Hispanic, hosted the workshop for Cohort 1. Tempe High School, with a student population that is 55 % Hispanic and 17 % African American, hosted the workshop for Cohorts 2 and 3. Teachers at the host schools distributed brochures and applications to students. Teachers at these schools were instructed to include average students for the Eyes in the Sky program instead of picking only their very best. Students with an interest in science and technology were welcomed, and particularly those in need of economic support, since students were paid a stipend of $150 for attending the weeklong workshop.

During the Institute, teachers taught students the basics of geospatial technology. They planned and delivered the instruction, utilizing materials they had used in the distance learning course and adapting them appropriately for the Institute. This part of the professional development placed teachers directly in the role of pedagogical experts. The project team helped teachers lead students through a selection of fun GPS activities, including one that involved geocaching. Teachers indicated that during these sessions, they learned much about their teaching methods and how students react to the technology. One teacher wrote, "It was very effective when we were teaching because we could learn from what had happened that day."

During the Institute, teachers also assisted geospatial professionals as they led students through inquiry activities that highlighted the work they do in their careers. In these activities, students were given problems to solve or questions to answer using geospatial datasets and analysis techniques. One geospatial professional, a hydrologist, helped students investigate well water levels. An archeologist simulated an archeological dig, so that students used GPS and GIS to locate and map historical artifacts. Another geospatial professional helped students plot the spread of invasive plant species in a local national park to predict future environmental impacts. Other activities ranged from investigating total dissolved solids in well water to considering 50 years of changes in land use in the Phoenix metropolitan area. At the conclusion of each activity, students took screenshots of their computer work and annotated them with comments on the geospatial technology skills they used and the related career they learned about. By the end of the week, students had compiled portfolios of their experiences.

Teachers acted as mentors and tutors while geospatial professionals presented the activities. The ratio of teachers to students in the computer lab was high, with individual teachers positioned to assist approximately three or four students. Consequently, teachers had the opportunity to witness the parts of technology implementation that created difficulty for students and the parts that were comparatively easy. Teachers had the opportunity to see the activities through the eyes of a student. Working one-on-one with students, helping them over the rough spots, gave teachers invaluable experience with different aspects of the geospatial technology used. Teachers reported that it was helpful to see students considered "academically below average" work through the activities with enthusiasm. Teachers were able to compare the student population in the workshop with their own students and develop a degree of confidence that they could implement these same activities in their classrooms.

The strategy of involving students in the professional development was a very important part of the Eyes in the Sky program. Instead of waiting until they returned to their classrooms in the fall, teachers were given the opportunity to practice-teach with students in a collaborative environment. Teachers could reflect on what worked and what did not work with both their colleagues and the project team available to support them. Teachers reported that seeing students engage with the technology boosted their confidence about using it with their own students in their regular STEM courses. Students approached the activities with enthusiasm and interest, providing teachers with evidence that their students would engage with the technology in similar ways.

6.3.4 Classroom Implementation

During the workshop, teachers were asked to submit to project staff a first draft of their usage plan, emphasizing the effective implementation of geospatial technology research projects in their classrooms and the introduction of geospatial technology careers to students. The period of professional development extended through the school year, with project staff acting as mentors and advisors to teachers. Teachers were split into three groups and given deadlines to submit second and final drafts of their plans. Project staff reviewed and commented on each draft of each teacher's project via e-mail and sometimes by phone. Teachers facilitated a range of research projects in their classrooms, with some students studying the spread of diseases, others investigating pollutants in streams, and still others enacting the scaffolded research projects such as the Urban Saguaro and Dark Skies projects.

6.3.5 Research Showcase

The Research Showcase was the "publication phase" of our participants' implementation efforts. Teachers were asked to enlist their students in delivering either oral presentations or posters, modeling what occurs at a professional science meeting. A keynote speech was scheduled, along with a series of oral presentations followed by a combined lunch and poster session. Parents, school administrators, and geospatial professionals were invited. Many anecdotal stories were told about how the Eyes in the Sky research projects empowered students, giving them a sense of ownership and a realistic view of how scientific research is carried out.

6.4 Design Successes and Challenges

6.4.1 Components of Effective Professional Development

Relatively few studies have focused on the design of teacher professional development projects that use geospatial technology (e.g., Buss, McClurg, & Dambekalns, 2002; Coulter & Polman, 2004; Wilder, Brinkerhoff, & Higgins, 2003). However, there is a large body of research on delivering professional development to science teachers that applies to geospatial technology-based professional development. Eyes in the Sky was designed using professional development approaches associated with increases in knowledge and skills and changes in teaching practice (Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel et al., 2007). Components of effective professional development were integrated into both the distance learning course and the summer workshop, particularly (1) active learning by teachers, (2) the opportunity to collaborate with peers, (3) use of classroom-based instructional materials focused on specific content, (4) the opportunity to reflect on teaching practice, (5) frequent opportunity to practice new skills, and (6) sufficient time to implement what has been learned (Garet et al., 2001; Penuel et al., 2007). The overall length of the Eyes in the Sky program (18 months) ensured that teachers were well prepared and felt confident and able to implement geospatial technology with students. As mentioned previously, giving teachers the opportunity to practice-teach with students at the summer workshop was a very effective strategy that encompassed active learning and provided the opportunity to reflect on teaching as well as practice new skills. The discussion board of the Eyes in the Sky distance learning course gave teachers the opportunity to collaborate with peers as they discussed their data analysis and shared ideas about how to apply these techniques to STEM content.

6.4.2 Successful Aspects of the Eyes in the Sky Program

Four key aspects helped make the Eyes in the Sky program successful. First, the professional development began with a 12-week distance learning course. This meant that teachers arrived at the summer workshop with significant geospatial technology experience, saving a great deal of time that typically would have been spent learning basic skills. Second, teachers were placed in the role of pedagogical expert in terms of implementing geospatial technology-based curricular materials with their students. The Eyes in the Sky program provided teachers with a range of activities that could be adapted for their own classroom use, increasing the likelihood of classroom implementation. Third, teachers taught students at the summer workshop. The experience served as a mini pilot test for our teachers, demonstrating that ordinary students from diverse backgrounds could learn and apply geospatial technology to solve problems and analyze data. Last, instead of asking geospatial technology professionals to come and talk about their careers, professionals were asked to bring in data representative of the work they do and to guide students through an analysis of that data. The project team codeveloped these inquiry activities together with the geospatial professionals, ensuring that the activities were neither too technical nor missing key analysis opportunities. These activities enabled students and teachers to experience problem-based scenarios focused on real-world issues that arise as geospatial professionals carry out their jobs.

6.4.3 Revisions to the Eyes in the Sky Program

The Eyes in the Sky professional development program served three cohorts of teachers. Lessons learned from the first cohort led to revisions in the program when it was offered to Cohorts 2 and 3. When Cohort 1 began the distance learning course, it was divided into three sections consisting of approximately seven teachers. While discussion in some sections was frequent and engaged, despite research-based facilitation strategies, the discussion was inconsistent and superficial in others. This was due in large part to the sizes of the sections. In this format, having a critical mass of teachers is important to maintain the "conversation." That critical number was found to be between 15 and 20. Over time, the Cohort 1 sections were collapsed into two distance learning sections and then later one section. For Cohorts 2 and 3, all the teachers were placed in one section. Another revision made to the overall program was to expand the face-to-face components in years two and three. These events were optional but were attended by most. In years two and three, distance learning course materials were distributed at a face-to-face meeting. Rather than meeting for the first time online, this gave teachers the chance to meet in person and connect a face with the postings they would later read online. Today, this same goal could be accomplished with virtual Internet conferencing tools that were not as widespread when Eyes in the Sky began. A field trip was also added to provide another opportunity for teachers to engage in data collection and analysis. Teachers performed water quality testing on water samples collected from a local river, mapping their distribution with a GIS.

6.4.4 Challenges Faced by Eyes in the Sky Program Participants

Teachers who try to implement technology-based programs encounter school-wide and district-wide barriers that make it difficult to carry out projects with their students. This was the case for many Eyes in the Sky teachers. Several teachers described, both in interviews and in their classroom implementation reports, difficulty in gaining access to computer labs and in having necessary software installed. Furthermore, data sources such as the USGS and the Arizona Regional Image Archive were frequently blocked at their school servers. In these cases, teachers had to gather needed data on their home computers and bring it to school for student use. Additionally, the pressures of the competing mandates that have trickled down from the No Child Left Behind (NCLB) Act have made it hard for many teachers, both in Arizona and nationwide, to incorporate information technology into their curriculums in innovative ways. Instead of utilizing information technology to enhance critical thinking and problem solving skills, the influence of NCLB has led to a focus on using information technology to support test preparation (Hoffman & Mardis, 2008).

Implementing new technology in school settings requires time. During the Eyes in the Sky professional development program, teachers had to submit project proposals and implementation reports under fairly strict deadlines. Some teachers simply could not begin a substantial research project using geospatial technology during the year they participated in the professional development. Across all three cohorts, many teachers actually implemented more activities during the year following their participation in Eyes in the Sky.

6.5 Outcomes

Eyes in the Sky impacted teachers at 43 different schools, most of which had large percentages of rural and urban underserved student populations. The teachers who participated in the program taught a variety of subjects at different levels. The numbers of years they have spent teaching ranged from 2 to 27, with an average of nearly 12 years teaching experience. They taught subjects including math and technology as well as a range of sciences, spanning from biology to chemistry to physics to earth science.

Eyes in the Sky produced a successful, effective model of professional development. In a final evaluation report, the external evaluator wrote:

> The delivery model itself, a preparatory distance-learning followed by a residency summer workshop, leading toward supported in-class research projects combined different learning modes in a sequence that seemed to have best utilized the knowledge and expectations of participants, and the expertise of the design team and instructors. The content and curriculum was relevant to teachers and many students and served to garner interest and stimulate technology and science learning. The ranges of classroom projects gave evidence to the strength of the professional development, and successively, the student learning. The core design team proved responsive to teacher and program needs by modifying content, schedules, expectations, and technologies, and providing ongoing support to the field. Each year a significant majority of teachers praised the program along each of these dimensions. … Eyes in the Sky…is a strong, efficient, scalable, and replicable model of professional development that prepared teachers to develop and enact inquiry-based science activities that use advanced technology in the classroom. Teachers as well as students reported satisfaction and general enthusiasm for the program.

The Eyes in the Sky program has lasting effects. In the summer of 2008, all teachers who had participated in the Eyes in the Sky program were surveyed. 51 % of all participating teachers, distributed over each of the three supported years, responded, which demonstrates the extent to which program effects endure. The survey was designed to collect summative findings. In general, geospatial technology use was very high, considering formal instruction had ended more than 2 or 3 years ago for many respondents. Nearly 90 % of responding teachers reported using geospatial technology in their classrooms, with the highest use in GIS. Participation in the program has helped most classrooms increase and sustain general technology use. According to the survey, the majority of responding teachers felt extremely able to facilitate students in learning inquiry-based research, conducting research themselves, and in using GPS technology. 40 % felt very capable ("know it pretty well") of using geospatial technology, and 30 % felt very able to use image analysis. Many teachers became professional development providers for colleagues within their schools or districts, a strong indicator of program adoption: 25 % in inquiry-based science and 21 % in geospatial technology. This suggests that the Eyes in the Sky program helped many participants feel comfortable with increasing their own science and technology learning and then take the next step by teaching it to peers. Teachers reported that students responded very well to the Eyes in the Sky geospatial technology and methods. The program enhanced students' learning experiences and, in many cases, the program techniques lend themselves to differentiated instruction.

6.6 Recommendations for Practice

Professional developers designing new geospatial technology programs should consider using a mix of online and face-to-face components. Online courses enable teachers to learn new technology over extended periods of time. Professional developers should also consider involving geospatial professionals interactively in their programs and not just as guest speakers. Third, professional developers should consider including instructional practice with students as a part of the professional development. A more significant recommendation involves the project team. Designing and delivering Eyes in the Sky required a unique combination of skills. The Eyes in the Sky project team consisted of curriculum developers and former classroom teachers as well as educational technology specialists. This enabled the project team to work with geospatial professionals to rapidly create activities that reflected their subject matter expertise but that were usable by teachers and students. This was also the case when creating the distance learning course. The authors recommend that program developers choose a project team that has intersecting and complementary skills to bring to the program.

6.7 Recommendations for Research

Teachers assume various roles within professional development programs. They may act as researchers, collaborators, mentors, or students. In addition to these overarching roles, teachers influence the curriculum materials of a professional development program. During professional development, teachers may be asked to create new lessons, implement existing lessons without changes, or modify and adapt existing lessons. Teachers are sometimes haphazardly placed in these roles and sometimes they take on a role different from what the professional developer intended. Eyes in the Sky placed teachers in the role of pedagogical experts, relying on them to adapt instructional materials to meet the needs of their students. However, some of our teachers spontaneously became curriculum developers, creating entirely new activities for both students in the summer workshop and for the students they taught at their home schools. Penuel et al. (2007) studied the role of teachers in designing, adopting, and adapting curriculum materials and found that even when teachers were randomly assigned to the adopt condition, some form of adaptation took place, suggesting that adoption without modification may likewise be difficult to achieve. Although three distinct roles with respect to the curriculum materials can be conceptualized, teachers may move fluidly between them in any given professional development program. What is not known is what affect these roles have on classroom implementation and, in particular, what happens when that implementation involves geospatial technology. Do teachers view their roles as the same as the professional developer? Are programs that provide teachers with choices in terms of these roles more effective than those that require them to take on a specific role such as adopting curriculum materials? If curriculum development is the goal, then do teachers need to acquire more geospatial technology skills to be successful in their classroom implementation? More research is needed in this area.

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Chapter 7
CoastLines: Commitment, Comfort, Competence, Empowerment, and Relevance in Professional Development

Steven D. Moore, Don Haviland, Allison Whitmer, and Jenny Brady

Keywords Long-term ecological research • Urban • Coastal ecosystems • Self-determination • Diffusion of innovations

7.1 Background

CoastLines built on lessons learned by the principal investigator and project staff from previous efforts to offer GIS-based training to K-12 educators. As the fifth in a series of GIS-in-ocean-science education projects funded by the National Science Foundation's Geoscience Education and ITEST programs, National Oceanic and Atmospheric Administration, and National Geographic Society, CoastLines carried forward work accomplished by the Center for Image Processing in Education (CIPE), an early innovator in the GIS-in-education field.

CoastLines attempted to lay the foundation for sustained implementation of project strategies, materials, and technologies at three sites in the National Science Foundation's Long-Term Ecological Research (LTER) network: Florida Coastal Everglades LTER site (FCE LTER), Baltimore Ecosystem Study LTER site (BES LTER), and the Santa Barbara Coastal LTER site (SBC LTER). The goal of

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the CoastLines evaluation program was to identify and organize best practices that can be improved from year to year and then offered as a teacher professional development model to the LTER program and K-12 education in general. This goal was supported through data collection via online pre- and post-project surveys, an online Webinar survey, online post-summer institute surveys for students and teachers, face-to-face debriefing sessions during each summer institute, an online attrition survey administered each project year, and participant observation during the summer institute. Evaluation data was summarized into interim reports that were provided to the project team to support organizational learning and iterative programmatic improvement.

7.2 Focus and Concerns

This chapter describes how best practices identified from 8 years of experience in developing instructional materials and conducting professional development on geospatial technologies in ocean science education were evaluated in the CoastLines project. A conceptual model developed from previous evaluation work is described, as well as efforts to iteratively evaluate and revise the model in the 2008 CoastLines project year.

7.3 Conceptual Framework

In its evaluation program, CoastLines tested the following hypothesis derived from the literature noted above and from organizational experience: GIS professional development for teachers that emphasizes commitment, comfort, competence, empowerment, and relevance will promote implementation of the technology in the classroom (Fig. 7.1).

These elements were measured in the professional development curriculum offered by CoastLines and in its evaluation program (Table 7.1). Before describing how the curriculum was implemented, what the evaluation results were, and what lessons were learned from the results, the theoretical underpinnings of the model are discussed.

7.3.1 CoastLines from a Diffusion of Innovations Perspective

According to Everett Rogers (2003), the decision-making process affecting implementation of innovations such as GIS in education “is essentially an information seeking and information processing activity in which an individual is motivated to reduce uncertainty about the advantages and disadvantages of the innovation.” Members of a social system (e.g., teachers in public schools) are more likely to adopt innovations that are perceived as better than the ones they are replacing

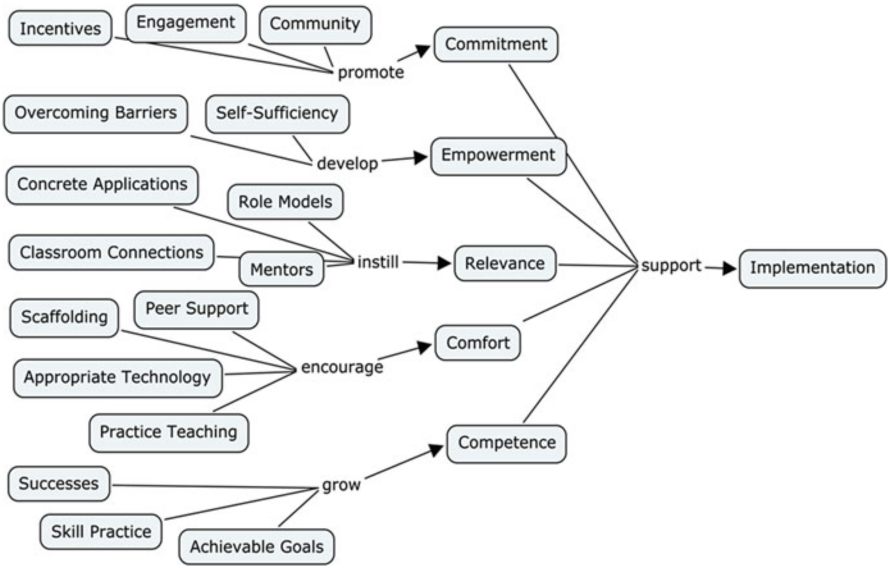

Fig. 7.1 CoastLines' initial professional development model

Table 7.1 How the CoastLines evaluation program measured outcomes indicated in its professional development model

Element	Measurement Method
Commitment	The project monitored attrition rates and interviewed teachers who dropped out of the program. Pre- and post-project year surveys also probed teachers' enthusiasm and commitment to the project's goals and objectives
Empowerment	Pre- and post-project year survey items asked teachers about their self-perceived ability to troubleshoot software issues and solve problems. The surveys also probed the teachers' comfort with using GIS to encourage discovery-based learning in their classrooms
Relevance	Pre- and post-project year survey items asked teachers about how well the instructional strategies and content introduced by CoastLines fit their teaching situations. The project also examined how well teachers were able to connect the LTER program's five core areas of research to classroom activities and relevant instructional standards
Comfort	Pre- and post-project year survey items asked teachers to rate their comfort with using GIS as an instructional tool. Project staff also monitored reactions to practice teaching activities conducted during the summer institute
Competence	Pre- and post-project year survey items asked teachers to rate their competence with using GIS as an instructional tool

(relative advantage); are consistent with existing values, past experiences, and the needs of potential adopters (compatibility); can be experimented with (trialability); exhibit results that are visible to others (observability); and are less complex than other choices (complexity) (Rogers 2003).

These five categories – relative advantage, compatibility, trialability, observability, and complexity – meshed with many factors in the CoastLines professional development model (Fig. 7.1). Perceptions of the relative advantage of CoastLines technology and pedagogy were promoted by the professional development model's use of role models and mentors as opinion leaders, the notion of structuring opportunities for participants to experience success, and the framing of novel technology in the context of technologies used in everyday life. Concrete applications provided by LTER research, the five core areas of research for the LTER network – primary production, population studies, movement of organic matter, movement of inorganic matter, and disturbance patterns – and LTER scientists and teachers serving as role models were used to demonstrate compatibility with the participating teachers' instructional environment. Trialability was conveyed through practice teaching and skill practice. Community (external and internal to the project) and peer support were utilized to engender observability. Scaffolding, help in overcoming barriers, mentoring, appropriate technology, and achievable goals were meant to reduce perceptions of complexity.

7.3.2 CoastLines from the Perspective of Andragogy

Embedded in the CoastLines professional development model was andragogy, the formal study of adult learning in the context of learning theories based in modern psychology (Zappala, 2007). Two foundational components of andragogy are social constructivism and transformative learning. Social constructivism posits that optimal learning environments are created when learners have the opportunity to collaborate with one another. Through their interactions, collaborators create shared meaning about and individual connections to the material being studied (McMahon, 1997). The path through this learning process by necessity includes some degree of cognitive dissonance as adult learners transform how they view the world (McLoughlin & Luca, 2002). Accordingly, the transformative process may not be linear or quick. Adult learners typically negotiate a series of personal and perhaps professional transformations, changes, and periods of growth during which they confront preconceptions, beliefs about themselves and others, and theories about how the world works in light of what they have learned (Mezirow, 1978, 1991). As indicated by its professional development model, CoastLines attempted to promote success in the adoption of GIS in education by facilitating transformations with scaffolded activities providing participants with experiences of success; promoting challenges and reflection through mentoring, peer support, and practice teaching; and focusing on concrete applications and classroom connections.

7.3.3 CoastLines from the Perspective of Self-Determination Theory

Underlying the CoastLines professional development model was self-determination theory, a general theory of motivation that attempts to explain the dynamics of human needs and well-being within social contexts (Chen, 2007). A keystone of the theory is the assumption that humans actively seek a sense of wholeness, vitality, and integrity (Deci & Ryan, 2000). According to self-determination theory, psychological growth and integration is facilitated when humans feel autonomous, competent with tasks and activities, and included or affiliated with a relevant social group (Ryan & Deci, 2000; Schunk, Pintrich, & Meece, 2008). By satisfying such needs, humans may "experience an elaborated and unified sense of self, embrace self-oriented motivation, and achieve a better sense of well-being" (Chen, 2007). CoastLines addressed the need for autonomy by empowering teachers to be self-sufficient in troubleshooting and problem solving and to achieve competence through practice teaching sessions and carefully crafted activities that allowed participants to experience success and promote connectedness through the use of role models, mentors, and peer support.

7.4 Iterative Design of the Project

The CoastLines professional development model was evaluated in the context of Science Approach's goal of strengthening its capabilities as a learning organization. According to Senge (1990), a learning organization is "a group of people continually enhancing their capacity to create what they want to create, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning to see the whole together." Generative learning – learning that enhances an organization's capacity to create – is critical to the learning organization approach.

Science Approach implemented Senge's (1990) learning organization approach by (1) regarding CoastLines as an integral component of the American education system instead of something external to it (systems thinking); (2) viewing project implementation as a process of learning how to better conduct effective GIS-based professional development for teachers (personal mastery); (3) reflecting on and challenging assumptions about teachers' and schools' needs, the function of technology in education, and the roles of project staff and participating teachers as agents of change (mental models); (4) building a vision of the project in collaboration with participants (building a shared vision); and (5) continually engaging in dialogue to align and develop the capacities of the team (project staff, participants, and other stakeholders) to create the results its members truly desire (team learning).

Table 7.2 Gender and ethnic characteristics of the teachers and students participating in the CoastLines project

Targeted category	Percentage of teachers (%)	Percentage of students (%)
Females	65	67
Hispanic	35	63
African Americans	8	27

7.4.1 Project Design and Description

CoastLines was a 3-year project that began in December 2007 and ended in December 2010. The project year ran from January to December. Each year, a new cohort of 30 teachers was trained by the project, with the training schedule beginning in the spring and ending in the fall. The project location also changed each year. In 2008, CoastLines was focused on the FCE LTER and its summer institute was held in Miami, Florida. In 2009, the project focused on the BES LTER and conducted its institute in Washington, DC. In 2010, CoastLines addressed the SBC LTER and conducted face-to-face professional development in Santa Barbara, California. As stipulated in the program requirements at the time of award, teachers participating in CoastLines completed 120 h of professional development per year (in 2008, the structure was 16 h of Webinars before the summer institute, 80 h at the institute, and 24 h after the institute).

7.4.2 Recruitment: 2008

In March 2008, the CoastLines project issued a national call for science educators to apply for admission into the project. Messages were posted to the EdGIS and Scuttlebutt listservs. Helping broadcast the call for applications, recipients of these messages reposted them on several local and statewide listservs. Nicholas Oehm, the education coordinator for the FCE LTER site, used communication networks established during his work with the FCE LTER site to publicize the project statewide through various channels.

As a result of the efforts by Science Approach, Oehm, and other anonymous recruitment, more than 150 teachers completed the CoastLines online interest form. All of the applicants in the southeastern United States region were invited to participate in the project. Forty-nine teachers were accepted into the program by early April. For personal and professional reasons, 8 of these teachers decided to not participate in the project, leaving 41 teachers at the beginning of the cohort. Twenty-one of these were high school teachers. The remainder taught middle school.

The LTER site's recruitment efforts in Florida and, particularly, in the Miami region yielded a participant population that included significant representation of targeted ITEST categories (Table 7.2). The participating teachers taught a variety of

Table 7.3 The most frequently listed courses taught by teachers participating in CoastLines

Course	Percentage of teachers (%)
Biology	62
Earth science	46
Chemistry	27
Mathematics	15
Geology	15
Physics	12

Table 7.4 Experience levels of the teachers participating in CoastLines

Experience level	Percentage of teachers (%)
< 5 years	21
5–9 years	24
10–14 years	24
15–19 years	21
> 19 years	12

science and mathematics courses (Table 7.3). Other classes taught by the teachers included alternative education, earth and space science, environmental science, physical science, general science, geography, human geography/macroeconomics, integrated science, language arts, middle school (comprehensive) science, social sciences, special education, and technology. One participant was an instructional technology support person for his school. The teachers' experience levels were almost evenly divided among four response categories (Table 7.4). More than half of the participants taught at large urban schools.

7.4.3 Project Format: 2008

During 2008, which is the focus of this chapter, teachers participated in 25 Webinars, attended a 2-week summer institute held in June at Felix Verela High School, and implemented a GIS-based activity with students during the fall.

The online Webinars were conducted with GoToWebinar, a turnkey Webconferencing system offered by Citrix Online LLC (GoToWebinar, 2009). Pre- and post-institute Webinars were chosen as an economically efficient and flexible method (Zygouris-Coe, 2007) for providing professional development to teachers spread across a broad geographic region (Texas, Tennessee, North Carolina, Mississippi, and Florida). A lecture-discussion model (Rasmussen and Northrup, 2002) was used for the Webinars, supported by implementation of an online learning community via the project's Joomla!-based e-Learning site (Moore, 2009). A Webinar format was also implemented because of its benefits in establishing a learning community and offering extended, content-rich support (Walsh & Beckham, 2004).

Table 7.5 Pre-institute and post-institute Webinar topics for the CoastLines project in 2008

Pre-institute webinar topics

1. Orientation to the project, Webinar structure, and e-Learning system
2. Introduction to GIS
3. How to accomplish GIS software installation on teachers' computers and school computers
4. Introduction to the LTER Core Areas of Research and their relevance to the standard school curriculum
5. Introduction to online GIS using the NOAA Now COAST Web site
6. Introduction to the CoastLines Lessons (a trio of lessons created to support use of My World GIS software to explore the ecology of southern Florida and gather and analyze data in and around the FCE LTER site)

Post-institute webinar topics

1. Getting organized for classroom implementation: discussing needs and defining expectations for the implementation phase
2. How to start the classroom implementation and how to assess student learning
3. Brainstorming implementation plans, motivating students, and teaching GIS to diverse student populations
4. Writing grant proposals to fund GIS in schools
5. Advanced GIS analysis techniques

Table 7.6 Linkages of standards and concepts cited by teachers in their implementation plans to the LTER core areas of research

LTER core areas of research	Standards and concepts cited by teachers
Primary production	Chemical elements that make up living things are combined in different ways
Population studies	Compare the adaptive characteristics of species that improve their ability to survive and reproduce in an ecosystem
Movement of organic matter	Identify and observe actions that require time for changes to be measurable, including growth, erosion, dissolving, weathering, and flow
Movement of inorganic matter	Significance of the water, carbon, and nitrogen cycles
Disturbance patterns	How conditions that exist in one system influence conditions that exist in other systems

The Webinars were conducted in two sessions: 7 of the 25 Webinars were offered during April–June before the institute. The remainder of the Webinars were conducted during August–December. The pre-institute Webinars were designed to introduce participants to the My World GIS software (GEODE Initiative, 2009) to be used during the institute, the LTER program, the five core areas of research for the LTER network, and science being conducted at the FCE LTER site (Table 7.5).

Topics covered during the pre-institute Webinars included an orientation to project expectations, an introduction to the e-Learning systems used by CoastLines, help with installing the My World GIS software, and introductions to GIS and LTER science (Table 7.6). Each Webinar was presented live and recorded for posting to the

CoastLines Web site. “Makeup” Webinars conducted by CoastLines staff were offered weekly. During the makeup sessions, the recorded Webinar from that week was shown and the staff person interacted with participants via online chats and telephone conversations. Since full attendance was rare at any one live Webinar, the makeup sessions became an integral part of the CoastLines schedule.

The institute, which was the cornerstone of the year’s activities, was attended only by teachers during the first week and by both teachers and students during the second week. This structure was used so that the teachers could learn and practice skills they would implement during the second week. The institute included the following activities (generally in temporal order):

7.4.3.1 Week 1: Teachers Only

1. Welcome and orientation for teachers
2. Introduction to the use of GPS receivers and PASCO GLXplorers and probes
3. A field trip to Florida Everglades National Park (part of the FCE LTER site) and data collection at the park with GPS receivers and PASCO GLXplorers and probes
4. Face-to-face GIS training with prepared lessons, GIS map building from field-trip data, and adding data to an FCE LTER GIS project
5. Teaching prepared lessons to peers (teacher to teacher)

7.4.3.2 Week 2: Teachers and Students

6. Welcome and orientation for the students, including GIS and GPS training, geocaching, and presentations by FCE LTER scientists
7. Joint GIS project creation by teachers and students
8. Field trip for teachers and students to Florida Everglades National Park and data collection with GPS receivers and PASCO GLXplorers and probes, led by teachers
9. Completion of joint projects and presentation to the group

After the institute, teachers attended a second series of Webinars that focused on facilitating and sustaining classroom implementation (Table 7.1). Participants who completed all project requirements by December 2008 were honored during a special graduation Webinar. The Webinar also provided an opportunity for the participants to share their CoastLines implementation stories.

7.5 Data Collection

Several data sources informed the findings reported in this chapter as well as the evolution of the project. First, participants completed both pre- and post-project surveys to assess changes in their practice, confidence, and content knowledge over the course of the project. The pre-project survey was administered during the first week of CoastLines as participants were becoming oriented to project expectations and before any content was covered. The post-project survey was administered to participants as they completed the requirements of the project and prepared to "graduate."

In addition, participants completed event-specific surveys. All participating teachers completed a survey following the completion of the Webinar series. This survey explored the value of the Webinar series and changes in teachers' self-reported practices using technology. Teachers also completed 2 weekly surveys over the course of the summer institute. These surveys collected teacher feedback on the value of the experiences each week as well as any ideas for how to improve the project in the short and long term. In addition, the evaluator attended the summer institute and collected data through documenting observations and conversations in field notes. Finally, students who participated in the second week of the summer institute completed a survey on the value of the experience and participated in a focus group led by Science Approach staff to gather student feedback.

For the purposes of this chapter, descriptive statistics were run on each survey to determine ratings on individual survey items. Paired t-tests were also run to detect significant ($p < 0.05$) changes in teachers' pre- and post-project responses to the survey items.

7.6 Outcomes: What Worked and What Did Not Work

In this section, findings relevant to research conducted for the 2008 project year are described.

7.6.1 Commitment

CoastLines built commitment into the project by providing personal and ongoing communication with the participants, offering incentives for participation, and building a community of practice. As a key element of the diffusion of innovations and the CoastLines professional development model, communication was fostered through mass media channels such as listservs and Webinars and interpersonal channels such as online forums, e-mail, a chat room, open mike portions of Webinars, and, particularly, the 2-week summer institute. Interpersonal channels of communication (e.g., e-mails, forum postings, teleconference calls, and face-to-face training) were particularly important in building commitment to the project and to the idea of GIS in education. They allowed subjective evaluations of project innovations to be shared among participants and staff. Sharing "reinventions" – changes and modifications to an innovation made by a participant during the adoption and implementation process (Rogers, 2003) – demonstrated through a highly visible practice that teachers can take ownership of GIS in education and mold the technology to their purposes. As one teacher commented on reinventing GIS for her purposes:

> The lessons worked great. I'm planning on doing many more lessons. One thing that some of my classes are doing is a video series for our morning announcements called "The Wonders of the Earth." They have to research some aspect of the earth, find pictures and make a map or several maps on MyWorld showing where the animal/place can be found. I am also working with several teachers on campus planning lessons for their classes. I'm working with the 3rd grade teachers on a lesson about the Oregon Trail and the Lewis and Clark Expedition. I'm also going to try to put a lesson together for a first grade class using a map of the school."

At the end of 2008, 16 of 17 teachers who completed the pre- and post-project surveys indicated that they would continue using GIS in their teaching (some teachers completed the project in 2009 and not all participants completed both surveys). Commitment was greatly facilitated by the weekly Webinars, which became a primary mode of communication with the participants during most of the project year. A listserv was used to send bulk announcements to the participants and telephone and chat support was offered as well. A forum was created and used for posting information relevant to the topics being covered in the Webinars and to the project in general. The project Web site, http://coastlines.ws, was constructed with community-building software (the community builder component for Joomla!) that allowed participants to create profiles, communicate with one another via e-mail and chat, and post forum entries. A CoastLines Facebook group was created to give teachers and students a place to engage in social networking and post photos and messages. Teachers were also encouraged to post content to the Web site and share Web links they had found useful. Only a limited number of teachers in the first cohort participated in such sharing. A common problem was that Facebook was blocked by security software in many schools.

The most significant factor that fostered commitment to the project was the 2-week CoastLines Summer Institute offered in Miami during 9–20 June 2008. The institute solidified interpersonal connections initiated during the spring Webinars and, through training and field events, gave plenty of opportunities for teachers, students, and staff to bond with one another. The connections and sense of community built during the summer institute carried into the fall Webinars.

Less altruistic, though equally compelling in building commitment to CoastLines, was the impact of stipends and tangible rewards. The project experienced a drop-off in participation after the summer months, when the participating teachers had received most of their annual stipend after the summer institute and a full license to the My World software. A concerted effort of frequent communications and new incentives was required to bring wandering participants back into the fold.

7.6.2 Comfort

The project intended to encourage teachers' comfort with GIS and global positioning system (GPS) technology by (1) scaffolding the introduction of the software and technologies so that the development of new skills and understanding of new concepts were not overwhelming, (2) offering training events and materials designed to give participants experiences of success, (3) diminishing the social discomfort of learning a new technology by conducting early training online, (4) introducing teachers to a GIS platform (My World) specifically designed for educators, (5) providing localized lessons in Word format that can be adapted by the teachers, (6) providing ready-to-use My World projects and data libraries local to the FCE LTER site, and (7) providing opportunities for the participating teachers to practice teach the technology to their peers and to small groups of students. All seven strategies worked reasonably well, though the project had to readjust priorities at the summer institute because the participants thought that the introduction of new material was happening too slowly. Additionally, nearly all of the teachers rejected the usefulness of peer teaching (e.g., practice teaching a lesson or activity to one's peers at the institute). As the following comment from the post-summer institute survey illustrates, the general feeling was that the group wanted more time learning tricks of the trade:

> Since we were the "beta" teacher group for the project there obviously has to be some fine tuning and adjustments made to the sessions. Overall I thought they were quite effective. I would have liked to have seen some interactive computer based tutorials on the GPS and data collection devices that we could have referred to or looked at prior to the workshop.

Practice teaching to students met with some controversy; the participant cohort divided into camps of those who found the opportunity beneficial and those who felt that too much time was spent interacting with students. Teachers in the "pro-practice student" camp tended to enjoy the enthusiasm of the students and their willingness to experiment and find answers and think outside of the box. The "anti-practice student" camp felt that valuable time was wasted managing students when advanced GIS techniques could have been taught. One "pro-practice student" teacher described the differences between the two camps in this manner:

> Working with the students, any students, to provide me a source of experience in working in a classroom setting (even if with unrealistic teach/student ratios). The groups that complained about this simply did not plan well and could have established times where one teacher could teach the group while the others observe, take a short break, etc.

Interestingly, as evidenced by the following comment, the students were very positive about their experience with teachers:

> The one-on-one student-teacher interaction was fantastic. I enjoyed being with my group and teachers very much. Having a small group was worthwhile and beneficial because during the school year we do not receive such attention from teachers because there are so many students in the class. I got to learn a lot more and found that the teachers were very willing and helpful.

An important component of the project's attempt to reduce the complexity of implementing GIS in schools was the choice of the My World GIS software (GEODE Initiative, 2009). My World was chosen as the software tool for CoastLines because it simplifies many operations implemented by teachers, uses natural language for queries and other selection processes, imports data directly from the

PASCO devices used in field work, and protects users from having to navigate to data and other resources through their operating system (often a deal killer in GIS training). Use of My World in CoastLines was not directly evaluated by the teachers because few of them had used any other GIS program. However, project staff who had conducted teacher training with professional GIS software felt that My World greatly reduced the complexity teachers had to deal with in learning GIS, increased the rate at which teachers grasped GIS skills and concepts, and enhanced the likelihood that participants would implement GIS as an instructional innovation.

The introduction of three template lessons created for the FCE LTER site – "A Buffer from the Storm," "Exploring the Everglades," and "Matter of Inches" – was highly successful with the participants. Created in Word and given to teachers in electronic files, the lessons provided locally relevant platforms for the teachers to build from and teach ecological concepts. These concepts included information on how coastal marshes, wetlands, and barrier islands serve as the first line of defense against hurricanes and how topographic variations of only a few inches can shape the kinds of habitats found in the Florida Everglades. The purpose of introducing the lessons was to (1) enhance the trialability of using My World software and FCE LTER data to teach concepts relevant to Florida educational standards, (2) demonstrate the relative advantage of using GIS as an instructional tool, (3) enhance the compatibility of GIS by offering localized lessons for the Florida teachers, and (4) raise comfort levels with GIS by eliminating the complexity of creating one's own lesson. Experience with all of these factors was enhanced by introducing the lessons during workshops, giving opportunities for teachers to modify the lessons, and adding field data to the base maps. Nearly all teachers in the 2008 cohort adapted these lessons for use with students. Some teachers conducted field trips into the Everglades so that their students could add georeferenced data to the lesson projects. Many teachers created explorations of their own, using the template lessons as a guide. As a result of this success, the practice of offering template lessons was extended to the 2009 cohort.

7.6.3 Competence

The CoastLines project attempted to help teachers become more competent practitioners of GIS in education by providing training and support to enhance their ability to install and use GIS software properly, understand the data that is used in GIS projects, and effectively use GIS to teach scientific content to middle school and/or high school students. Considerable online and face-to-face time was spent on these issues. Competence also received significant attention in the pre- and post-project surveys.

GIS competence was measured in two ways in the pre- and post-project surveys: as four "competence" items and fifteen "professional use," "instructional use," and "functional use" items. The competence items showed significant ($p<0.05$) increases during 2008. For instance, agreement with the item "I can show students how to use GIS software as part of a class lesson" increased from 60.0 % to 93.8 % during the project year. Similar gains were uncovered for the items "I can explain to students how GIS is used in the workplace" (54.2–87.5 %), "I can explain to students how GIS relates to their daily lives" (67.6–86.7 %), and "I can use GIS to conduct relevant scientific investigations" (61.7–87.6 %).

A preliminary analysis of data from the pre- and post-project surveys for the 2008 cohort indicated that the teachers gained dramatically in current use of GIS-related practices and self-rated competence. For instance, at the beginning of the project year only 5.4 % of the participants felt that they were prepared to use GIS to work through a structured activity in front of students. At the end of the year for the graduating group, 68 % felt prepared or well prepared to do so. Corresponding gains were seen for items such as "Discussing GIS with my colleagues," "Using GIS to teach concepts relevant to state instructional standards," and "Using GIS to help students learn to 'do science' in ways similar to real scientists." Noteworthy is the finding that the gains are stronger for feelings of preparedness rather than actual practice: at the end of the project year, 38 % of the participants said that they were using GIS to help students practice real science while 75 % said that they were prepared to do so. To address this gap in 2009, the project changed the institute agenda to allow for more GIS practice, allow teachers to participate in either a GIS storytelling track or project development track, and put more focus on local project development.

7.6.4 Empowerment

Empowerment can be an intangible that is difficult to measure or express. As noted by McLoughlin and Luca (2002), cognitive dissonance is part of the transformation process, and adult learners can be reticent to reveal the depth and breadth of the changes that are occurring within themselves. In projects like CoastLines, evidence of empowerment can be observed as teachers who begin the project with little technology experience become enthused and infused with the capabilities of the technology. Teachers also begin using the nomenclature of GIS and become comfortable conversing in technical circles. And, they reach out to draw others into the fold and consider taking on new challenges:

> Being able to spend time on the modules and playing around to get what I wanted helped me develop my skills with My World. I feel comfortable trying to build my own lesson now, involving my school as a training site. If I get brave enough to push through the paperwork, I'd like to take my students through the field trip that we did with CoastLines, because that is a truly awesome experience. Loved it!

As evidenced by the following comment offered after the summer institute, an important empowering feature of CoastLines was the trialability (Rogers, 2003) offered by practice teaching:

> It is an EXCELLENT idea to recruit student "guinea pigs" to test drive our new skills. Technology is sometimes difficult to learn and VERY difficult to teach. Practicing with

> students gives teachers the confidence building that we need in order to implement the technology effectively.

Empowerment was measured in the CoastLines pre- and post-project surveys as the ability to troubleshoot problems with GIS software oneself, looking forward to integrating GIS into instruction in the future, expecting to be successful when using GIS in instruction, and having a good sense of what problems may arise when trying to integrate GIS into teaching practice. The items about troubleshooting and anticipating problems showed particularly impressive and statistically significant ($p < 0.05$) gains, with the "ability to troubleshoot problems oneself" moving from 37.1 % to 80.0 % agreement and "having a sense about problems" increasing from 45.8 % to 81.3 %. The other two items started with nearly 70 % agreement (probably because of outcomes the participants anticipated) and ended just as high.

7.6.5 Relevance

Providing pathways for making CoastLines relevant to teachers were the five core areas of research for the LTER network. The core areas provided foci for teacher and student investigations and afforded connections to the curriculum taught at participating schools. Pursuant to Rogers (2003), connecting the core areas to standards helped make the GIS technology innovation more compatible with the needs of the potentially adopting teachers and enhances the observability of the innovation. Teachers are very savvy adopters and must be convinced of the relative advantage of the innovation:

> The GIS lessons on the Everglades and the subsequent field trips were the most effective aspects. Connecting the field work to specific GIS gave me lots of insight and ideas on how to develop a program in my class (on any subject). GIS is now at the place where the internet was 8 years ago. We can see what a great tool it is, but how to integrate it into a class, the lessons, and the timeline so that it is an effective tool that helps students learn the content and helps to reach the objective of the lesson is the big question.

Teachers connected their teaching to the five core areas of research of the LTER program via state standards for science education (Table 7.3). As evidenced in the following quote from an implementation plan submitted by a participant, most teachers focused on concepts more readily explored with geospatial technologies, disturbance patterns and population studies:

> I will implement a three-period exploration of niche ecology in my 11th-grade marine science class. During the first period, we will use My World to study the influence of topography on habitat niches in the Florida Coastal Everglades (FCE) LTER site. Then, we will use GPS units to gather data about topography and habitats in a nature preserve near my school. Finally, during the third period, we will map our findings and compare them to the conditions at the FCE LTER. I will be investigating the Everglades National park using a weeklong study that will include an introduction of GIS and data gathering, a trip to the national park and incorporating the gathered data to construct a map using the GIS software.

One remarkable "Aha!" moment related to relevance occurred during a fall 2008 Webinar. There, a teacher who was resistant to using GIS came to understand how to connect it to her curriculum. During the Webinar dedicated to making such connections explicit, an older teacher stated that she did not see how she could integrate GIS into her already packed curriculum. Another participant took up the challenge and explained that the teacher could use GIS-based activities to replace activities that teach key concepts less effectively (i.e., expressing the relative advantage of GIS). The reticent teacher took the advice to heart, implemented GIS in her middle school classroom, and has proudly shared her students' work with the project staff. The work included GIS projects and PowerPoint presentations on the ecology of the Everglades.

7.7 Lessons Learned

Science Approach implemented Senge's (1990) learning organization approach by keeping in continual dialogue with the project participants, fostering discussion among project staff, and remaining flexible. This strategy helped CoastLines adapt to systemic events outside of its control (such as the economic downturn and its effects on the Miami-Dade Unified School District) and reinvent itself in response to teachers' concerns, needs, and suggestions. An excellent example of project flexibility occurred when teachers, at the end of the first week of the summer institute, became concerned about how they were going to interact with students during the second week of the institute. In collaboration with the teachers, project staff rewrote the second week agenda and created a structure that was much more comfortable for the teachers. One advantage of Science Approach's small organizational size is that change can be implemented relatively easily and realigning the project to create the results its members truly desire happens on a day-to-day basis.

7.8 Changes Made Over Time

As a result of the first year evaluation, CoastLines implemented a number of changes for project year two. First and foremost was an increased recognition of the importance that extrinsic rewards play in motivating project participants and fostering commitment to the project. As noted above, CoastLines encountered declining motivation from participants after the summer institute, when most of the stipends had been paid, permanent My World software licenses had been shipped to participants' schools, and teachers became busy with the fall semester. To help alleviate the "post-summertime blues" in project year two, the stipend payment schedule was adjusted so that a larger amount was held out until a participant has provided evidence of successful implementation in the classroom. Distribution of permanent My World software licenses was delayed in cohort two in comparison to year one: teachers only received a permanent school license after completing all requirements of the project. The fall Webinar schedule for year two was also adjusted to be less demanding than the schedule in year one and allow for greater attendance flexibility.

Another significant change was a shift from accountability based on hours spent with the project to a system where teachers must accomplish a specified list of tasks to graduate from CoastLines. Year two participants benefited from knowing exactly what had to be accomplished for the project and could track their status from the CoastLines Web site. Conducting the project in this manner engendered a better sense of accomplishment and feeling of autonomy, two important andragogical requirements.

Finally, owing to the controversies about peer teaching and practice teaching in year one, peer teaching was dropped from the schedule in year two and practice teaching to students took place in a more structured manner. Greater time was allocated to GIS skill development and less time was dedicated to having teachers manage students during the institute. Teachers who participated in any project year continued to receive support throughout the duration of the project.

7.9 Recommendations for Practice

Several recommendations for practice fell out from the 2008 CoastLines experience:

1. Like the old maxim "pray to God, but row to shore," GIS-based professional development initiatives need to pay attention to extrinsic desires in addition to theoretical ideas of intrinsic motivation. Although teachers are deeply motivated by inner drives and psychological states, stipend schedules, timing of incentives, and even the food offered at professional development events go a long way toward encouraging commitment to a project and fostering implementation of an innovation.
2. When properly structured, practice teaching appears to be a strong technique for promoting instructional comfort with a technology, fostering a sense of empowerment and confidence, and easing the complexity of implementing GIS as a teaching innovation.
3. Choice of software appears to be influential in reducing the complexity of implementing GIS as an innovation. My World has performed well for the CoastLines project.
4. Patience is a virtue in GIS-based professional development. Often, the most reticent and apparent non-adopter will convert to an ambitious innovator when given the appropriate cue.
5. Flexibility is critical to andragogy. As teachers negotiate the process of personal and professional transformations, the project plan must remain flexible enough to adjust to the needs of adult learners. Project managers and staff must also understand that they are being transformed as the project is transforming others.
6. Connecting the GIS innovation to each teacher's instructional needs cannot be underestimated. Compatibility with instructional standards, bureaucratic hazards,

and the time available for GIS-based instruction all help sell the relative advantage of GIS as an instructional innovation.

7. Relative advantage, trialability, and compatibility can be enhanced, and complexity reduced, by providing localized and customizable lessons, ready-to-use data, and support for adding one's own data to pre-built GIS projects.

7.10 Future Research

Evaluation research conducted for the 2008 CoastLines project has demonstrated that the diffusion of innovations, andragogy, and self-determination theory frameworks can be useful in designing and interpreting the results of a GIS-based professional development intervention. The original CoastLines professional development model, developed primarily from experience instead of theory, can now be revised with the wisdom gained from theoretical introspection and empirical results. Consistent with a learning organization approach, this process of model revision continued to take place throughout the life of the project.

Empirical results drove the first revision. A preliminary component analysis conducted to validate pre- and post-project survey scales designed to categorize participants according to the five elements of the CoastLines professional development model indicates that responses to the pre-project survey items focus on three of the hypothesized elements: relevance, competence, and commitment. The two remaining elements – empowerment and comfort – could potentially be confounded with or be precursors to the three identified factors.

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Chapter 8
The Inquiring with GIS (iGIS) Project: Helping Teachers Create and Lead Local GIS-Based Investigations

Cathlyn D. Stylinski and Cassie Doty

Keywords Community-based • Local investigations • Watersheds • Youth education

8.1 Introduction

Local environmental investigations can engage students with science content, while helping link prior knowledge to new understanding. Geospatial technologies offer powerful visualization and analysis tools for these community-based activities (e.g., Bodzin, 2008; National Research Council, 2006). Like other information technologies, they can also expand opportunities for student-centered inquiries (e.g., Varma, Husic, & Linn, 2008), illustrate complex scientific phenomena (e.g., Bell & Trundle, 2008; Gordon & Pea, 1995), and improve technological skills and attitudes (e.g., Baker & White, 2003). Furthermore, GIS can dramatically extend the classroom experience, allowing students to make real-world applications and develop crucial information technology skills that are fundamental and expanding components of most occupations.[1]

Despite their value, geospatial explorations, particularly locally based activities, present many challenges for classroom teachers. These challenges include limited skills and time for acquiring and preparing local datasets, limited training opportunities and resources appropriate for the classroom, and limited administrative and technological support (e.g., Kerski, 2003; National Research Council, 2006). Even when they have access to geospatial software, many teachers are not using it or do so in limited ways (Edelson, 2008; Kerski, 2003; National Research Council, 2006;

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[1] Bureau of Labor Statistics, http://www.bls.gov/oco/ocos042.htm#outlook, accessed April 10, 2009.

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J. MaKinster et al. (eds.), *Teaching Science and Investigating Environmental Issues with Geospatial Technology: Designing Effective Professional Development for Teachers*,
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White, 2008). One of the chapter authors (Stylinski) conducted a survey of 17 leaders in GIS education from university, national and regional organizations, and research institutions. Survey respondents described the status of GIS integration in K-12 schools as "abysmal" and "challenged." They described "small pockets of excellence surrounded by large oceans of ignorance," and categorized usage as "excruciatingly varied….[T]he capability of educators extends from stunningly inadequate to consistently inspiring." These trends parallel overall information technology use in schools, much of which is limited to low-level applications such as word processing, email, and drills (e.g., Bebell, Russell, & O'Dwyer, 2004; Becker, 2000; U.S. Department of Education Office of the Under Secretary, 2003).

The *Inquiring with GIS* (iGIS) teacher professional development project sought to take advantage of the benefits of geospatial technology as a tool for teaching and learning, while addressing educational needs and challenges. With funding from the National Science Foundation's Innovative Technology Experiences for Students and Teachers (ITEST) program, the iGIS project helped teachers incorporate authentic GIS investigations into their classrooms to enhance students' scientific understanding and interest in technology-based careers. Through the professional development experiences, teachers learned to use and apply geospatial technology and the iGIS unit in the examination of human impact on their local watersheds. Teachers and students used GIS to delineate watersheds, calculate percent impervious surface, and estimate stormwater runoff using techniques similar to environmental scientists and resource managers. Dr. Cathlyn Stylinski led the project with staff at the University of Maryland Center for Environmental Science Appalachian Laboratory and partners at the University of Wisconsin, Madison (content support), Northwestern University (curriculum support), and The Learning Partnership (evaluator). This chapter reviews the theoretical framework, design, and outcomes of the iGIS project.

8.2 iGIS Theoretical Framework

The iGIS project built on the theory that local investigations are a valuable and effective approach to learning. In addition to having students engage content relevant to their lives, community-based activities legitimize students' prior knowledge (e.g., familiar places, issues, organisms) and allow them to use this knowledge to enhance their understanding of new concepts (Carlsen, 2001). Lieberman and Hoody (1998) suggest the local environmental context can serve as a "…framework within which students can construct their own learning." These authors further provide evidence of improved academic achievement, reduced disciplinary issues, and increased engagement and enthusiasm. Such investigations also have the potential to expand students' awareness and knowledge of their local environment – a critical first step towards environmental stewardship (Fishman, 2005).

Watersheds provide a particularly useful focus for local real-world investigations (Donahue, Lewis, Price, & Schmidt, 1998). They come in all sizes; can be delineated for any stream flowing near students' schools or homes; combine concepts from multiple disciplines including ecology, chemistry, biology, physics, geology, and social studies; and connect curriculum content to authentic issues outside the classroom walls. Furthermore, both children and adults harbor common misconceptions about watersheds and the water cycle (National Environmental Education and Training Foundation/ Roper Starch Worldwide, 1998; Shepardson, Wee, Priddy, & Schellenberger, 2007). With their landscape-level visualization and analysis capabilities, geospatial technologies are particularly well suited to improving students' understanding of watershed concepts (Bodzin, 2008; Donahue et al., 1998) and provide an opportunity to apply geospatially based environmental data in authentic and meaningful ways.

The iGIS design also drew from effective teacher professional development features identified in two seminal research papers – Penuel, Fishman, Ryoko, and Gallaher (2007) and Garet, Porter, Desimone, Birman, and Yoon (2001). First, effective professional development activities should focus on improving and deepening teachers' content knowledge, as teachers confident in content will allow for more student discussion (National Research Council, 2000). For geospatial technology, this includes understanding the intersection between technology, subject matter content, and pedagogy – in other words, technological pedagogical content knowledge (e.g., Bednarz & Bednarz, 2008; Doering, Velestsianos, & Scharber, 2008; MaKinster & Trautmann, this volume). Second, there should be proximity to practice; that is, professional development activities should help teachers prepare for classroom situations. For technology-based professional development, providers should imitate the kind of teaching participants promote, and teachers should use technologies in ways that parallel their own classroom use (Basista, Tomlin, Pennington, & Pugh, 2001; Easton, 2008; Linn, 2003; Vrasidas & Glass, 2005). Proximity to practice can be supported by mentoring or coaching by professional development staff during the school day, which Varma et al. (2008) found particularly effective in their technology-intensive teacher education program. It may include curriculum-linked professional development (e.g., Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003), which can be a powerful way to promote changes in teaching practices (Cohen & Hill, 2001). Third, there should be opportunities for active learning, which occurs when teachers are engaged in meaningful discussions, planning, practice, and reflection. As described by Penuel et al. (2007), teachers are more engaged and better able to understand underlying curricular framework when materials are tailored for their classrooms, when implementation of these materials is planned, when they have the opportunity to observe others teaching these materials and be observed in their own teaching, and when they can review student work. Fourth, there should be good coherence with teacher professional lives, including alignment with professional development, other training activities, and state/district standards and assessments. Teachers' interpretation of this alignment is most relevant, as this affects how they perceive the experience and ultimately apply it in the classroom. Fifth, effective professional development promotes *collective participation* involving teachers from the same school, grade, or subject. As described by Garet et al. (2001), Penuel et al. (2007), and others, discussions and collaborations are likely to be more productive and support sustained changes in teaching practices when teachers have similar goals and challenges. Sixth, many professional activities are too short and provide little or no follow-up support during implementation.

Thus, effective professional development should be of an extended duration, allowing time for active learning, including discussions of students' preconceptions, practicing strategies, and receiving feedback. Finally, Penuel et al suggest that, although it is not directly part of the professional development experience, providers must consider and supply resources necessary to support classroom implementation.

8.3 iGIS Design

8.3.1 Participants

From 2005 to 2009, 69 middle and high school teachers from the Central Appalachian region of Maryland, West Virginia, and Pennsylvania participated in the iGIS project in one of four cohorts (Fig. 8.1). Teachers were recruited throughout this region via the project website; email solicitations; phone calls to science supervisors, school principals, and science teachers; and presentations at local schools, district meetings, and regional conferences. Recruitment also occurred through word of

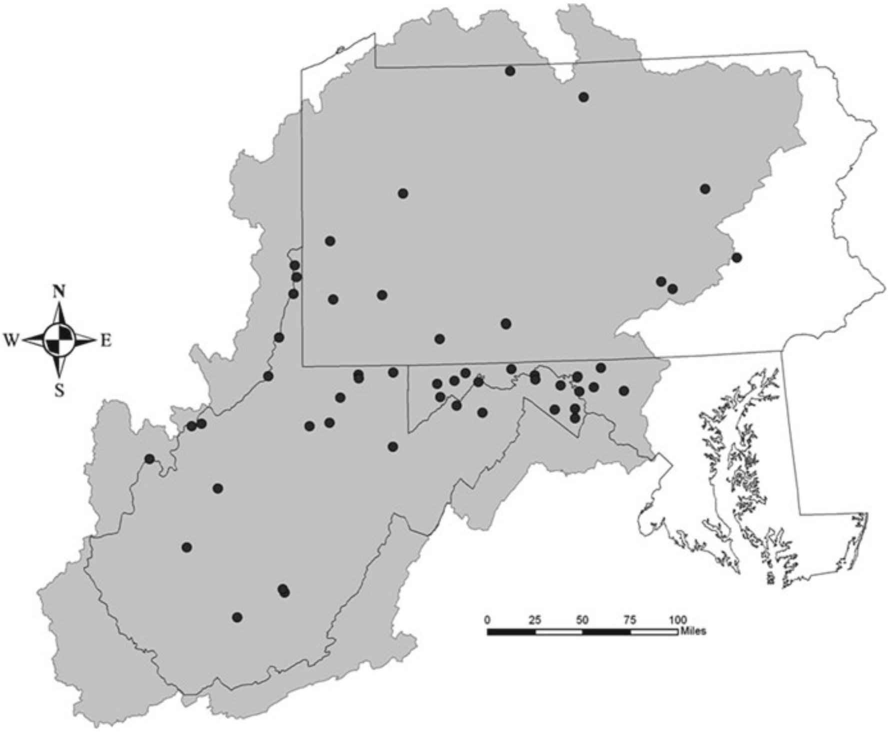

Fig. 8.1 iGIS target area (*grey*) and iGIS teacher participants' schools (*circles*)

mouth, especially from past participants. While the target region was quite extensive, *collection participation* was promoted by limiting participation to those teaching middle or high school science courses that incorporate water cycle and land use concepts (environmental science, earth science, general science, and biology) and encouraging teachers from the same school to apply (through school visits, calls to principals, and asking applicants to promote the project with colleagues). Ultimately, participants included four, three, and five pairs of teachers from the same school in the first three cohorts; the fourth cohort included one pair plus four teachers from the Maryland Department of Juvenile Services. Most iGIS teacher participants were mid-career and certified in their subject areas, had a Masters degree, and taught at schools in small towns and rural areas. Most had little or no prior experience with GIS. Each teacher participant received a stipend ($1,575), iGIS unit and datasets, GIS desktop software program (school-wide license), GPS device, various GIS and watershed video and print resources, access to watershed lending kits, and optional university graduate credit (tuition/fees were not covered). A significant portion of the stipend was withheld until participants completed all project requirements including classroom implementation or until participants could offer a reasonable explanation for their inability to implement. Many participants traveled significant distances to attend workshops in Frostburg, MD, and summer institutes at host schools; they were compensated for all travel expenses. One hundred and fifty-five Central Appalachian teenagers also participated in the project through summer youth institutes. Youth participants received a small stipend, inflatable globes, and professional-looking portfolios with maps created during the institute. Each year two iGIS teachers hosted an institute at their middle or high schools. As hosts, they handled logistics (e.g., catering, computer access, field trip buses), recruited and selected youth participants, and received an additional stipend for their efforts.

8.3.2 Structure

The iGIS project was extended in duration to 120 contact hours, with each cohort of teachers participating from May through June of the following year. The project was nonresidential, although travel expenses were provided for teachers living a significant distance from workshop and institute locations. After project refinements, the professional development activities were as follows:

- Mid-May – One- to two-day introductory workshop. Teachers reviewed the project goals, watershed focus, and requirements, were introduced to the staff and each other, started initial lessons in the iGIS curricular unit, learned basics of the GIS software, and reviewed logistical issues (e.g., loading the software/data on home computers for the online session).
- June, approximately four hours per week – Four-week online session. Each week teachers worked independently through one to two unit lessons, submitted answers to unit reflection questions and posted screengrabs of their GIS work, and shared

asynchronous online comments on the units' strengths and weaknesses with project staff and each other. Answers and comments were due Thursday of each week, with staff feedback provided within a few days.

- Early July – One-week core workshop. Teachers completed the unit; worked through each optional activity in the unit, including collecting biotic, abiotic, and geographic data at a stream site; attended lectures and field trips with environmental scientists and GIS specialists to get a deeper understanding of stream ecology and environmental hydrology; created local datasets necessary for implementation of the iGIS unit; started working on curriculum adaptations; and prepared for upcoming summer youth institutes.
- Mid-July and immediately following the core workshop. One-week youth institutes. From 9 am to 1 pm, teachers led youth through hands-on activities from the iGIS unit, allowing teachers to practice their new skills and knowledge and examine youth work. At each institute, a local GIS professional gave a presentation on his or her own watershed and/or land use change work. Each GIS professional interacted with teachers and youth and helped assess youth work. After the youth departed each day, the teachers spent the afternoon reflecting on the morning's activities, planning for the next day, working on any unit adaptations, and developing classroom implementation plans.
- Mid-September and Mid-March – Two one-day follow-up workshops. Teachers learned about GIS careers and worked through several GIS career activities from the iGIS unit, reviewed key software functions, and shared implementation challenges, strategies, and successes.

Each professional development activity was designed to build directly on the preceding one. The iGIS project used a blended approach, which offered the strength of both face-to-face interactions and online learning (Dede, Ketelhut, Whitehouse, Breit, & McCloskey, 2009). This included giving participants opportunities to work both on their own and with peers and staff, to share opinions in different settings, and to spend less time away from home. Time away is a significant issue in rural areas where participants must drive long distances and often stay overnight to attend in-person events. Because retention problems can occur during web-based instruction, the online session was sandwiched between the in-person introductory and core workshops to reduce attrition, ensure assignments were completed on time, and promote online communication. Specifically, the introductory workshop established relationships among participants and with project staff and ensured confidence with basic GIS skills. The core workshop applied online works to complete and customize the iGIS unit (e.g., finalizing the unit's local stream site using sites proposed during the online session). After the spring and summer professional development activities, the project staff regularly emailed and telephoned participants during the school year to check on progress and help address problems or concerns. The iGIS staff also visited each participant's classroom to observe unit implementation, assist with any technical or pedagogical issues, and provide encouragement. Support continued beyond the yearlong professional development experience, including ongoing staff feedback,

Table 8.1 Teachers' participation in the iGIS professional development (PD) and curriculum implementation in their classroom

Cohort	Completed all iGIS PD activities (%)	Submitted the final report (%)	Implemented all or most of iGIS unit (%)	Implemented only some of iGIS unit (%)	Unknown or did not implement iGIS unit (%)
1 ($n=19$)	100	89	58	32	10
2 ($n=17$)	88	71	76	0	24
3 ($n=19$)	100	100	100	0	0
4 ($n=14$)	100	100	93	7	0

updated versions of the iGIS curriculum and software, and access to watershed lending kits. This extensive follow-up support was instrumental in achieving a high rate of classroom implementation (see Table 8.1).

8.3.3 Curricular Materials

Using the curriculum-linked professional development approach, the iGIS professional development centered on the iGIS unit, which explores human impacts on the water cycle and in watersheds. Students' preconceptions of the water cycle often lack understanding of the movement of water across the landscape as surface runoff and groundwater, and their understanding of a watershed is often quite limited – sometimes literally defining it as a shed that holds water (Shepardson et al., 2007). The iGIS unit addresses these misconceptions and gives students an opportunity to understand water quality issues in their communities. The unit focuses on teaching with the tool, rather than about the tool (also see McAuliffe and Lockwood, this volume), and thus incorporates GIS functions only when necessary for visualization and analysis. Others have promoted this strategy including one GIS education leader who recently responded in a survey that, "Too much time has been focused on the nuts and bolts of the software and data, and too little time on what problems students can solve with these tools or how they can turn information into knowledge" (Stylinski, unpublished).

In the first pilot year, the project staff created an extensive unit (23 lessons) that compared spatial patterns among large watersheds in the Central Appalachian region. Most teachers only implemented a small portion of the unit (see Table 8.1), and many expressed concern about the length and complexity. In addition to the main unit, optional activities were also developed to support more local explorations. Because these units were more difficult to enact, the project staff thought teachers would incorporate them only after becoming skilled with the main unit. Instead, participants were more enthusiastic about the local activities and wanted to use them in place of or before the main regional investigation. As one teacher explained, "Students reacted better when the lesson progressed from the concrete (local stream/watershed) to the abstract (regional ecosystem/watershed)."

With this feedback, the project staff significantly revised the unit – removing the regional-level investigation and centering the unit on a local stream site selected by the teacher. The Understanding by Design framework (Wiggins & McTighe, 2005) was used to ensure that revised activities supported targeted student outcomes. First, following a backward design, project staff identified Maryland, West Virginia, and Pennsylvania education standards. Staff members then developed enduring the following enduring understandings and essential questions for the iGIS unit:

Enduring understandings

- A stream site is affected by environmental conditions in its upstream watershed.
- Human land use choices can impact the water cycle and stream ecosystems.

Essential questions

- Will a new housing development affect a local stream site?
- What should we consider to understand health of a stream at a particular site?
- Are there ways to reduce negative impacts on local streams?

These overarching concepts and questions were "unpacked" into key knowledge, skills, and abilities, such as:

- Water flows from areas of higher elevation to areas of lower elevation.
- A watershed is all the land that drains to a particular site on a stream, lake, bay, or ocean. You can pick any site on a stream and draw its watershed.
- The water cycle includes evaporation, transpiration, condensation, precipitation, stormwater runoff, infiltration, and groundwater movement.

Second, the iGIS staff determined assessment evidence that would allow students to demonstrate the desired results. This consisted of reflection questions on specific concepts and performance tasks. Sample reflection questions include "Is it possible for a stream to flow north? Explain your reasoning" and "Recall how you used GIS software in this lesson. Describe how this would have been difficult to do with a paper map." For the performance task, students take on the role of a GIS specialist to report on how a hypothetical proposed housing development will impact a local stream site. This framework helped the project staff identify the need for additional scaffolding on the water cycle (e.g., using GIS software to explore changes in elevation along a stream) and for more opportunities to identify students' preconceptions about the water cycle, hydrology, and watersheds.

As the final step, the staff created a five-lesson unit that met these desired results and incorporated this assessment evidence. The unit begins with students discussing local development pressures, created when urban residents from nearby metropolitan areas seek cheaper rural housing options. Students use GIS and aerial photos to predict how a proposed housing development will impact their local stream site then take a step back to examine concepts necessary to understand this impact. First, students consider human impacts on the water cycle by (1) creating their own water cycle model, comparing it to a provided model, and explaining how a new housing development would impact each component of the water cycle and (2) by reading about impacts of impervious surfaces on stormwater runoff and proposing ways to reduce runoff in their schoolyard. Next, students use GIS to examine water movement across their landscape. Using only prior knowledge and provided stream and elevation layers, they delineate the area that they think impacts their local stream site (often ignoring elevation data and drawing a circle around the site). They then are guided more closely to examine the provided layers to determine stream flow direction, identify the stream network for their stream site, and predict the flow direction of provided "raindrops" near their stream site. They also read about watersheds. Applying this information, students redraw the area impacting their stream site (i.e., watershed) and compare this to their initial prediction. They then examine an impervious surface layer with the proposed housing development, clip it to their watershed, determine the percentage and distribution of impervious surface in their watershed, and use these results to calculate the volume of stormwater runoff with and without the proposed development. Finally, they return to their original question and use their findings and new understanding to describe how the proposed development will impact their stream site and propose ways to reduce this impact. The unit activities parallel those of professionals conducting a watershed analysis intended to determine stormwater runoff and other impacts on a particular stream site.

In addition to the lessons, the iGIS curricular materials include extensive guidance on implementing each lesson in the classroom, technical support documents, and optional activities (e.g., creating a physical model of a watershed, collecting field data at the local stream, and examining infiltration and runoff for different surfaces in the schoolyard). Curricular materials were provided in Microsoft Word format so that teachers could revise text as needed. Teachers were strongly encouraged to connect the hypothetical housing development to actual development projects in their communities and incorporate schoolyard and stream field trips into their unit. Such trips were supported by the optional activities and were thoroughly reviewed and practiced during the core workshop and youth institute. Sixty-five percent of teachers led students in a stream field trip as part of their iGIS unit, based on a follow-up survey with 50 of the 55 teachers in cohorts, one, two, and three.

8.3.4 Classroom-Friendly Software and Data

The iGIS unit uses a GIS software program developed by Northwestern University specifically for the classroom environment (*My World GIS*, Edelson et al., 2006). This program allows teachers and students to complete sophisticated GIS functions using an intuitive interface with separate sections for accessing data layers, visualizing spatial patterns, analyzing data, and creating new data layers. Instructions are straightforward with minimal jargon. Many complex functions are automated, and common hurdles are addressed (e.g., easy navigation to needed data layers and recommended file names for new data layers).

Teachers have to create their own local data layers before implementing the iGIS unit in their classroom. To minimize this challenge, only a few local data layers are required, and all are given names to match the unit text. These data layers were relatively easy to create using provided iGIS regional baseline datasets and My World GIS software. Teachers created these layers by subsetting provided regional layers (e.g., streams, elevation) or delineating new points or polygons using these provided layers as a guide (stream site, proposed development). They had to acquire only one new layer (local aerial photo), which was done in one simple step using the software. Ultimately, each iGIS teacher received the following CDs:

- Training CD (sample data to work through the unit)
- Regional CD (data of their region used to create the local data layers)
- Classroom CD (all local and regional data needed to complete the unit; this is the only CD that needed to be loaded on school computers)

Teachers created all local layers during the core workshop; they also received written instructions in case they wanted to create additional layers in the future. Initially, the Regional CD was only needed during the core workshop to create the Classroom CD. However, teachers could return to it for additional environmental data layers as they developed expertise and expanded their GIS classroom investigations. All other resources needed to enact the unit and optional activities were provided, including a school-wide My World GIS software license and access to iGIS watershed lending kits. These included materials such as schoolyard rainwater infiltration kits with multiple GPS devices and digital cameras and stream sample kits with PASCO water quality probes.

8.3.5 Delivery

The iGIS professional development highlighted active learning through discussion, practice, reflection, and planning. Before and after working through the iGIS unit, the project staff reviewed and discussed the iGIS Understanding by Design framework so that teachers were aware of targeted learning goals and strategies. Like students, teachers worked through each unit lesson and optional activity, including completing the unit worksheet ("report") and answering unit reflection questions. During the online session and the core workshop, teachers met virtually and face to face to reflect and share challenges, concerns, strategies, and successes for teaching the unit and promoting learning. To gain a better understanding of environmental hydrology concepts, participants also interacted with scientists during lectures and on field trips examining different stream sites, various land cover types, and hydrological gauging stations. On the last day of the core workshop, participants prepared for the youth institute (see below) and began work on their implementation plans for the upcoming school year. In planning, participants described how the iGIS unit complements existing curriculum, considered relevant local or state content/skill standards, weighed any unit adaptations, and formed plans for assessing student work. In afternoons of the youth institute, participants completed these implementation plans and worked on unit adaptations. Based on the follow-up survey with the first three cohorts, many teachers did some customization of the iGIS unit, including deleting lessons or parts of lessons (63 %), adding lessons or parts of lessons from other sources (54 %) or iGIS optional activities (40 %), and switching the order of lessons or activities (42 %).

The weeklong youth institute provided iGIS teachers with an opportunity to plan, practice teaching, observe other teachers, be observed, and review student work. Teachers worked in teams to colead the half-day nonresidential institutes. The institutes had two goals – (1) enhance teachers' skills with GIS and the iGIS unit outside the pressures and constraints of the classroom and (2) promote teenagers' interest in GIS investigations and science/technology careers. Skill development served as the initial goal of the program, which led to participant teachers guiding youth through each lesson in iGIS unit. But this focus created a setting too much like school in what was intended as an informal education experience. Further, the school atmosphere led to poor youth engagement. So, the focus shifted to developing youth interest in GIS. The iGIS staff provided an outline of the overall institute structure using selected hands-on and field-based elements from the unit and optional activities like sampling a local stream site and measuring rainwater infiltration rates at the host school campus. Teachers adapted this structure, modifying activities, adding additional activities (e.g., geocaching with GPS units), and developing a schedule. Teachers were strongly encouraged to use a "paperless" approach for institute activities. That is, they only used their unit binders as a guide and instead orally presented activity goals and key steps with visual supported from a computer and LCD projector as needed; this allowed youth to apply their developing skills with the intuitive software to complete the tasks. This approach was modeled in the workshops and encouraged for classroom implementation (the iGIS unit includes short written summaries of each lesson that can be distributed to classroom students). One teacher captured the pedagogical benefit of this approach, saying, "[Working] without using our [unit] binders made us 'think' about what we were teaching and why." Teachers also helped develop and apply a rubric to assess youth participants' work through an embedded assessment. Individuals or teams prepared and orally presented portfolios of their spatial investigations.

Throughout, the project staff tried to be nimble in the professional development to meet the individual needs of each teacher and cohort. During the workshops and throughout the classroom implementation, the staff gathered verbal feedback on current concerns and questions and then adapted delivery and activities as needed. For example, at times staff expanded discussion and planning time, added an additional field activity, or streamlined the implementation report. Other providers have highlighted the value of this rapid response for project success (Granger, Morbey, Lotherington, Owston, & Wideman, 2002; Varma et al., 2008).

8.4 Outcomes

The impact of the iGIS project on teacher participants was examined using surveys, informal discussions, and teacher artifacts, including project applications and classroom implementation plans and reports; findings from this evaluation are summarized below.

To ensure full participation, a significant portion of teachers' stipends was deferred until completion of the final implementation report, which contributed to low attrition rates. Overall, most teachers participated in all project activities, submitted their implementation reports, and implemented all, most, or portions of the iGIS unit in their classrooms (Table 8.1). The percentage implementing all or most of the unit increased substantially after the first cohort, presumably due to curriculum refinements described earlier. One teacher volunteered in an email that "The new [unit] accomplishes the task of introducing GIS and watersheds without overwhelming the course taught. And although I will miss some of the parts…this one is more realistic and will more likely be integrated into classes." In the follow-up survey conducted with the first three cohorts two or more years after participating, 77 % of respondents reported using the iGIS unit at least once since the yearlong iGIS project, and 78 % reported they plan to use it again. Twenty-two of the 50 respondents reported using GIS beyond the project's minimum requirement of integrating the iGIS unit into one course. This included integrating GIS into other existing courses like mathematics and AP environmental science, creating new GIS-based courses like "GIS and the Environment", using GIS for other environmental science field investigations, and assisting with other GIS-based teacher professional development.

There was evidence of good coherence within the iGIS project with teachers' broader professional development goals and with district standards and assessment (Table 8.2). Penuel et al. (2007) identified teachers' perception of coherence as a key element in their study. Teachers also found communication with other teachers useful. One teacher commented, "I learned a lot of great ideas from the other [teachers] as they shared how they implemented GIS in the classroom and how they extended concepts." Another wrote, "I…liked hearing the stories from the other teachers so that I can see that I'm 'about right' in terms of my teaching new things with other teachers making similar efforts." However, teacher feedback also indicated that they needed more opportunities for this.

Based on pre- and post-project surveys, teachers' self-reported GIS skills, knowledge, and abilities improved dramatically (Table 8.3), especially for our final cohort. One teacher noted, "I felt I was lacking in integrating technology in the classroom and now I feel comfortable using GIS software, GPS units and water quality probes with my students – I'm excited!" By contrast, their overall computer skills and comfort did not change much, possibly because the iGIS unit constituted only a small portion of their yearlong teaching activities. Two or more years after participating in the iGIS project, a majority of participants believed the project had a moderate to high impact on their knowledge of GIS and land use impacts within their watershed (96 % and 83 %, respectively) and their skill integrating this knowledge into the classroom (92 % and 94 %, respectively).

Most teachers gave very positive feedback on the yearlong project, with some improvement after piloting activities and materials with the first cohort (Tables 8.4 and 8.5). Overall, many participants felt that the professional development activities were useful, effective, and appropriate and gave them confidence to integrate the iGIS materials into their classrooms. One teacher highlighted the strong proximity to practice, commenting, "Everything had a purpose to why we were doing it.

Table 8.2 Teachers' rating of the coherence of and communication during the iGIS professional development activities. Data are the average percentage of teachers who gave the two highest ratings on a four-point scale ("agree" and "strongly agree," "satisfied" and "very satisfied," "frequently" and "very frequently," or "useful" and "very useful") for five or six iGIS professional development activities. Data are not available for cohort one

	Cohort 2 (%)	Cohort 3 (%)	Cohort 4 (%)
The workshop built upon what you learned in the previous iGIS workshop(s)	87	97	95
The workshop was consistent with your goals for professional development	89	97	98
The activities in this workshop were well aligned with your state or district standards and curriculum frameworks	91	94	94
The activities in this workshop were well aligned with state and district assessments	92	90	91
How useful was your communication with other participants?	82	86	83
How frequently did you communicate with the other participants?	59	66	68

Table 8.3 Teachers' rating of their GIS and computer skills. Average percentage of teachers who gave the two highest ratings on a four-point scale ("somewhat high" and "very high" or "somewhat comfortable" and "very comfortable") before (pre) and after (post) participating in the iGIS project

	Cohort 1		Cohort 2		Cohort 3		Cohort 4	
	Pre (%)	Post (%)	Pre (%)	Post (%)	Pre (%)	Post (%)	Pre (%)	Post (%)
How would you rate your current skill using GIS software?	6	56	0	83	5	83	0	93
How would you rate your current understanding of what GIS is?	11	81	6	92	5	83	14	100
How would you rate your ability to integrate GIS activities into your curriculum?	33	69	12	92	26	78	7	93
How would you rate your current skills using computers as a tool when teaching students?	78	81	82	92	79	89	46	64
How comfortable or uncomfortable are you using computers as a tool when teaching students?	89	94	82	92	89	94	86	79

Also all of this is directly transferable to the classroom." Teachers also indicated the experience would improve their teaching practices. One teacher wrote, "The experience has real concrete value. I can immediately apply the material to my curriculum and enhance it." Another volunteered:

> I am presenting a poster session at the AGU conference in San Francisco [titled] 'How [the Earth System Science Education Alliance] has changed how I teach.' I hope you don't mind but I've included iGIS in my presentation [as it has played a key] part of tying all the spheres together.

Table 8.4 Teachers' feedback on the iGIS professional development activities. Data are the average percentage of teachers who gave the two highest ratings on a five-point scale ("most of the time" and "always") for five or six iGIS professional development activities

During the workshop how often did you feel	Cohort 1 (%)	Cohort 2 (%)	Cohort 3 (%)	Cohort 4 (%)
What you were doing was not too difficult?	75	76	78	88
Excited about what you were doing?	56	81	80	78
Not bored?	56	80	76	77
Not frustrated or anxious?	58	46	61	74
Eager to learn more about the topic?	65	91	86	80
That what you are learning can be used in your classroom?	71	92	86	77
That you were involved in effective professional development?	80	99	90	89
That the instructors could relate to teachers like you?	89	88	86	83
That your needs as an adult learner were adequately met?	83	96	88	91
That what you are learning will help you be a better teacher?	76	94	88	84

Table 8.5 Impact of the iGIS professional development activities on teachers' satisfaction and confidence. Data are the average percentage of teachers who gave the two highest ratings on a five-point scale ("satisfied" and "very satisfied") or a four-point scale ("confident" and "very confident") for five or six iGIS professional development activities

	Cohort 1 (%)	Cohort 2 (%)	Cohort 3 (%)	Cohort 4 (%)
How satisfied or dissatisfied are you with this workshop?	76	98	91	89
How confident are you that you will be able to integrate what you have learned in this workshop in your classroom?	67	89	87	79

Teachers felt the youth institute was particularly valuable and reported that it enhanced their confidence to work with the unit and software. As one teacher said, "The highest order of learning is teaching. To teach the students, work through their problems and answer their questions [during the institute], was a great experience." Another wrote, "Having real students to 'practice' with makes me much more comfortable as I decide how I will implement GIS this fall." Many were surprised by the teenagers' technological literacy. One teacher noted, "I've seen how students can pick up the iGIS skills very quickly, so it makes me more confident in teaching it." Several highlighted the benefit of learning from other teachers. One wrote, "It was great to get practice with large group instruction and individual assisting. I feel much more confident now in my ability to implement the curriculum" while another said, "We all had things to contribute and we learned things from each other as well as the students. Too often we don't get a chance to be observers in educational settings." One participant even remarked on the value of working with students from another school system saying, "I lost all fear." With the fourth cohort, half of the institute was devoted to an open-ended investigation with teachers and students working as a team. Most teachers were quite pleased with this format, noting it helped them enhanced their skills while "…nurturing a genuine curiosity and interest of the young students." Teachers did identify some problems during the youth institute including the need to be "more student centered with less teacher-talk" and insufficient time to complete the open-ended investigation. However, most teachers felt the institute achieved the dual success for teachers and youth, noting youth "…had the opportunity to learn GIS in a non-threatening, supportive environment that interspersed outside 'games' with hands-on computer learning."

8.5 Recommendations and Conclusions

Findings from the iGIS project support other studies that highlight critical features of effective professional development (e.g., Garet et al., 2001; Penuel et al., 2007). Specifically, the yearlong project included a strong focus on curriculum and content; good coherence; access to essential classroom resources; opportunities to plan, practice, discuss, and reflect; and extensive support to tailor and implement a provided curriculum in the classroom. This approach helped ensure high participant retention and classroom use. All of these elements laid the foundation for classroom implementation, with extensive follow-up support serving as a linchpin to successful implementation. Squire, MaKinster, Barnett, and Luehmann (2003) also found that extensive technical, emotional, and personnel support was critical for technically innovative curricula.

Results here also illustrate that, with the appropriate resources, teachers new to GIS can create local data layers and adapt GIS-based investigations for their communities. For the iGIS project, these resources include a standards-based unit focused on content and using classroom-friendly software and data. Wilder, Brinkerhoff, and Higgins (2003) have shown that professional development focused on generating datasets offers teachers ownership, better understanding of content, and experience with real-world problem solving. Squire et al. (2003) note that adapting curriculum to local needs and contexts can be a very powerful learning experience for teachers.

The iGIS informal youth education experience was a particularly effective component of this K-12 teacher professional development and illustrated that emphasis can be placed on promoting youth interest without compromising opportunities for teachers' classroom skill development. Other ITEST-funded projects have also identified these teacher-youth experiences as critical components of their professional development activities (McAuliffe and Lockwood, this volume; Moore, Haviland, Whitmer, & Brady, this volume; Parker et al., 2010). The summer institute experience was required by the NSF ITEST grant program and aligns with elements of effective teacher professional development regularly cited in the literatures, such as review of student work (e.g., Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet et al., 2001; Penuel et al., 2007). However, neither formal nor informal learning research has specifically examined approaches, challenges, and benefits of integrating K-12 teacher training within out-of-school settings. Results presented here indicate that involving K-12 teachers in informal learning experiences can (1) enhance teachers' confidence and understanding of new content and skills outside the pressure and constraints of the classrooms and (2) increase informal science education opportunities, especially for youth in rural areas with few such offerings. Research is needed to better understand benefits to teacher education and informal learning and to determine best practices.

Teacher feedback suggested that the iGIS project could have benefited from more collaboration and promotion of communities of practice, particularly by having participants communicate and work together beyond the iGIS professional development activities. Promoting communities of practice within and beyond the confines of formal professional development has been shown to be particularly effective at supporting adaptation and implementation of provided curricular materials (Avery & Carlsen, 2001). Such interactions might have helped mitigate significant challenges that iGIS teachers faced during implementation (expressed during informal discussions). These included insufficient time, insufficient technology facilities, delays in software/data installation, and difficulty storing and accessing student data files. Researchers of technology-based teaching and learning have cited similar challenges (e.g., Ertmer, 2005; Hew & Brush, 2007), including a recent review of other teacher education projects funded through the NSF ITEST program (Parker et al., 2010). Technology has changed considerably over the course of the 5-year project. For example, almost all US schools now have classrooms with Internet access (Parsad & Jones, 2005), including many of the rural schools involved in the iGIS project. As a next step, the iGIS project staff is exploring the use of a regionally based online software program (developed by the National Geographic Society) to support local watershed investigations. Of course, new hurdles associated with online geospatial inquiries will need to be considered, including restrictions on student Internet access and data file size (and thus spatial resolution). Additionally, because yearlong efforts like the iGIS project require considerable financial support and may hamper efforts to reach teachers who do not frequent professional development offerings, the project staff is also examining ways to adjust their blended learning approach to increase online training and support while still maintaining critical face-to-face interactions.

Lasting change in teaching practices takes time and often does not occur in the first year of implementation (Basista et al., 2001; Squire et al., 2003). The iGIS project provides evidence of initial changes in teaching practices with a majority of past participants continuing to use the iGIS unit in at least one course and almost half using GIS beyond this course. Teacher surveys and pre-/post-embedded assessment suggest improvement in content knowledge of iGIS teachers' classroom students (data not included here); however, it is difficult to directly link iGIS teacher professional development to changes in student achievement and participants' teaching practices (e.g., Bebell et al., 2004; Blank, de las Alas, & Smith, 2008). To understand this more broadly, the project staff has joined colleagues at Educational Development Center and TERC to examine links between technology-intense teacher education and changes in teaching practices using NSF ITEST projects as a study group.

Overall, research on geospatial technology in K-12 education is still in its adolescence and lacks a clear agenda (Doering et al., 2008). There are many unanswered questions, including the following: What pedagogical models are being used or should be used to support integration of geospatial technologies into the classroom? What knowledge/skills/attitudes should we target in teacher education? How do geospatial tools foster learning transfer from one subject to another? How can geospatial technologies promote student-centered learning? What teacher education strategies are most effective at helping teachers integrate geospatial technologies into their classrooms? Additionally, like many other teacher professional development efforts (Blank et al., 2008; Parker et al., 2010), the iGIS project used customized instruments and depended on teacher self-reporting, which presents validity concerns and limits broad application of the findings (Brinkerhoff, 2006). To convince teachers and administrators of the importance of spatial fluency and the efficacy of geospatial technologies in fostering learning, education researchers and practitioners need to develop and apply a universal, valid, and robust set of evaluation instruments.

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Chapter 9
Communities for Rural Education, Stewardship, and Technology (CREST): A Rural Model for Teacher Professional Development

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> *It's integrating technology completely. It's building a curriculum on the heritage and strength of our community. It's an example of how to engage kids in authentic learning. This is the biggest example we have of what education is supposed to look like.*
>
> Principal of a CREST school

Keywords Coastal ecology • Rural education • Sustainable learning communities • Place-based education

9.1 Introduction

Technology often provides an opportunity to engage student interest in self-directed learning. While technology can be a hook for students, a variety of obstacles such as a lack of technical expertise and lack of support often cause teachers to avoid using technology as an inquiry tool in the classroom (Groff & Mouza, 2008). This chapter examines a model for professional development created with the goals of building greater teacher IT fluency and of increasing student interest and awareness in STEM fields. This model was developed, implemented, revised, and evaluated through the Island Institute's Communities for Rural Education, Stewardship, and Technology (CREST) program, a 5-year project working with grades 6–12, funded by the National Science Foundation. CREST focuses on building curricular connections between schools and their communities while integrating technology in a nonhierarchical learning environment.

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The investigation detailed in this chapter identifies the theoretical frameworks guiding the CREST professional development model, examines the design principles, and describes how this methodology leads to geospatial technology integration in the science curriculum while providing concrete examples of project implementation using GIS in middle- and high-school science classrooms. Project outcomes and evaluation findings provide suggestions for best practices and identify areas for additional research.

9.2 Theoretical Framework

The CREST professional development model entails weaving (1) sustainable learning communities (SLCs), (2) integrated technologies, and (3) place-based education, into a highly effective pedagogy that addresses the STEM education needs of rural schools. This methodology was originally developed with 99 participants (44 teachers and 55 students), from Maine's island and remote coastal communities, and has grown to include more than 150 teachers and students from 16 schools. Participating schools range from unique one-room schoolhouses (with enrollments as small as eight students grades K-8) to more traditional regional schools with student populations of several hundred students grades 9–12. These 16 schools are spread across Maine's 5,300-mile coastline, and five are within island communities accessible only by boat. The CREST program model provides practical experience for delivering professional development effectively with rural school districts.

Maine's rural coastal and island schools are excellent collaborators for developing and piloting a professional development model because of their small school sizes, engaged teachers and students, and their close school and community connections. CREST's participating schools exemplify the strengths and challenges of working in rural districts. These strengths include a strong sense of community allowing schools to partner effectively with local leaders, provide students a chance to interact with people of all ages, and encourage individualized attention through small class sizes. Their small staff sizes and geographically isolated locations often make it more difficult for teachers and students to access professional development opportunities. While this model has proven successful in a rural environment, many of its core concepts are transferable across educational settings.

CREST focuses on delivering database development, GIS mapping, website design, and ethnographic research skills in an interdisciplinary approach that reconnects students to their communities and motivates teachers to integrate technology and create partnerships to work in interdisciplinary teams. The CREST framework is built upon four key theoretical constructs, focusing on integrated technologies, place-based education, resource stewardship, and nonhierarchical learning. The CREST professional-development model uses an integrated-technology approach that includes ethnographic research methods, website design and coding, and geographic information systems (GIS). This chapter will briefly describe the constructs of that approach and will present best practices and outcomes from the training and curricular integration using GIS, examples specifically.

9.2.1 Integrated Technologies

In recent publications, there is increasing recognition that the end result of IT literacy is not knowing how to operate computers but using technology as a tool for organization, communication, research, and problem-solving (Eisenberg & Johnson, 2002). The CREST program has three primary IT focus areas: geographic information systems (GIS) mapping, website development, and digital ethnography. Teachers learn to use GIS and incorporate Global Positioning System (GPS) technology to gather and analyze local community information. Through website development training, participants learn basic coding languages and create webpages as a platform for telling local stories. Digital ethnography creates skills in teachers and students to gather local data through interviews and original research and communicate that information through the creation of digital videos. While each technology area is different, all three require the acquisition and enhancement of database-management skills. The result is an integration of database-management competencies – the foundation of IT careers – with the capacity for creative inquiry. Teaching the technologies of GIS, website design, and ethnographic research methodologies, with a focus on database management, allows greater thought for data organization, storage, and easy retrieval of information to assist students in answering pressing community questions using the technologies. This integrated approach will serve both teachers and students well in the future as their level of IT literacy expands.

To use it effectively in the classroom, teachers must feel comfortable seeing technology as a tool in their toolbox, not an add-on, but an effective means for fostering inquiry-based learning to be integrated seamlessly into the curriculum. The curricular outcomes of CREST, technology, and place-based projects offer an effective pedagogy that allows teachers to draw on technology as appropriate in their day-to-day instruction. Students become experts in technology, allowing the teachers to focus on how the concepts can be applied to their curriculum. In this way, implementation becomes meaningful for all. Students are empowered to become technology leaders in the classroom while teachers are free to guide the learning process by framing inquiry-based questions (Kerski, 2008).

One participating teacher has a unit designed to help students better understand the state's resource-based economies, which are heavily reliant on fishing and farming. In the past, this may have included completing research from online and printed materials culminating in a written paper. Following participation in CREST, the teacher recognized the potential to integrate the technologies as effective learning tools for this unit. Students met the same learning goals by creating maps to analyze patterns of the state's agricultural land, digitally recording interviews with local business owners and creating short video vignettes, and writing an accompanying narrative. All three pieces were then integrated into a completed website to share the findings from this unit. Student leaders who had attended CREST summer institute were integral in teaching their peers how to use the technology to complete the assignments central to completing the unit.

This chapter focuses primarily on the outcomes from the GIS portion of the CREST professional development model. In practice, many participating teachers learn each of the three different technologies offered through CREST by participating in different training sessions each year during the annual summer institutes, while some decide to focus on learning one technology more deeply. In this way, educators expand the technology tools available in their toolbox, and are able to integrate them as appropriate. This method encourages participants to develop new ways of teaching with, rather than about, technology.

9.2.2 Place-Based Education

CREST's place-based education strategies provide youth and adults – teachers and students – with opportunities to connect with their communities and public lands through hands-on, real-world learning experiences on community-based projects (Conservation Study Institute, 2006). At the project's core are the assumptions that (1) schools and young people are among our most important community resources, (2) CREST's place-based education projects must begin locally (they are not prepackaged), and (3) all project results must answer questions that are relevant to that community.

All of CREST's place-based activities reflect the desired outcomes common to most place-based education strategies: enhanced community and school connections, increased understanding of and connection to the local place, increased understanding of ecological concepts, enhanced stewardship behavior, increased academic performance in students, improvement of the local environment, improvement of schoolyard habitat and its use as teaching space, and increased civic participation (Powers, 2004). In addition, a place-based education program, such as CREST, enables rural communities to meet needs and solve problems by using the total community environment and its human resources (Young, 1980). CREST's place-based education projects are informed by research such as that completed by the Harvard Graduate School of Education (Bryant et al., 1999, Abstract) that validates the power of this approach to transform schools and communities "by grounding students' education in the local community and intentionally moving away from didactic approaches to standardized schooling," concluding that "as schools and communities work together to design curricular goals and strategies, students' academic achievement improves, their interest in their community increases, teachers are more satisfied with their profession, and community members are more connected to the schools and to students."

CREST projects are carried out inside and outside of the classroom and encourage teachers to invent new ways of engaging students in the education process through combining the power of the school's technology infrastructure and the store of local knowledge found among students' families, friends, and neighbors. CREST's 16 participating schools have partnered to create authentic learning experiences with over 70 organizations, from community groups such as local historical societies to state agencies such as Maine's Department of Marine Resources.

CREST's approach to place-based education uses Orion's recommendations for engaging a broader student audience in science education by the following: (1) placing learning in an authentic and relevant context, beginning with concrete concepts and moving toward more advanced and abstract thinking, (2) creating opportunities to make connections through a variety of learning styles, (3) integrating the outdoor environment as a key component in the learning process, and (4) relating to both the cognitive and emotional aspects of learning. Using the community as a resource and an outside classroom fosters a more holistic approach to teaching and learning about science, and it helps students become better prepared citizens (Orion, 2007).

Place-based education strategies lend themselves particularly well to incorporating geospatial technology, as GPS units become tools for data collection within the students' backyards and GIS software facilitates inquiry and analysis of local community data. In one example from a CREST high school, participating teachers partnered with a local marine nonprofit organization to teach broad ecological concepts linked to local resources. They connected with one of the driving forces of Maine's economy – the lobster-fishing industry. This made the learning more relevant to the students, empowering them to act as consultants to fulfill a real-world need identified by a local lobster hatchery. The hatchery raises and releases larval lobsters into the local embayment to promote a healthy lobster population. Students worked with the lobster-hatchery manager and local lobstermen to identify habitat areas that are particularly favorable for larval lobster settlement. Students used GIS to analyze bottom type, bathymetry, and water-temperature data to locate these important lobster settlement areas and inform the hatchery manager as to where to best release their larval lobster stock.

This student-led project enabled teachers to meet state and national science learning standards while empowering students to use geospatial technology for fully interdisciplinary learning. Students learned science content while becoming more informed citizens with a deeper understanding of their local environment and maritime industries – a driving force behind the local economy.

9.2.3 Resource Stewardship

The third essential design component of the CREST project is the continual provision of opportunities for participants to develop a sense of resource stewardship. As a measure of this intent, all CREST place-based IT projects have a focus in resource conservation, entrepreneurial economic efforts, preservation of local history, and other community- development activities, all of which are considered an intrinsic part of the resource-stewardship approach (Sobel, 2004). CREST's hands-on digital-ethnography, GIS-mapping, and website-design projects have begun to reconnect students with their communities and have helped them develop a deepened appreciation for the natural resources around them and the value of preserving fragile ecosystems and seafaring traditions.

As students and teachers complete research that help to manage and conserve their local resources, their capacity to become deeply engaged can have a significant impact on their educational and career-path decisions. This becomes particularly relevant in rural areas where natural resources are often the mainstay of local economies, for it heightens the need for students to understand the degree of interrelatedness – the mixing of societal functions and natural processes (Orr, 1992).

The CREST principle of guiding students toward a sense of resource stewardship adapts Hungerford and Volk's research that identifies a linear progression of three categories that contribute to environmentally responsible behavior (1990). This progression begins with understanding an issue and imparting content knowledge. Understanding is followed by ownership, where students become personally invested in the problem. The third variable in this progression is empowerment, when students have a strong understanding of the issue and believe that they have the power to make a difference (Hungerford & Volk, 1990). Within the CREST program, teachers and students work together to identify a local community question that is of interest to students and that allows teachers to meet the requirements of content knowledge. Once the question has been identified, students become leaders within the learning process, using technology to gather information, engage in a cycle of inquiry, and become a community resource by finding and suggesting solutions to local community problems.

In an example from one CREST school, students were interested in learning why their local clam flats were closed and how the flats could be reopened for harvesting. To answer these questions, students mapped historic clam flat locations, completed population-dynamic field studies using GPS to plot inventory locations, and identified potential sources for clam flat contamination. At the same time, students interviewed old-time clammers and scientists from the state's Department of Marine Resources to learn why the flats were closed and to better understand the clamming industry's past, present, and possible future. Students created maps and videos of their findings, which they presented to the community, identifying the reasons and action steps for reopening local clam flats. Students made important connections with their community through this process while meeting national science-education standards.

9.2.4 Nonhierarchical Learning

The focus on place-based education and resource stewardship has been especially effective when combined with the fourth of CREST's design components: a nonhierarchical learning environment. Each participating CREST school forms a sustainable learning community (SLC) comprised of teachers, students, and community members. SLC members receive technology training and meet regularly to plan for curriculum integration. The SLC structure takes to heart Mitchell and Sackney (2000) observation that, within a learning community, the learning of the teachers is every bit as important as the learning of the children and that a learning community consists of a group of people who take an active, reflective, collaborative, learning-oriented, and growth-promoting approach toward both the hidden dynamics and the problems of teaching and learning. They experience and express different forms of leadership, confronting uncomfortable organizational truths, and they search together for shared solutions (Hargreaves, 1994).

The CREST project focuses on creating a learning environment that enables both students and teachers to learn and ask questions freely, working together in school-based SLCs to formulate project ideas, and provide a network for local technical support. During the Summer Institutes, CREST staff members facilitate activities designed and structured to promote participant interaction on a peer-to-peer level: teachers become students and students become teachers. This design principle embodies Senge (2000) findings for the need to see the "learning organization" approach to education as more than just talking and working in groups, but instead a process that involves everyone in expressing their aspirations, building their awareness, and developing their capabilities together. Through the creation of this nonhierarchical learning environment, the enhanced sense of "buy-in" to the learning process and the increased level of student empowerment lead to a shift in interpersonal dynamics as teachers discover the wealth of knowledge and resources that their students bring to the table.

This structure not only leads to student empowerment but also helps teachers experience the power of collaborative learning, through the discussion and reflection of new ideas found within a learning community. Having teachers experience first-hand an effective learning community is a necessary step to allow them to see the value in creating and sustaining these structures within their own classrooms (Whitehouse, Breit, McCloskey, Ketelhut, & Dede, 2006). Particularly as the CREST and SLCs work together to integrate innovative technologies in the classroom, teachers take on the role of facilitators guiding the inquiry questions, while students lead the integration of the technology and become self-directed learners. When teachers become comfortable in this new role of facilitators, it enables them to become lifelong learners and imparts the same qualities to their students while creating a collaborative atmosphere of professionalism in the classroom (Holland, Dede, & Onarheim, 2006).

Once CREST students and teachers have learned new IT skills and concepts side by side during the Summer Institutes and regional trainings, they continue to gather regularly in their school-based SLCs throughout the school year to engage in an ongoing cycle of inquiry, gathering data, examining student and professional work, and giving and receiving meaningful feedback. Students whose ancestors settled Maine's islands bring to the table a vast store of collective knowledge and can contribute equally with teachers to the research, development, and execution of projects. Not only do students bring the enhanced value of local knowledge to their learning; they also become technology coordinators in the classroom. Throughout the process of technology integration, students provide training and tech support in the classroom, taking on leadership roles and helping teachers feel more comfortable with integrating technology in their day-to-day classroom instruction.

As one example of this process in action, many CREST schools have created annual geohunts (GPS-assisted treasure hunts) around their local school campus or within their neighboring community. Students who have received training in using GPS units during the summer create small geocache experiences for younger grade levels in their school. Students become leaders among their peers, teach other students GPS technology, and create experiences for younger students to learn more about their local school grounds and/or surrounding community.

9.3 Structure for CREST Professional Development

The CREST professional development (PD) model consists of a series of dynamic technology trainings, college and career-awareness events, and nonhierarchical team-building activities that occur over a 5-year period. The longevity of the program is an important aspect to its overall success in increasing teacher IT fluency and student interest in and awareness of STEM-related fields. Professional development experiences are more effective when delivered over a long-term period and coupled with a variety of training opportunities tailored to different needs and learning styles (McClurg & Buss, 2007). As such, the CREST program developed a series of iterative events throughout the 5-year program designed to provide intensive technology training, foster inquiry-driven learning, promote healthy SLC structures, raise awareness of and interest in STEM-related careers and college opportunities, and offer a consistent support mechanism for schools throughout project implementation.

At the core of the PD model are the annual Summer Institutes, where the most intensive trainings occur. These are weeklong workshops where participants receive structured training in one technology focus area (GIS, ethnographic research methods, or website-design coding), engage in team building, and plan curriculum. This approach provides participants with the necessary technology skills and allows them to work together as a team to develop the curriculum plan for how the technology will become integrated in individual classes. CREST Summer Institutes support a nonhierarchical learning model in which both teachers and students attend the workshops together as SLC teams and learn side by side. Individual SLC members select a technology focus area to become an expert within their team; this method grows the technology capacity of the group through the knowledge of its individual members.

The Summer Institutes' structure, however, places as much emphasis on transferring technology skills as on forming strong sustainable learning communities, through team building and curriculum planning time. For example, participants receive intense technology training in the morning and in the afternoon have time to process how their new skills will be used in the classroom during curriculum planning time. Curriculum planning time is structured in a variety of ways throughout the week including time for individual planning, collaborative work with SLC teachers and students together, and workshops spent with technology trainers to brainstorm integration strategies. In this way, CREST works to increase technology integration and inquiry-driven learning while giving participants the freedom and support to design their own curriculum within which integration takes place.

In order for teachers to feel comfortable in this nontraditional role as facilitators – not deliverers – of knowledge, they need a professional development model that prepares them for this role. Through a variety of team-building activities, student-led goal-setting protocols, and shared responsibilities during the implementation phase, teachers learn how to step back and let the students drive the learning.

During the Summer Institutes' technology training, teachers and students work together to learn geospatial skills through hands-on, collaboratively applied activities. These learning activities follow project-based learning (PBL) models, allowing participants to apply new technology skills within a particular context to problem-solve and engage in a cycle of self-directed learning (Eggen & Kauchak, 2001). By modeling the step-by-step process for participants when implementing projects back at their schools, teachers and students feel more confident in their own technological capabilities and how they can be applied to answer a variety of place-based questions. Through project-based learning, the technology training focuses on imparting larger geospatial concepts through in-depth analysis, and by having participants begin using GIS tools to ask questions about why, and not just where the problem occurs (Baker & White, 2003).

This focus on geospatial concepts is reinforced by working with participants on how to apply the technology skills using existing school infrastructure and working across many software platforms. The CREST program provides modest technology equipment (such as four recreational-grade GPS units) to increase the technological capacity within participating schools, but implementation primarily occurs through preexisting available technology infrastructure. The infrastructure at each participating school widely varies, reinforcing the need for technology trainers to teach across multiple geospatial-software platforms. To accomplish this, CREST provides beginner and intermediate classes in each technology area. The GIS training courses provide a variety of software package options including QGIS, Google Earth, ESRI's ArcExplorer Java Edition for Education (AEJEE), and ArcView. The software package CREST trainers use is determined by the participants' project needs and the technology infrastructure available at each school. While this complicates the delivery of technology training, it ensures that learning is targeted and directly applicable to the classroom.

Throughout the weeklong intensive training, participants learn software basics and then apply their new skills by completing an individual project, so that they each leave with a finished map product. This allows participants to experience the project from conception to completion, an important training aspect for modeling what will occur during the implementation of projects throughout the year. Individual project topics vary, but all are focused on practicing skills that will be necessary for successful project implementation throughout the school year.

Many projects focus on local data collection and analysis using GPS units, while others focus on searching for and centralizing data layers to plan for curricula to be implemented back at school.

Throughout the school year, project staff members regularly follow up with participants, assess their needs, and ensure that teams stay on target with the implementation timeline that is created during the Summer Institutes. CREST staff members visit each school quarterly and provide additional on-site technology trainings and place-based curriculum-development seminars as necessary to keep the momentum of implementation at each site going. Professional development reform strategies are incorporated by continuing the PD experience throughout the school year by providing additional training within the classroom creating greater chances for lasting change in teacher practice (Garet, Porter, Desimone, Birman, & Yoon, 2001).

Just as important as providing strong professional development training opportunities is the development of a strong partnership between the PD provider and participating schools. CREST schools were recruited through ongoing relationships with teachers and administrators in each of the communities. Creating long-term partnerships builds in a level of trust and accountability, for both sides to work together collaboratively, and this assists not just for recruitment but also for higher levels of retention throughout the project. The importance of building good relationships and providing adequate on-site support led the CREST project to hire one full-time staff member whose job is to support CREST schools through all stages of project implementation. This staff member provides technical support and assists with curriculum planning via remote communications (email, and phone calls), creates how-to guides for frequently asked technology questions, and is available as a resource for teachers to attend classes during project implementation to assist with technology questions, becoming a support mechanism for teachers as they begin to incorporate this new pedagogy. Employing these supportive implementation strategies has proven effective through exciting curricular and project outcomes within the schools.

9.4 Project Outcomes

The CREST program was originally designed and delivered with 11 middle and high schools over a 3-year period. Further funding extended the program an additional 2 years, allowing for the addition of a new cohort of middle- and high-school teachers into the project to test the educational model for professional development. This brought the total number of participating schools in years four and five to 16. Qualitative and quantitative program evaluation instruments, including pre-/post-surveys, school site visits, and phone-interview protocols, measured the success of the CREST professional development model. Throughout the program, these instruments collected stories of successful curriculum development, measured gains in teacher and student confidence using new technology skills, and tracked levels of teacher change in technology implementation in the classroom and increases in student motivation in STEM-related fields. Below is a discussion of these findings from 11 schools after 4 years of participation and five schools with 1 year of experience in the CREST program.

All 16 participating schools incorporated geospatial technology into the curriculum in some form. While the types of projects varied depending on the community questions that SLC teams identified, three general categories naturally emerged:

- Environmental management: teachers and students use their surroundings as backdrops to study ecology and environmental-science concepts. Examples include using GPS to gather information about local clam flats, lobster habitat, and heirloom apple orchards and combining this student-collected data with GIS analysis to make recommendations to the community about resource management.
- Community planning: classes partner with towns and local organizations to plan for future land uses within their surrounding communities. Examples include students serving as consultants for a local town using GPS to collect data on mooring locations and harbor characteristics for the town's harbor-management plan, students creating a land-use plan for a local park by mapping potential trail locations and other park features, and students researching the feasibility of different alternative-energy sources to provide "green" power for their school building.
- Historical preservation: teachers and students partner with local historical societies and local senior citizens to learn about the cultural heritage within their communities. Project examples include students mapping the gravesites of sailors from a victorious early twentieth-century America's Cup sailing team comprised entirely of local residents and studying changes in residential and commercial development by digitizing old city maps and comparing them with current development patterns.

Pre-/post-surveys following the CREST Summer Institutes technology training captured gains in participant confidence in using geospatial technology in the classroom. Participants answered a series of skill-based questions indicating confidence levels on a six-point Likert scale. Questions ranged from measuring confidence in completing specific tasks, such as collecting and downloading GPS data, to understanding broad geospatial concepts such as how GIS can be used to guide inquiry-based learning to answer local community questions. The 2008 Summer Institute survey showed statistically significant changes in comfort-level responses ranging from 1.0 to 4.0, with mean gains of 2.5 for the middle-school teachers and 2.6 for the high-school teachers (Nave, 2009).

The confidence levels of technology implementation reported during the Summer Institutes are reviewed during the school year as CREST evaluates the level of teacher change in technology integration. Among veteran CREST teachers, 90 % integrate the technologies fully, 3 % do so for special projects only, and 7 % do not use the technologies. Among the teachers from the new CREST schools (after less than 1 year in the program), 36 % fully integrate the technologies, 28 % do so for special projects, and 36 % do not yet use the technologies (Nave, 2009). Teachers reporting full integration do not view the technologies as strategies to be reserved for special occasions nor do they view the technologies as instructional “add-ons.” As one middle-school teacher observed, “CREST has helped me teach the way I have always wanted to teach” (Nave, 2008). As has been observed in many other pedagogical research studies, these results reinforce findings that teacher engagement in long-term professional development experiences increases the impact that the PD experience has on teacher practice (Shields, Marsh, & Adelman, 1998; Weiss, Montgomery, Ridgway, & Bond, 1998).

The ultimate goal for the CREST project was to build in a level of sustainability that would continue past the 5-year grant period. The large percentage of teacher-change data showing technology integration is one measure that the CREST model is effective for creating lasting change. The pedagogical shift toward connecting schools and communities through place-based and project-based learning using technology is powerful once teachers experience the impact this type of learning has on their students. Another aspect of sustainability is continuing the relationships built before and over the 5-year grant period between project staff, teachers, school administrators, students, and community partners. These strong partnerships are one of the keys to successful program delivery, and continuing to communicate and to value each partner as a resource for the future keeps the lines of communication open and innovative ideas flowing. Similarly, the sustainable learning community structure of teachers and students encourages participants to foster and build a local network of educators who have experienced this professional development model and who are committed to supporting each other to continue this method of teaching and learning.

9.5 Successful Practice and Ongoing Research

CREST is unique in the design elements that define the PD model and that work toward changing pedagogy throughout an entire school site, not just in individual teachers’ classrooms. Below is a description of this successful practice at work; it is useful as a guide when seeking to design similar professional development experiences.

CREST works with teachers across disciplines, including not only science teachers but also history, English, art, horticulture, technology, and math teachers. It provides a new context in which to think about how teachers interact and learn from one another. When pairing an art teacher and an economics/technology teacher together on a project, cross-pollination begins to occur and students benefit from that idea sharing in more than just one class. They begin to see connections and related applications of what they are learning in different classrooms, and their attitude about school begins to change into one of participatory learning instead of merely listening on the sidelines, asking “What does this have to do with me?” Geospatial technology works seamlessly with this cross-discipline learning strategy, enabling analysis at local, regional, and global scales to make real-world connections to learning in the classroom while meeting state and national standards in education (National Research Council, 2006).

Program evaluation has identified several key factors that lead to higher degrees of success in participating CREST schools implementing local projects including effective SLC teams and administrative support. Teachers begin to feel supported and comfortable in trying new ideas when there is a team of teachers in their building committed to the same goals of technology implementation. They also have more incentive to succeed in meeting their individual and team-project implementation goals because other team members are depending on their success. Critical to attaining these goals is the inclusion of school administration and leadership in developing the overarching SLC strategy for project implementation. When school leadership is vested in the SLC model, this style of teaching and learning becomes institutionalized, creating lasting, meaningful change (Nave, 2009).

While the CREST model provides one approach for delivering successful science professional development, there are several questions and complementary strategies that merit further research. CREST evaluation data has identified several successful means to affect teacher practice through professional development and has begun to measure baseline impacts on student motivation; this, however, is an area that requires further investigation. Additional research studies could identify factors and strategies that have positive outcomes for student motivation and correlate change in teacher practice with the effect on student motivation. The CREST model has been developed and tested in a rural environment; however, many of the program concepts could be applied in urban/suburban settings as well. Further research for transferring the model to urban/suburban schools would be a valuable way to test and refine ways in which this methodology may be used within a variety of professional development settings.

Integrating technology in the classroom often requires overcoming challenges, both technical and curricular. The growing accessibility of geospatial technology, coupled with effective professional development strategies, creates a powerful opportunity for integrating curricula and engaging students across disciplines and grade levels.

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Chapter 10
Curriculum-Aligned Professional Development for Geospatial Education

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Keywords Curriculum aligned • Hybrid • Learning for use • Environmental science

10.1 Introduction

The work described in this chapter is based on a perspective, built on a range of research on teacher learning spanning more than a decade, that teacher professional development is highly effective when designed to accompany particular curriculum materials. Teacher learning from the professional development is thus preparation for specific classroom instruction and ideally is designed to help prepare teachers for practice, guides them during practice, and creates opportunities for reflection on practice. In this chapter we present the theoretical underpinnings for our model of curriculum-linked professional development and describe a hybrid (face-to-face and online) professional development program for the *Investigations in Environmental*

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*Science: A **C**ase-based **A**pproach to the **S**tudy of **E**nvironmental **S**ystems (CASES)* curriculum materials (Edelson et al., 2005), which employ My World™ Geographic Information System software (hereafter referred to as GIS) to support student investigations into environmental impacts and decision-making processes.

Teachers face a host of challenges in learning to enact the *CASES* curriculum, an example of so-called coherent curriculum rooted in standards and benchmarks that link scientific ideas across multiple lessons and activities (Kali, Linn, & Roseman, 2008). First, *CASES* requires teachers to shift to an inquiry-based instructional approach. The professional development (PD) is designed to convince teachers that such a shift is advantageous to their students' learning, and it must provide them with the pedagogical and content knowledge to make this shift. Incorporating geospatial or other technology into PD has the dual challenge of teaching teachers both how to use the technology and how to integrate it into their teaching.

This chapter first addresses our PD design theory, focusing on general requirements for supporting curriculum adoption as well as specific issues surrounding technology applications. We then describe the learning theory that informs both the curriculum and the PD design. We apply this learning theory to the description of the curriculum, including a description of the GIS software and the specific PD design. We conclude with the lessons learned through our ongoing research on the PD and experience supporting teachers in using geospatial technology embedded in curriculum.

10.2 Professional Development Design

We employed a design-based research approach (Collins, 1992) to curriculum-aligned PD (Fig. 10.1). We looked at what we wanted the students to learn with respect to science standards, designed the PD using research-supported strategies, and evaluated the impact on teacher learning and practice on their students' learning. Finally, we used these findings to inform the next iteration of PD redesign (Fishman et al., 2003).

In this section we elaborate on findings using this model that ultimately inform the design of our PD supporting teacher use of geospatial technology (Kubitskey, Fishman, & Marx, 2003, 2004; Kubitskey & Fishman, 2005, 2006).

The challenging shift to inquiry-based pedagogy (Crawford, 2000), combined with the need to learn (1) new technology, (2) how to teach with the technology,

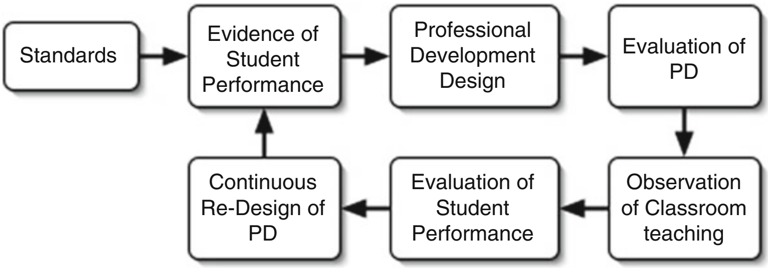


Fig. 10.1 Professional development design model (Fishman, Marx, Best & Tal, 2003)

(3) how to teach students how to use the technology, and (4) how to use the technology in inquiry, can be overwhelming to say the least. Teachers need PD to support this instructional transition (Audet & Paris, 1997). Based on our research and the literature, common goals of quality PD necessary for successful implementation of reform-oriented science curricula include the following. Teachers need to "buy-in" to the practice being taught at the PD (Kent, 2004; Kubitskey, 2006; Richardson, 2000, 2003). Good PD results in teachers joining a *professional community of practitioners* (Lave & Wenger, 1991; Loucks-Horsley, Hewson, Love, & Stiles, 1998; National Research Council, 1996; National Staff Development Council, 2001). Teachers need improved *subject matter knowledge* (Blakeslee & Kahan, 1996; Garet, Porter, Desimone, Birman, & Yoon, 2001; Kubitskey et al., 2003; Loucks-Horsley et al., 1998) and *pedagogy for science inquiry* (Kubitskey, 2006; National Research Council, 1996; National Staff Development Council, 2001). Professional development that motivates teachers to take up reform-oriented practices and provides subject matter and pedagogical knowledge should result in teachers' increased use of *inquiry science instruction* (National Research Council, 1996; National Staff Development Council, 2001; Watkins Jr, 2003), ultimately resulting in increased *student learning of science* (Garet et al., 2001; Loucks-Horsley, & Matsumoto, 1999; National Research Council, 1996; National Staff Development Council, 2001; Supovitz, Mahyer, & Kahle, 2000; Watkins Jr, 2003). The technology component embedded within the *CASES* curriculum structure can be seen as specialized subject matter with its own pedagogy for inquiry, especially relevant in reform-oriented inquiry instruction providing students with a mechanism to learn science.

Curriculum-aligned PD has additional goals in supporting teachers' instruction of specific lessons and a particular learning framework. In addition to the above goals, curriculum-aligned PD also provides teachers with a theoretical framework informing the curriculum design so that their modifications maintain the integrity of the units (Kubitskey, 2006). Teachers must understand connections between lessons across the curriculum and have the pedagogical tools and commitment to assist students in consistently making connections across and amongst the lessons in the curriculum (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Lin, 2008; Rivet, 2004; Singer, Marx, & Krajcik, 2000). Professional development must include goals specific to the technology. Teachers need to know how to install/support technology or know someone locally who can and also must know how to work with the technology. This is called *technology knowledge* (Margerum-Leys & Marx, 2002; Mishra & Koehler, 2006). Teachers also need to know how to teach students to use the technology and how to support the students' application of the technology as it relates to the curriculum task. Finally, one of the most important yet often overlooked components is knowledge of classroom management with technology. Combining these general goals, curriculum specific goals, and goals for incorporating technology is a challenge for PD designers (Table 10.1). Our curriculum-aligned PD focuses on teaching *with* geospatial technology, not teaching *about* geospatial technology (Kerski, 2001). Thus the strategies and content of our PD were informed by our research on student and teacher learning in the context of the curriculum and in using technology. We structured our PD to support the enactment of *CASES* by adopting the "Learning for Use" learning theory that it incorporates (Edelson, 2001).

Table 10.1 Goals of professional development

	Goals for general PD	Goals for curriculum-aligned PD	Goals for technology in curriculum-aligned PD
Content knowledge	To learn subject matter (Shulman, 1986)	To learn specific science content and background needed to teach the designated curriculum (Kubitskey et al., 2003)	How (geospatial) technology fits into the science and is used to meet the student learning goals in that context (Audet & Paris, 1997)
Pedagogical knowledge	To learn instructional techniques for teaching (Shulman, 1986)	Specific instructional techniques needed in the curriculum (creating and sustaining context, etc.) (Kubitskey, 2006)	How to set up for the classroom and manage the students as they use (geospatial) technology (Audet & Paris, 1997)
Pedagogical content knowledge	To learn how to teach the particular subject matter (Shulman, 1986)	Instructional techniques unique to the specific science content taught in the curriculum (Kubitskey et al., 2003)	How to teach students to use (geospatial) technology (Audet & Paris, 1997)
Curriculum knowledge	N/A	The theoretical constructs guiding the curriculum (Shulman, 1986)	How (geospatial) technology fits into the curriculum (Audet & Paris, 1997)
Technology knowledge	N/A	N/A	What (geospatial) technology is and how to use it (Audet & Paris, 1997)
Beliefs	Buy-in to the theoretical constructs (Guskey, 1986)	Buy-in to adoption (Kubitskey, 2006)	Buy-in to value added and need to use technology (Audet & Paris, 1997)

10.3 Learning for Use

Based on cognitive science research on learning and motivation and practical classroom experience, the goal of Learning for Use (LfU) pedagogy is to support learners in developing knowledge in a way that will be easily retrievable when needed in the future (Edelson, 2001). The four design principles of this framework align with a constructivist theory of teaching and learning. In particular, these principles specify that (1) learners learn when they construct and modify what they know, (2) this process of constructing and modifying knowledge structures is goal-directed, (3) contextual cues determine how knowledge is retrieved, and (4) learners must construct knowledge in a usable form before it can be applied (Edelson, 2001).

The LfU design framework consists of three phases of learning that support the development of knowledge structures in a usable form. For each LfU cycle, students experience a need for new knowledge through a *motivate* phase, *construct* new knowledge through their participation in activities, and *organize* this new knowledge to be used in future applications (Fig. 10.2).

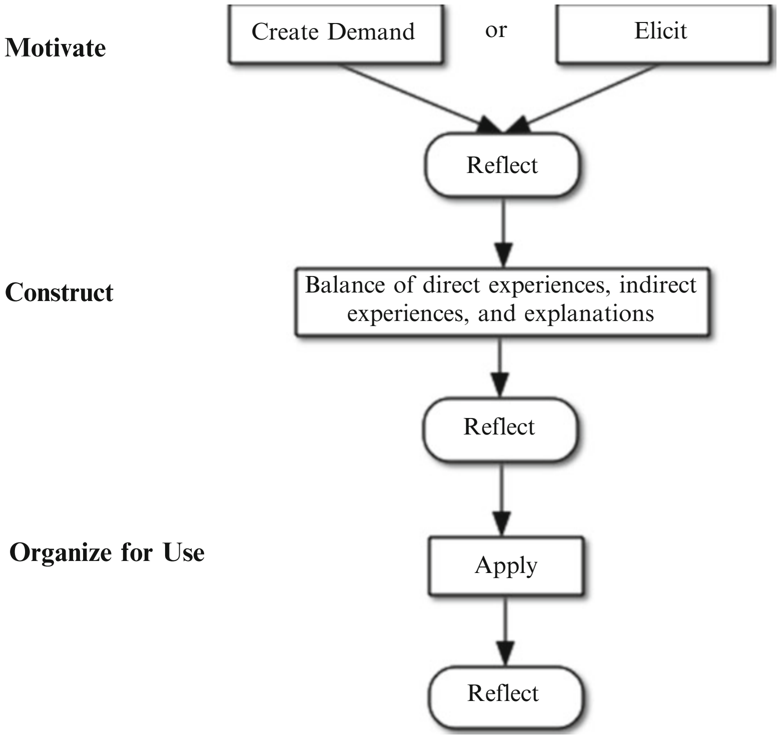


Fig. 10.2 Learning for use framework (Adapted from http://www.geode.northwestern.edu/investigations/overviewlfu.html)

10.3.1 Phase 1: Motivate the Need to Learn New Knowledge

The objective of this stage is to motivate learning through highlighting the utility of knowledge and skills. This can be accomplished through creating demand for this knowledge by presenting learners with a real-world problem that requires new knowledge or skills to solve. Alternatively, motivating activities can elicit curiosity by placing learners in a situation that exposes gaps in their understanding, which creates a need for new knowledge.

10.3.2 Phase 2: Construct New Knowledge

Building on their motivation to learn, learners then develop new knowledge and skills. They construct new understandings through a balance of indirect or direct experiences, modeling, instruction, and explanations. The activities within this phase include several inquiry-based learning opportunities that help learners construct new knowledge that will be useful for the final phase.

10.3.3 Phase 3: Organize Knowledge for Use

Finally, learners retrieve and use the knowledge they constructed. In this phase, students use their knowledge through practice, application to a task, or reflection upon knowledge previously constructed. Learners use the knowledge and skills they acquired from the knowledge construction phase to reinforce their understandings and expose the need for further knowledge construction.

10.3.4 Application of LfU

Motivation must precede knowledge construction, and to ensure appropriate retrieval, learners must organize their knowledge for use after they construct the knowledge and skills (Edelson, 2001). Traditional science curricula and PD tend to focus solely on knowledge construction. It is important to note that LfU draws attention to the *motivate* and *organize for use* stages. Learning for Use cannot happen if either of these two stages is overlooked in practice. These phases are not optional, but critical for successful learning.

Technology activities are merged with the LfU framework in our curriculum discussed below. GIS software is used in two of the three phases of the LfU framework: construct and organize for use. Geospatial technology activities are used to help students construct knowledge about the content and analyze multiple datasets related to the local context of the case to help inform their environmental decision making.

We use the LfU model both as the foundation of the curriculum at the center of this work and also as a principal design component of the PD supporting the use of geospatial technology in the classroom. In this way teachers' participation in PD serves to model the pedagogy they will enact in *CASES*. Next we describe the curriculum at the center of our PD, *CASES*.

10.4 Investigations in Environmental Science

Investigations in Environmental Science: A Case-based Approach to the Study of Environmental Systems (CASES) (Edelson et al., 2005) is a three-unit 1-year high school research-based environmental science course incorporating specifically designed geospatial technology as part of the instruction. Below is a brief description of the curriculum and the technology.

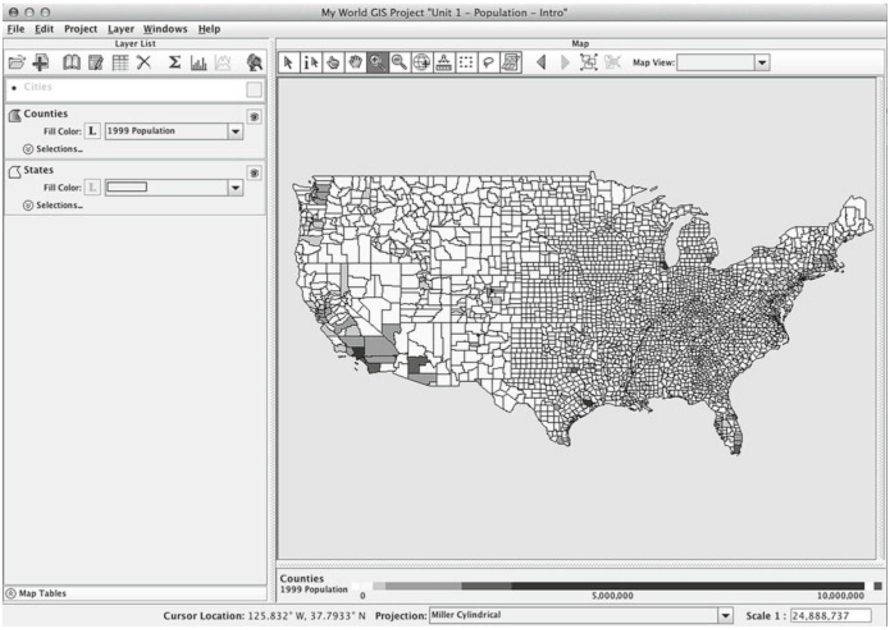
10.4.1 CASES

The CASES curriculum (Edelson et al., 2005), designed to engage high school students in a yearlong exploration of environmental science content, is the context for this professional development. The three-unit curriculum is organized around real-world cases bearing on the sustainable use of resources that provide a motivating context for learning fundamental scientific principles. The first unit of CASES, *Land Use*, covers issues of population and resources, with a content emphasis on ecology. It engages students in a case-based investigation of the challenge of land-use planning to minimize impact on a threatened upland ecosystem in Florida. *Energy Generation*, the second unit of CASES, introduces students to the environmental consequences of electrical power generation. This unit focuses on the growing demands for energy in the upper Midwest. Water Management, CASES' third unit, teaches students about water resources, with an emphasis on agriculture, soil, and water supply. Focusing on the case of water resource management in California, students investigate tensions between the natural supply of water and increasing human demand. As the curriculum unfolds across the units over the course of the year, students carry out inquiries with environmental data, conduct laboratory investigations, engage in extended research, participate in classroom discussion and debate, and use GIS software to visualize and analyze geographic data.

10.4.2 Geospatial Technology and CASES

A critical goal in development of *CASES* was to create a technology-integrated science course that used technology to (1) support authentic scientific investigations with data and (2) present concepts to students through dynamic, interactive representations. The National Research Council (2006) *Learning to Think Spatially* report stresses the usefulness of geospatial technology in teaching children to think spatially and the need to incorporate this into standards-based curricula. Leaving teachers responsible for integrating geospatial technology into their existing curricula is time consuming and significantly limits geospatial technology adoptions (Kerski, 2001). *CASES* requires that students use geospatial technology visualization and analysis tools to analyze real-world environmental data. Professional geospatial technology tools, such as ArcView™, are more powerful than necessary for the curriculum. *CASES* initially incorporated ArcView™, but *CASES*' developers and support personnel realized teachers required a great deal of support to use the software, sometimes unnecessarily impeding adoption. This left the developers with two choices: increase the PD time spent on ArcView™ or create more learner-friendly software aligned with the needs of the curriculum (Edelson, Gordin, & Pea, 1999).

The GEODE Initiative at Northwestern University, the developers of the curriculum, designed My World™ GIS for classroom applications from middle school through college to support inquiry-based learning (http://www.myworldGIS.org/). Students are able to investigate geographic data with easy-to-use tools to explore the environment and much more with a carefully selected subset of features of a professional geospatial technology environment. These include multiple geographic projections, table and map views of data, distance-measurement tools, buffering and query operations, and a customizable map display. This GIS software functions well in school environments, where security software and Internet access might be issues. It is used in frequent intervals for a total of 17 instructional days over the



Counties Fill Color: L 1999 Population

States Fill Color: L

Cursor Location: 125.832° W, 37.7933° N Projection: Miller Cylindrical Scale 1 : 24,888,737

Fig. 10.3 Screenshot from unit 1

entire curriculum, broadly facilitating students' use of real-world data to investigate the phenomena they are studying. Furthermore, in order to overcome some of the inherent complexity in working with geospatial data, the developers of *CASES* carefully sequenced the introduction of features and operations. Because student mastery of tools increases over time, as the curriculum unfolds the specific instructions on how to manipulate the software slowly fades as students move into Units 2 and 3, a benefit of employing technologies built around learner-centered design principles (Soloway, Guzdial, & Hay, 1994).

In Unit 1, students work with GIS to construct knowledge about population trends in the United States (Fig. 10.3). As they consider the features of a map of the United States, they learn basic GIS skills including opening data sets and working with *Modes*, *Layers*, and *Zooming*. After students have been introduced to these basic skills, they are introduced to more advanced skills such as creating population queries. Using the *Analyze* mode, students ask questions and develop queries to analyze data. The curriculum in Unit 1 is designed to teach students that one of the most useful ways to ask a question is to create *Selections* – a subset of items in a layer. As students become more comfortable making selections, they are encouraged to combine them to formulate more complex questions. At this point students are also introduced to the *Get Information* tool allowing them to find out the names of the cities or states they have selected. In Unit 1 students are also taught that another way to look at the selected records is to display them in a table – for instance, a *Layer Table* contains all of the records in a layer. Students return to the GIS skills they developed in Unit 1 in the culminating projects for Units 2 and 3, but at this point the tasks have become more open-ended and sophisticated given the students' experience with the tools.

The two culminating projects within Unit 2 involve students' analysis of spatial data. The first project requires students to explore the impacts of fossil fuel power plants as they work to select a location to construct a new coal-burning power plant. Students use GIS to evaluate locations to determine their suitability for locating the power plant. For instance, students use skills they learned in Unit 1 to determine which lakes in Southeast Wisconsin have an adequate volume of water to support a power plant. Students also use GIS to explore how the land around each lake is used so they can consider the environmental impact of building a power plant in that location. In order to do this, students learn how to create a *Buffer* that extends the area of an object on a map. Finally, students examine the proximity of the lakes to roads and railroads. In the process, students learn to use the *measurement* tool to determine the distance from the location. This makes it easy for students to visualize the area surrounding the selection. In the second project, students compare alternatives to building a coal-burning plant for meeting the electrical demands of the region. Using GIS, they gather and analyze data about different locations and question which alternatives might make sense for each. As students investigate the alternative power sources including wind energy, biomass, hydroelectric, solar, and nuclear, they employ a variety of previously learned basic and advanced GIS skills. In addition, they learn how to use the *Add New Polygon* tool to draw an outline of the power plant area.

In Unit 3, students use GIS to explore major dams in California by looking at relationships among land reservoirs, dams, and river networks. In doing so, they learn how to use the *Summarize* tool to find patterns in large amounts of data contained in one layer. Students then use their GIS skills to determine which of two dams is better for the Fresno area. Finally, students use GIS to explore the current state of water use in the Fresno region and evaluate three different proposed water budget referendum proposals to determine the optimal solution.

10.5 Professional Development Supporting Curriculum Adoption

An NSF-funded study called *The Impact of Online Professional Development: An Experimental Study of Professional Development Modalities Linked to Curriculum* (IOPD) provided a context for designing and studying PD, including PD focused on the GIS used in the *CASES* curriculum. IOPD's research goals were to enhance both theoretical and practical understandings of how online PD environments contribute to teacher learning, improvements in classroom practice, and improvements in student learning in comparison to face-to-face PD. In this study, teachers were randomly assigned to either a traditional 6-day face-to-face workshop or a hybrid 2-day face-to-face workshop followed by 12 asynchronous online workshops, three of which specifically support geospatial technology. The IOPD project constructed a custom software

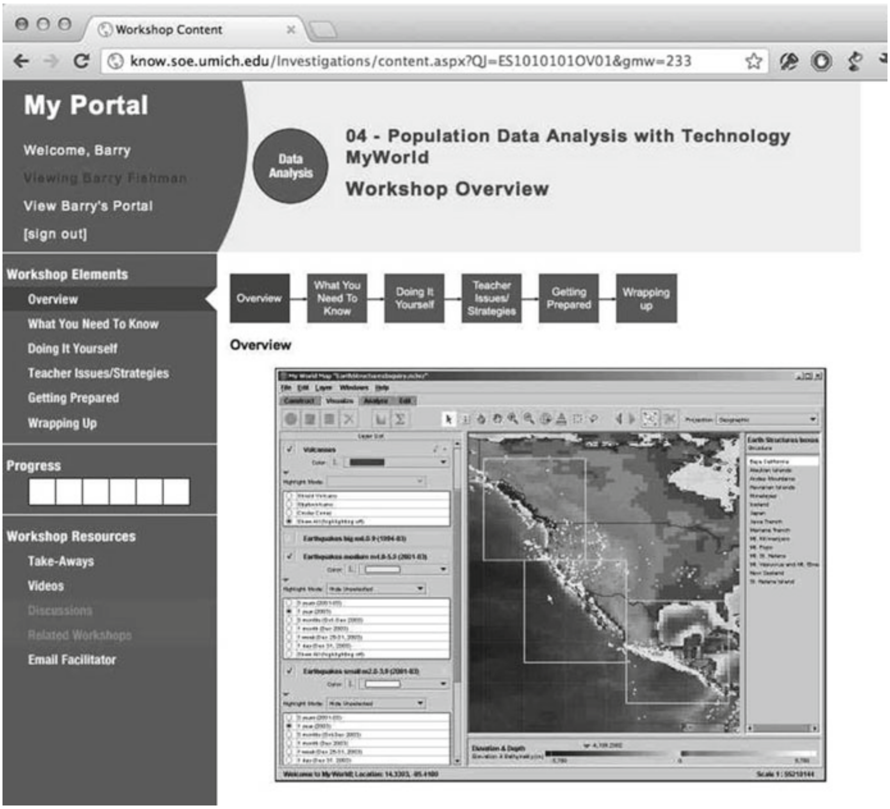


Fig. 10.4 Screenshot of GIS online workshop

platform for the web-based asynchronous online workshops. The remainder of this chapter focuses on the design of these three online workshops as an example of online environments supporting teachers' adoption of geospatial technology.

First, teachers participated in a face-to-face 2-day introduction where they received information about the overall design of the curriculum (background in LfU, overviews of the units, etc.). In addition, teachers participated as "students" in one of the early activities using GIS with a brief discussion about other applications, guided by a face-to-face facilitator acting as teacher. We believe it essential to have an opportunity to engage the teachers with the software, but recognize that this short activity months before instruction is not sufficient to support their adoption since this lesson primarily focused on the curriculum and content knowledge of the technology. Due to the short time together, teachers could not deeply engage in developing the other important knowledge components discussed above. Thus we designed online workshops intended to remind teachers of what they had done at the face-to-face workshop and to address the other essential knowledge issues (Fig. 10.4). Learning for Use informed the structure of the online workshops, which are made up of seven components: (1) Overview, (2) What You Need to Know, (3) Doing It Yourself, (4) Teaching Issues and Strategies, (5) Getting Prepared, (6) Wrapping Up, and (7) Reflection, each discussed below in detail.

10.5.1 Overview

Each online workshop began with an overview, which introduced the workshop by providing teachers with the context of how the particular workshop fit with the other workshops and with the curriculum itself. In addition, the overview provided the teacher with specific learning goals of the workshop and a brief description of what they were going to do and concluded by providing the teacher with an essential question that the workshop intended to answer. The overview was designed to motivate the teachers and set the scene for use of GIS within the context of the curriculum. This space also provided an opportunity to link back to the face-to-face workshops, activating the teachers' prior knowledge.

10.5.2 What You Need to Know

What You Need to Know provided the background information needed in order to complete the remainder of the workshop. Typically this included teachers constructing or reconstructing background content knowledge related to learning theory, science, and technology. First, the workshop emphasized how the technology fits into the curriculum unit as a whole. This helped teachers construct knowledge of the curriculum and motivated them to take the time to learn the technology so they could incorporate its use in their instruction. We also utilized hyperlinks to other resources as well as discussion boards to facilitate teachers' learning about geospatial technology more generally.

The second GIS workshop used this space to remind teachers about knowledge generated during the first workshop and was hyperlinked back to this first workshop if the teachers needed a refresher. Knowledge of geospatial technology applications as a whole is not explicitly part of the curriculum but was seen as useful background for teachers. Information focused on GIS as an integral component of the curriculum, as opposed to presenting a stand-alone lesson on using geospatial technology applications without this curricular context.

10.5.3 Doing It Yourself

In Doing It Yourself, teachers constructed knowledge of GIS technology within the context of the curriculum. The workshop began with flash animations walking teachers through installing the software on their computers. This proved to be one of the most important components of the PD, helping to overcome a common barrier to implementation (Kerski, 2003). Our animations included screen shots and step-by-step directions so that teachers could have the workshop and the installation happening together simultaneously. Next we provided animations walking teachers through an activity that introduces use of the GIS software. After practicing how to use modes, layering, and the zoom tool, teachers were prompted to share issues they were concerned that their students might have when they would do the activities. Teachers were encouraged to spend time exploring the software at their own pace. This opportunity to "mess around" proved an essential component of successful geospatial technology PD. Notes created by the teachers went to their "takeaway" pages, which they could print out at the conclusion of the workshop to help with their later instruction, helping teachers take their learning and organize it for use in the classroom. Teachers then engaged with advanced GIS skills, analyzing data through making selections, using the "Get Information" tool, and using layer tables. Again, teachers traversed between animations, the software, and the student workbook. They practiced these tools as their students later would and were prompted to anticipate issues their students might face. Finally, teachers used asynchronous discussion boards to post their thoughts on how geospatial technology lent itself to inquiry instruction and the advantages of using the GIS software. The intent was to remind teachers of the integrated nature of the technology as part of the curriculum and to situate their new understanding in their teaching, informed by others in the community. This discussion and the takeaway contributions were initial efforts to assist the teachers in beginning to organize this new knowledge for use.

10.5.4 Teaching Issues and Strategies

Teaching Issues and Strategies focused on specific pedagogical content knowledge unique to the topic of the workshop. In this case, the first workshop focused on anticipated issues that students might face in using the software. We used prompting questions about issues the teachers might observe in the classroom, with radio button answers and pop-up responses as to why certain answers were preferred. These were designed to help teachers be prepared for issues we have observed as problems in other classrooms. In addition, we provided short videos of experienced teachers providing practical advice about the software and curriculum. In an asynchronous forum, teachers could discuss the video with peers. The next workshops specifically addressed how spatial analysis helps students attain specific learning goals in the curriculum. This drew on teachers' discussions about making connections between the software and learning goals. In addition, the workshops provided examples of student research conducted using GIS. Teaching Issues and Strategies allowed teachers to construct new knowledge about the software and organize that knowledge in the context of their future teaching with students, informing both content and pedagogical knowledge of technology. This space provided a means for sharing the “nuts and bolts” issues observed in real classrooms by researchers or experienced by real teachers in their own classrooms, constructing new knowledge, and then organizing it for use.

10.5.5 Getting Prepared

First, Getting Prepared reminded teachers of practical issues, for example, that they will need to schedule computer time, and provided a space for teachers to note the dates to go to the “takeaways.” In addition, this section linked back to prior discussions in which teachers had noted concerns so they could revisit and resolve these with new information gained in the workshop. A discussion board provided a space for teachers to share issues they had not resolved to get help from colleagues and workshop facilitators as part of a community. In addition, Getting Prepared provided teaching tools such as planning templates. The primary purpose of this section was to help teachers identify pedagogical knowledge for planning and *organize for use* what they learned by participating in the workshop for their practice.

10.5.6 Wrapping Up

The last section revisited the goals set out during the overview to check and make sure teachers attended to these goals. The next workshop was also introduced. In addition this section provided links to future GIS workshops.

10.5.7 Reflection

Each teacher’s personal PD home page included a space to reflect on each of the lessons in the unit. This space served three purposes. First, the reflection provided a space for teachers to synthesize their own experience. Second, this space became a resource for future enactments. The teacher could return to his or her reflections in later enactments to help improve instruction over time. Finally, the reflection space provided a place for teachers to ask specific questions to the facilitator about particular lessons. Through reflections, teachers evaluated their enactments and thought about what they needed to improve upon, thereby entering into a new LfU cycle. In particular, teachers raised questions that *motivated* them to revisit the online workshops, collaborate with peers, or question the facilitator to *construct* or modify their knowledge about using the technology in their classrooms so they could improve on their *application* of their technology knowledge in future enactments.

Table 10.2 Online workshop design overview

Section	Focused goals	Learning theory (LfU)
Overview	Buy-in, create context, and activate prior knowledge	Primary: *motivate*
What you need to know	Content knowledge of technology Technology knowledge	Primary: *construct* Secondary: organize for use
Doing it yourself	Content knowledge – technology Technology knowledge Curriculum knowledge – technology	Primary: *construct* and *organize for use*
Teaching issues and strategies	Pedagogical content knowledge of technology Curriculum knowledge – technology	Primary: *organize for use and construct*
Getting prepared	Pedagogical knowledge of technology	Primary: *organize for use* Secondary: construct
Wrapping up	Curriculum knowledge – technology, buy-in	Primary: *organize for use*
Takeaways	Teacher/workshop generated knowledge outline available for download to assist with instruction	Primary: *organize for use*
Reflections on instruction	Potentially all knowledge and beliefs with respect to technology, practice, and the online workshops	Primary: *motivate*, construct, and organize for use

10.5.8 Role of Facilitator

Two facilitators supported the teachers during the online workshops. The first facilitator acted as a "guide on the side," commenting on teachers' posts in the discussion boards, answering curriculum/technology-specific questions, and otherwise reinforcing positive interactions of the teachers within the context of the online workshops. A second facilitator acted as a moderator for participation, gauging teachers' activity on the workshops and regularly communicating with each teacher about their participation. In addition, both facilitators acted as resources outside the confines of the online workshops, providing support for implementation, materials acquisition, technology issues, as well as classroom management, and planning challenges that would arise. The facilitators communicated with teachers primarily through e-mail, but also through a private discussion board in the online space.

10.5.9 Workshop as a Whole

These components of the workshops focused on the learning goals identified above applying LfU. Each section covers a variety of goals and focuses specifically on a few. Table 10.2 provides a synopsis for how teachers going through the online workshops traversed through the Learning for Use framework, including motivation, constructing new knowledge, and organizing this knowledge for use.

10.6 Lessons Learned

Though researchers and developers have put much energy into the development of new curriculum materials, comparatively little effort is put into the design of professional development (Fishman et al., 2003). Little empirical research exists that focuses on how to design PD that leads to changes in teacher and student learning (Dede, Ketelhut, Whitehouse, Breit, & McCloskey, 2006). Our prior and current work employs a design-based research approach to identify characteristics of quality PD (Kubitskey et al., 2003, 2004; Kubitskey, 2006). We identified learning goals for the PD, focusing on using specific GIS software within the context of provided curricular resources. We adopted a learning theory to guide our design and created empirically and theoretically informed PD. We then created online PD explicitly incorporating research-based theories. The flexibility of our online PD allowed teachers to participate in workshops proximal to their practice (Dede et al., 2006). We believed this would be especially advantageous for implementation of GIS because of the unanticipated issues that often arise with technology that can impede successful use. Although presented systematically here, these ideas developed and evolved over time. We recommend starting with clear goals for what teachers need to know for successful enactment. Stick to a clear learning theory for internal consistency and modeling curriculum, and use multiple strategies to meet the diverse needs of participating teachers.

Of course, we also discovered weaknesses in our design. (1) Motivation: Expecting that the "need to inform instruction of a new curriculum" is motivating enough to encourage participation is naive. Different teachers will undoubtedly have different motivations, and some may believe that the curriculum materials are self-evident or that their skills are already in place. Either of these assumptions can be detrimental to their initial success with the materials. (2) Time: Professional development during the school year competes with teachers' other responsibilities and commitments that often take higher priority. We believe teachers can benefit from PD that is proximal to practice, particularly with respect to technology, but in the midst of practice teachers often have the least amount of time to participate in the PD. "Just in time" often comes when the teacher has no time. This is of concern since teachers' belief that PD is important and a priority increases the chances of successfully incorporating geospatial technology into instruction (Kerski, 2003; McClurg & Buss, 2007). Therefore facilitators must continually engage teachers in the PD to encourage their participation. (3) Creating community can be challenging: We hoped the 2-day face-to-face PD and prompted discussion boards would help catalyze relationships. However, these resources and interactions did not seem to provide enough of a community to foster interdependence among the participants, a challenge others have acknowledged (Selwyn, 2000). Again, the facilitator plays a key role in responding to teachers' needs and linking teachers' ideas with one another. Although teachers received a stipend for participation in the study, quality participation in the discussion board was not a prerequisite for receiving the stipend since we were interested in what type of discussion would emerge naturally. (4) Ongoing technology challenges: Just getting the software running proved to be the biggest impediment to successful instruction. Because many of the technological issues were idiosyncratic, teachers needed real-time support for using technology. Local technology support personnel were required to approve of the teacher's participation in the study during the spring prior to implementation.

Although most schools received the software in the summer prior to adoption, many still faced issues with local computer and network security procedures. The best-designed workshops require active facilitators to put out fires. The facilitator proved an integral and necessary part of the PD. This need for active participation on the part of the facilitator proved the limiting factor in the number of teachers that could be supported at a given time using this model. In our case, 20 teachers seemed the maximum for support from a quarter-time facilitator. This need might be able to be transferred to the technical support personnel supporting the particular software being used. However, having an informed facilitator proved invaluable given the importance of the context in our curriculum-aligned model. We currently are exploring the practicality of data-mining tools that would automatically examine log files in order to help facilitators identify which teachers need the most support.

10.7 Recommendations for Practice

Based on our research and experience, we suggest the following design principles for curriculum-aligned PD.

10.7.1 Identify Goals for the Professional Development

From the literature and our own prior research, we identified categories of goals covered in PD designed to support reformed-oriented science instruction (see Table 10.1). Professional development designers need to identify those necessary for teachers' enactment and design PD to inform these goals. In the case of technology-rich curriculum-aligned PD, designers must pay careful attention to the setup of the technology and teaching with the technology in the context of the curriculum. Paramount to successful implementation of the technology is to provide teachers with the rationale for incorporating the technology, highlighting the value added to their students' learning. This serves to inform their instruction and motivate them to make the effort to learn and implement the material. Motivation directly relates to teacher buy-in, an essential component for successful enactment.

10.7.2 Adopt a Learning Theory and Use It

Too often PD reduces to a list of things teachers need to "know" to teach a curriculum. A leader presents this list, often as some sort of PowerPoint, and teachers make notes on the handouts. It is our belief that the same time and effort that goes into the curriculum development needs to go into the PD design. Applying a learning theory provides an internally consistent structure to the PD. Learning for Use (LfU) provided a loose structure for our PD design. LfU reminded us to include often overlooked goals of "buy-in" and the pedagogical content knowledge of technology. Using LfU in our particular PD had the additional benefit of modeling the main pedagogical philosophy from the CASES curriculum for teachers while facilitating their own learning.

10.7.3 Evaluate Whether Professional Development Learning Goals Were Met and Adapt

The ultimate goal of teacher PD is to improve student learning, yet measures of student learning often are left out of the equation. Each of the goals discussed in Table 10.1 are intended to lead to improved practice and student learning. It is our belief that quality PD includes a mechanism to measure teachers' practice and student learning outcomes. Identification of successes and failures inform redesign of the PD.

10.7.4 Adaptations and Modifications to the Professional Development

We do not intend our final online PD design to be *the* model for online PD, but rather one example of an approach that successfully applies our design principles. We are in the process of testing this model and fully expect to modify it based on our research findings. This is not a challenge to our design principles, but rather its fundamental tenet. Good classroom teachers modify their instruction to meet the needs of the students while maintaining the integrity of the instruction. Quality professional development should do the same.

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Chapter 11
Impact of Science Teacher Professional Development Through Geospatial Technologies: A 5-Step Program of Support

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Keywords Environmental education • In-service teachers • Professional development • Geospatial technology • Geographic information systems • Global positioning systems • Google earth • Teacher leaders

11.1 Introduction

Research on the use of geospatial technologies (GT) in schools has shown that teachers and students are able to engage in data visualization and analysis, spatial interpretation, and real-world problem-solving (National Research Council, 2006). A recent report by the National Research Council, *Learning to Think Spatially* (McWillimas & Rooney, 1997), states that Geographic Information Systems (GIS) has the ability to meet four educational goals: (1) support the

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inquiry process, (2) be useful in solving problems in a wide range of real-world contexts, (3) facilitate learning across a range of school subjects, and (4) provide a rich, generative, inviting, and challenging problem-solving environment (p. 176). Additional research has further documented other important benefits for students, including increased motivation (Audet & Abegg, 1996), improved self-efficacy and attitudes toward technology (Baker, 2002), better acquisition of spatial analysis skills (Coulter, 2003; Coulter & Polman, 2004), increased mathematics ability (Alibrandi, 1998; Kerski, 2003), and improved geographic and scientific content knowledge (Hagevik, 2008; Stubbs, 2003).

For more than a decade, educators and researchers have developed curriculum while at the same time focusing on teacher professional development. These professional development efforts have engaged large numbers of teachers and provide compelling examples of the potential of GT to enhance teaching and learning (Edelson, Gordin, & Pea, 1999). Teachers and other advocates of geospatial technologies in schools argue that these technologies offer compelling classroom outcomes. Students are able to interact with dynamic visual displays of real-world data, which provides them with an opportunity to develop fluency in visual representations of data, practice quantitative data analysis, and gain experience in database techniques (Edelson & Moeller, 2004). But despite this enthusiasm, in a survey of more than 1,500 high school teachers who had purchased GIS software, Kerski (2003) found that 45 % had not used GIS, and another 15 % had no plans of using it. Of those that had used GIS, only 30 % had used it in more than one lesson.

A report by the GEODE Initiative of Northwestern University (2007) identified the significant challenges facing teachers and students in their use of GT in the school computing environment. These included (1) access to appropriate hardware and software, (2) technical and administrative support, and (3) integration of GT into the curriculum. Overcoming these significant challenges takes time and significant effort for teachers. Teachers need time to convince the school to install the software on school computers or servers, time to find ready-to-use data for their projects, time to identify and possibly modify existing curricular materials, and time to find and learn how to use the many types of GT tools available. Teaching with geospatial technologies in schools holds much promise, especially in environmental science where it is commonly used to investigate complex problems over time. Without effective preparation, the tremendous potential of GT in schools for teachers and students will be unrealized.

This chapter presents a professional development approach for implementing GT in schools. This approach was developed over the past 7 years for secondary science teachers in North Carolina. Supported by funding from both state and national sources, this professional development program focused on environmental science, specifically, land, air, and water. Over time, the 5-Step GT program developed. This program is unique in that it has a leadership component as well as a teacher professional development component. It focuses on personal development as well as the content and pedagogical development of teachers. This chapter will focus on the components of the program and results from 7 years of implementation. We investigated the following research questions:

(a) What are the important components of the program?
(b) Which elements facilitated the development of teacher leaders?
(c) What are the implications of these findings for GT professional development experiences for science teachers?

11.2 Theoretical Framework

11.2.1 Characteristics of Effective Professional Development

Subject-specific professional development is considered an essential mechanism for deepening teachers' content knowledge and developing effective teaching practices (Desimone, Porter, Garet, Yoon, & Birman, 2002). In a national study, Garet, Porter, Desimone, Birman, and Yoon (2001) identified the effective characteristics of professional development as a focus on content knowledge, the presence of opportunities for active learning, and coherence with other learning activities. Key structural features included activity; collective participation by teachers from the same school, grade, or subject; and duration of the activity. Other criteria for high-quality teacher professional development were opportunities for sustained professional development, increased content knowledge and understanding of learning, active and collaborative learning, program coherence, and increased teacher knowledge, confidence, and skills (Constible, McWilliams, Soldo, Perry, & Lee, 2007; Desimone, 2002; Supovitz & Turner, 2000). The Environmental Sciences for Elementary School Teachers (ESEST) 14-year program indicated a twofold increase in content knowledge and improved teaching skills by participants (Constible et al., 2007). They argued that partnerships between K-12 and post-secondary institutions are necessary for effective science teacher education. In addition, others have identified a critical need to go beyond content during professional development programs (Loucks-Horsley, Hewson, Love, & Stiles, 1998). Including such components as teaching self-efficacy beliefs and experiences, asking participants to reflect on their learning, providing emotional support and encouragement, and modeling and learning through contextual experiences were equally critical (Borko & Putnam, 1995; Reys, Reys, Barnes, Beem, & Papik, 1997; Showers, Joyce, & Benett, 1987). When analyzing the effects of different characteristics of professional development on teachers' knowledge and their ability to implement the GLOBE program, Penuel, Fishman, Yamaguchi, and Gallagher (2007) found that teachers having meaningful, ongoing, and coherent professional development experiences consistent with their local school and district goals were more successful. Effective programs provided support and equipment, were able to "localize" the implementation, were longer in length, and had university-based partners.

11.2.2 The SCI-LINK Program

SCI-LINK (Howe & Stubbs, 1998) brings together science teachers, environmental scientists, and others in summer institutes, on weekends, in the evenings, or on special days during the school year, providing opportunities for teachers to learn about current scientific advances. Teachers then translate their knowledge into interesting and effective lessons and activities for their students in environmental science (Howe & Stubbs, 2003). The purposes of the SCI-LINK program are for teachers to (a) increase their knowledge of environmental science, (b) infuse this new knowledge into their own classroom science curriculum materials, (c) become more self-confident as professionals, and (d) become a part of a learning community. The program, located in North Carolina at a large state university, has brought together teachers from across the United States, as well as countries such as India, Canada, Finland, Monaco, and Brazil, for residential workshops in North Carolina in the summers and at other times during the school year. Over the past 14 years, SCI-LINK has expanded to become a constellation of different programs and activities but has maintained its focus on current environmental research.

The building blocks of the SCI-LINK program are the formation of a learning community that includes scientists, science educators, and teachers, thereby encouraging the formation of productive professional relationships. The program recognizes individual differences so that each teacher can follow his or her own path, even as it challenges teachers' self-images and encourages reassessment and further guided challenge guidance by offering learning opportunities throughout the year for renewal and stimulation. In summary, the SCI-LINK program (Stubbs, 2010) shaped a broad model of professional development that incorporated a social constructivist perspective, with attention to personal and social development, in addition to the more traditional areas of content and pedagogy. This professional development program was adapted to incorporate the use of GT in environmental science for teachers. The program for leadership development, just as in the SCI-LINK program, includes and elaborates on a model of leadership development by Palus and Drath (1994).

Although neither Palus nor Drath were professional educators, their model draws on the work of Piaget, Perry, Erikson, and others who have influenced educational theory and practice. However, the Palus and Drath model is not limited to cognitive structures and is directed toward mature adults. Acknowledgements are given to Kegan (1994), who has also integrated many of the ideas in the field of adult development. The Palus and Drath model focuses on enhancing the individual's ability to participate in the leadership processes of the community of practice to which he or she belongs. Leadership development is accomplished by providing opportunities for persons to participate in and be changed through five interwoven processes: readiness, experience and disequilibrium, equilibrium and construction, and potentiation (Palus & Drath, 1995, p. 14).

Readiness refers to factors that play a significant role in determining if one is ready for the development program. Teachers in the 5-Step GT program brought with them a wide range of expertise, from geocaching to prior experience in using GT through college coursework or work experience.

Experience and disequilibrium refers to providing actively engaging and meaningful experiences for participants, in which they stretch their capacities and are challenged by new ways of seeing their world. They may feel anxious or may initially resist accepting the new experiences. The program must have flexibility to support people as they reach a state of equilibrium. When teaching with GT in environmental science, not only are many of the concepts new to teachers but so are the technologies. Teachers have remarked that they felt like their students and recognized the frustrations that occur when learning new concepts and skills.

Equilibrium and construction refers to providing an environment in which participants are supported as they explore new understandings. Since individual experiences are different, it is important that the program be flexible and able to support teachers at many stages of development as they work toward reaching a state of equilibrium and re-envisioning new possibilities for both themselves and their teaching. This is why it is critical that GT professional development models include ongoing support for teachers both professionally and technically. The GT professional development models should be intensive, sustained, involve communication and collaboration, and be integrated into the teachers' daily lives by meeting their curricular and/or personal needs. In this way, equilibrium and the construction of new and different ways of teaching with GT can take place for teachers.

The final step is potentiation and refers to future growth and development. There is a back and forth movement between old and new perspectives as an individual grows and new perspectives are attained. As a person goes through the process of disequilibrium followed by attainment, the new equilibrium created causes a sensitization to the possibility that other new perspectives and ways of knowing can be found. This allows for future development as individuals become more open to the possibility of future growth.

Since each person begins at a different point, the outcome of the developmental process will not be the same for everyone. Potential outcomes for individuals may be any or all of the following: (a) development of new competencies that include "facility for engaging the process of development, an experimental, reflective approach to taking action, and a better map of where developmental experiments may lead;" (b) the acquisition of new meaning structures that include "new, revised, and alternative ideas, maps, insights, and perspectives;" and (c) motion into a new developmental stage (Palus & Drath, 1995, p. 22). Outcomes may include an increase in effective actions taken; development of new, revised, and alternative ideas, insights, and perspectives; and motion from one developmental stage to a higher stage. The goal for all participants is to develop "the ability to foster and effectively participate in processes of leadership in their communities" (Palus & Drath, p. 25).

The 5-Step program provides opportunities for teachers to participate in and be changed by the five interwoven processes of readiness, experience and disequilibrium, equilibrium and construction, and potentiation. The 5-Step GT program is neither linear nor unidirectional; individuals move back and forth between disequilibrium and equilibrium as they gain new perspectives of meaning. Individuals may enter at any step of the 5-Step GT program, since it builds in complexity with each step. A teacher may remain at a step as long as the teacher feels it is needed. A teacher decides which level of the program is appropriate for them to begin with, and they can take each step many times. At any time a teacher can decide to become a teacher leader by assisting in the teaching of any one of the steps and, after assisting, teach that step individually or in partnership with another teacher. The program is flexible and offers support at many stages of development, either as a teacher participant or as a teacher leader, allowing individuals to vision and revision new possibilities both personally and in their own teaching. There is continuous support from other teachers, scientists, and GT professionals at every step of the model. The learning community is a network of educators, scientists, and GT professionals that provide ideas, support, and encouragement throughout the year through phone calls, e-mails, and occasional site visits. There is a personal as well as a professional relationship, as plans and ideas are discussed related to teaching environmental science using GT. Teachers assume leadership roles as they help other teachers use GT in their classrooms, present their projects at conferences, and become involved in environmental practices in their communities (Horton, Hagevik, Adkinson, & Parmly 2013).

11.2.3 The Components of the Program

The 5-Step GT program is composed of a series of summer and school year professional development opportunities for in-service secondary science teachers. Step 1 utilizes ArcGIS online and other GeoWeb applications like Google Earth as an introduction. This step is usually completed as a one to one and half day in-service, often in a school or at a community center. Steps 2 through 5 occur as summer institutes, 1 week or 5 days in length, with one to two follow-up days during the school year. Step 2 involves the GT curriculum Mapping Our School Site (Hagevik, 1999) to analyze a 10 × 10 m plot on a school campus using the Problem-Study Framework. In Step 3, teachers use ArcGIS and environmental data from North Carolina to compare their school data to state data, widening the perspective. In Step 4, teachers learn more advanced GT skills and broaden their focus from their schools, to their communities, to the global environment. For example, CITYgreen (American Forests, 2000) curriculum is used to create an environmental map of the teachers' own school campuses and to relate their ecological analyses to the community green

Table 11.1 The 5-Step GT program

Step	Description	Outcomes
1. ArcGIS online and Google earth introduction	Introduction to maps, spatial thinking, and using GT through internet mapping to learn about the environment (introductory – 3–10 contact hours)	Create map using provided data
2. MOSS land	Field mapping the microclimates of a site, learn problem-study approach (42 h/year) (www.ncsu.edu/scilink/studysite)	Conduct 10 × 10 m plot study on your school campus
3. Beginning land, air, water	Utilize statewide environmental data to develop an individual project (42 h/year)	Develop beginning GT project for your classroom
4. Advanced land, air, water	Relate your school to the community and then to the world. Use more advanced GT applications such CITYgreen GIS and global data sets (72 h/year)	Develop advanced GT project for your classroom
5. Apprenticeship Community-based projects	Conducting community-school projects with cooperating partners as mentors to bridge to leadership (variable)	Complete your school-based community project and associated curricula

layer. Global warming and climate change as it relates to carbon sequestration are then discussed. ArcGIS is used to examine global data sets. Finally, in Step 5 the teacher serves as an intern and develops an individual community project alongside a GT specialist and/or scientist. A brief overview of each step and the outcomes is shown in Table 11.1 above.

After 7 years of implementation of this program in North Carolina, teachers usually attended each step anywhere from one to five times. Some teachers became teacher leaders, but others did not and chose to use the GT applications only in their classrooms with their students. A few teachers have proceeded through all five steps and have become teacher leaders for each step.

In this chapter we will report the results of 7 years of implementation of the 5-Step GT program and (a) identify the important components of the program, (b) examine the elements that facilitated the development of teacher leaders, and (c) consider implications of the findings to GT professional development experiences for science teachers.

11.2.4 Strengths of the Program

The strengths of the program have been shown to be that it increases in complexity, provides inexpensive or free ready-to-use local and global data sets and software, creates a network of support by establishing a collaborative community of learners, demonstrates the use of the outdoors and teaching with technology, and provides time for teachers to connect example lessons to national and state standards. Steps 2–5 involved scientists, graduate students, and GT professionals. Depending on teacher interest or the GT project, these collaborations commonly continued into the school year. Additionally, on-site visits and support through e-mail and other electronic means were provided. The teachers received the books, software, data sets, paper maps, and equipment needed for their projects. Graduate credit is available to the teachers that attended the institutes. The opportunity to become a teacher leader has proven to be a strong motivator. Teachers received certificates as they completed each step. During the 7 years of implementation of the program, various steps were offered during different summers, depending on the needs of the teachers involved. Numbers of participants in the institutes have ranged from as few as 10 to as many as 20.

11.3 Methodology

Data were collected on the number of science teachers at each step of the program as well as those that had become teacher leaders. An in-depth analysis of 12 teachers at various steps in the program was completed using three focus groups and participants artifacts. A 17-item questionnaire was completed regarding the degree of GT implementation and leadership roles teachers had taken. The self-report questionnaire was triangulated with data from the teachers' schools, their colleagues, and their principals. From these teachers, three teacher leaders were interviewed and asked about their experiences using GT in their teaching. These interviews and artifacts – such as lesson plans, student artifacts, and GT projects – were analyzed (Glaser & Strauss, 1967) and compared to the classroom observations, e-mail, and field notes. Member checking was used for each teacher in the case studies. All names used are pseudonyms. From these data sources, case studies were created and compared around themes, and the Paulus and Drath (1995) model was used as a framework for interpreting the data.

11.3.1 Results of the 5 Steps

Four teachers in three North Carolina counties have completed all five steps and have become teacher leaders for each of the steps. Fifty-five teachers in 10 North Carolina counties have completed steps 1–4 with approximately 100 teachers between steps 1 and 3. There are eight community projects, including three on wetlands, one on soils, one on urban forest, one on land use, one on coastal ecosystems, one on wildlife habitat, and one on dengue fever. The coastal ecosystem project and the dengue fever projects (Gioppo & Barra, 2005; Gioppo, da Silva, & Barra, 2006) are international projects by partners in Brazil and can be downloaded from www.cinfop.ufpr.br/colecoes.

Table 11.2 GT questionnaire

Item	Responding "great extent" or "often" (%)	Mean score	Rating
Software on computers	100	4.6	Great extent
Confidence	100	4.9	Great extent
MOSS in class	75	4.4	Great extent
Present at conferences	75	4.6	Great extent
Teach a lesson using GT	100	4.7	Great extent
Present to faculty	75	3.0	Often
Teach another GT unit	75	3.0	Often
Teach another teacher GT	58	3.0	Often
Create own GT project	58	3.2	Often
Attend other GT institutes	42	3.2	Often
Teach a GT institute	33	3.2	Often
Grants to do GT	75	3.6	Often
Create a course using GT	17	1.0	Little
Create GT curriculum	8	1.0	Little
Use GT as part of an award	25	1.0	Little
CITYgreen in class	17	1.1	Little
Attend GT college course	8	1.3	Little

Note: $N = 12$. 5.0–4.0 = great extent, 3.9–3.0 = often, 2.99 or lower = little

11.3.2 GT Implementation and Leadership Roles

The 17-item questionnaire regarding the degree of implementation and leadership roles completed by the teachers showed a mean score of 3.5 (often) (Table 11.2).

An ANOVA was used to compare the effect of the number of years of teaching experience to the degree of GT implementation. There were no significant effects of GT implementation on the number of years of teaching experience. These findings suggest that regardless of years of teaching experience, teachers can implement GT into classroom instruction. It was noted through the interviews that while younger teachers tended to have better overall technology skills, teachers who had been teaching longer immediately saw how to integrate the technology into their classrooms, since they understood well how to teach the science content.

All teachers were able to install the software on their school computers and had confidence teaching using GT. All of the teachers reported teaching one lesson using GT in their schools. Many of the teachers had presented their projects to the faculty, taught another related problem-solving GT unit, taught another teacher new skills, created their own projects, attended other related institutes, and taught a GT institute or had written grants to fund their projects. Teachers were less likely to create their own GT curriculum or courses and were less confident in using CITYgreen in their classes.

The following case studies from three teacher leaders in the 5-Step GT program illustrate how these teachers became leaders for others and how the implementation of GT affected their teaching.

11.4 Case Studies

11.4.1 Case One

Sarah is a Caucasian woman who has been in the classroom for 10 years. She taught science to sixth, seventh, and eighth graders in a modern urban school. Before becoming involved in the GT professional development, she had never used GIS or any type of geospatial software before. In fact, she characterized herself as being able to use computers only for Microsoft Word and e-mail.

11.4.1.1 Readiness

Sarah displayed clear enthusiasm for using GT in her classroom. She came to the GT summer institutes originally to learn how to incorporate scientific models into her teaching. Her school system was encouraging teachers to use new technologies in their teaching, and there was a new technology exam that all eighth grades were required to pass. Sarah therefore felt that "a combination of technology and a personal goal of being better able to use data to create models with her students" was a win-win situation.

11.4.1.2 Experience and Disequilibrium

Sarah found it "very challenging and frustrating" when using GT in her classes originally. She began by having students do independent projects. Then, as she continued to take additional institutes, she began slowing using GT in her classes to teach earth and environmental science. She first used existing curriculum, modifying it for her needs. Eventually, she was able to design her own projects. She said, "It was evident that the students learned much faster than I did. I just had them help me. They were so excited about using the technology. It was different for them than what they normally did. It is so visual. Eventually, I became better and began to be able to solve my own problems. It was then that I could see the potential for my students."

11.4.1.3 Equilibrium and Construction

Through each of the steps within the GT workshops, teachers developed lesson plans for their own classrooms. The participants were provided with data sets of their counties and states to use in their lessons. Sarah explained, "Developing my own lessons that I could discuss with others and then try was the key factor in my success. I felt like I had a whole community of teachers and scientists supporting me." She said, "I could come back over and over again, learning a little more each time, and eventually I felt more comfortable." Sarah constructed a new understanding of her own potential through the process. She said that, "I went from being frustrated and thinking that I cannot possibly do this to becoming so excited not only for my students but for myself. I was so surprised that I could actually learn how to do this stuff."

11.4.1.4 Potentiation

Sarah explained that as she has continued to implement GT in her classes and began teaching GT to other teachers, she has become a leader for using GT in the state. She has presented at state and national meetings and has given GT workshops at the state NSTA meetings. Her participation in the institutes has led to her receiving her Master's degree. She plans to continue to learn more about GT and to share it with others. The experience has "changed my life and I no longer see things the same."

11.4.1.5 Implementation of GT

Sarah wrote and designed an elective course for her school district with GT as the focus. The course is called "Computers, Mapping, and Technology." In this class, she has completed two community projects, one with the zoo and the other on land use in the city where she lives. Sarah has completed a CITYgreen analysis of her school grounds and does the MOSS unit each year. She is constantly looking for ways to bring real-world data to her students. As a result of her involvement in GT, some of her students have received summer internships using these technologies. Sarah said, "There are so many ways students can become involved in real-world problems using GT technologies. The connections with other teachers, the support from scientists and other GT professionals has been amazing."

11.4.2 Case Two

Cheryl is a Caucasian woman with 18 years of teaching experience in a public, urban high school. Her content background is in chemistry, and she teaches primarily introductory and Advanced Placement chemistry and physical science. On occasion, she has been asked to teach earth/environmental science, which she reports that she "really enjoys." Cheryl was one of the first teachers in her county to receive advanced technology training through a local university initiative designed specifically for science teachers. It was from this experience that she learned about available training in GT.

She classifies her computer skills as better than many of her colleagues but also says she finds it difficult to remain up-to-date.

11.4.2.1 Readiness

Cheryl attended a session at the state environmental education conference in which a geoscientist explained and demonstrated new computer mapping and data analysis software. Cheryl immediately saw the possibilities of incorporating computer mapping and data analysis into both chemistry and environmental science classes. She was drawn to the possibility of "visualizing data" and felt GT could particularly benefit her students with reading difficulties. She immediately registered for the advertised summer institute with the intention of incorporating GT into an already established problem-based learning strand in chemistry and environmental science.

11.4.2.2 Experience and Disequilibrium

Cheryl found the implementation of her new GT skills "very frustrating with stumbling blocks at every turn." Her media coordinator and district technology director were not at all familiar with GT or its applications to science teaching. Consequently, the software Cheryl received at the first summer institute was only installed on one teacher's desktop computer, which drastically limited incorporation into the curriculum and student use. The second institute in the GT series introduced Cheryl to a free, less memory-demanding, and simplified version of the initial software that was designed specifically for educators. "This is exactly what I needed," she said. The software was loaded on the media center server, and Cheryl wrote or modified about 15 separate lessons for her environmental science class. All of her students, regardless of reading or math levels, became engaged in the lessons and remarked how fun and easy it was to learn using them.

11.4.2.3 Equilibrium and Construction

Cheryl reports that there have continued to be bumps in the road as hardware has been upgraded and technology directors have changed. "I have to fight the same battles over and over but it is worth it. My kids get so much from the lessons, and the unintentional geography and math content they learn is amazing." Cheryl developed a close working relationship with the GT professionals at her local city planning office, who continue to provide her with current local data and technology assistance. She often refers to this relationship as a partnership and frequently encourages other teachers to seek out similar resources.

11.4.2.4 Potentiation

Cheryl continues to incorporate GT in her chemistry and environmental science classes. She is known in her district as the "GT lady" and is often called upon to teach short GT workshops for elementary through high school science, math, and social studies teachers. As a result of the 5-Step Leadership model, Cheryl decided to continue her education in a science education doctoral program with a content concentration in GT. She continues to develop GT lessons for her students and has shared them at state and national science teacher and GT conferences. She plans to continue her training in GT and wants to develop more interdisciplinary lessons and projects for high school students. She comments that, "GT is the most powerful tool I have found to really impact my students' learning. Every teacher needs to be using the tool."

11.4.2.5 Implementation of GT

Cheryl has expanded her classroom role to include mentoring seniors who choose to explore GT projects as graduation projects. Students develop a semester-long project, collect and analyze data, and then present it to a panel of evaluators from the community. On multiple occasions her classroom students and senior project mentees have had the opportunity to present their own original GT work at conferences and competitions. Two students have competed internationally in Beijing, China, and three have received full college scholarships after presenting their projects. Cheryl explains that "[t]his is why I teach. My students become independent thinkers and problem solvers. They act and react like scientists." Cheryl has also packaged data sets for her students and other teachers to use on GT lessons and projects. Every semester Cheryl's students add local stream water-quality data to a GT project database that was initiated 16 years ago. The project has a key role for her environmental science students, showing hydrologic change over time. As the school grew, she completed a CITYgreen analysis of the site. Her students recently planted eight trees to help defray cooling costs for a new addition to the front of the school building. As part of a biodiversity unit, she uses the MOSS program at three permanent sites: a field that includes a driveway, a forested area that includes a stream, and a landscaped area that includes an artificial pond. With her students, she is studying and comparing the change over time to flora and fauna at the three sites. Cheryl facilitates GT training and implementation for other teachers at the local and state level by teaching institutes and classes. She comments, "GT changed the way I teach. Just like the real world, my lessons are no longer static but dynamic."

11.4.3 Case Three

Cara is a Caucasian woman who has been in the classroom for 27 years. She taught science to fifth, sixth, seventh, and eighth graders for more than 11 years in an urban school in a high-poverty area. Then she became a college instructor in Science Education. Before becoming involved in the GT professional development, she had never used GIS or any type of geospatial software. She characterized herself as being able to use computers for Word and e-mail, and she was also learning how to create websites.

11.4.3.1 Readiness

Cara's enthusiasm was not clear from the beginning. She came to the GT summer institutes as a PhD student, not knowing exactly what to expect from the technology. However, it was obvious that she wanted to learn how to include more outdoor science and technology in her methods course, as this was her dissertation research topic. Thus she felt that "a combination of the use of outdoors and the use of technology would fit perfectly for teaching college students to become science teachers."

11.4.3.2 Experience and Disequilibrium

Cara initially felt "overwhelmed" when using GT in her classes. She first developed lessons for teaching prospective teachers and then tested them in one of her college courses. She began by modeling an outdoor activity with her prospective teachers, and then she asked them to create independent outdoor project proposals. As she continued to take additional GT institutes, she started to figure out how to better use GT in her classes. She first used existing curriculum, modifying it for her needs. Eventually, she was able to design her own projects. She said, "I was embarrassed to realize that the students learned the technology much faster than I was able to learn it. The students were so excited about going outdoors in a methods course and learning alternative ways to use technology. It was very different than what they normally did in a course in the College of Education. We were able to model an entire project. Then the students designed their own proposals to use during their internships. When the students designed their own projects then I could see that they were really ready-to-use GT in their classes. Eventually we co-developed five activities and these lessons were really 'awesome.'"

11.4.3.3 Equilibrium and Construction

Cara has continued to implement GT in her classes and has developed small projects to teach GT to in-service teachers. She has become a leader in the college for using GT. She has presented at national and international meetings and has taught GT institutes for the State Educational Board. She created a network with other GT educators and is a special issue editor for a national research journal that will be published soon. She plans to continue to learn more about GT and to share it with others. This experience has "completely changed the way I teach my methods course and I will never teach the way I taught the course before."

11.4.3.4 Potentiation

Cara wrote a GT course for in-service teachers based on science teaching issues. In this course, participants have to design and present a science project using GT. One exemplary project focused on a local river close to the school site and considers historical and cultural issues. Another project considered the relationship between a forest environment and its residents by examining their needs and the way they deal with traditional knowledge. Cara now constantly looks for ways to include real-world data and lessons with her student-teachers.

11.4.3.5 Implementation of GT

As a result of her involvement in GT, she has had two of her in-service teachers receive international scholarships for a 15-day summer institute abroad using these technologies. Cara said, "There are so many ways to include GT in teacher preparation and to make them involved in real-world problems using GT technologies. The connections among teachers and the suggestions that arose created an impressive bond and in a supportive environment we were able to reach beyond all of us in ways that I would have never imagined."

11.5 Summary

From this data it was evident that teachers developed new ways of using GT in environmental science as well as new competencies and potential for personal growth. The 5-Step GT program is flexible and creates a road map for success in which teachers can receive support for their projects from each other, from scientists, and from GT professionals. Teachers have gained new confidences, and some have evolved into leaders. This can happen as teachers are provided with many opportunities to engage in stimulating learning at many levels of complexity. As teachers become more involved in the program, they often move into new leadership roles in their schools. Many of our teachers have reported that they have become the "technology experts" in their schools, and in some cases in their school districts.

The "inside-outside" approach has been very successful in the GT institutes. Teachers use GT to visualize and analyze the data, but the computer work is balanced with work in the out-of-doors. This means collecting data for themselves outside or going on a field trip to a site that focuses on an environmental topic. Field trips include, for example, a waste treatment plant, a local stream, or a visit to the local Department of Safety and Planning to experience how GT is used in hurricane preparedness programs.

Allowing teachers time to discuss and plan how they will incorporate GT into their teaching, and having teacher leaders who help them to visualize how that will happen in their classrooms, has been important to our success. In addition, we have found that discussing and modeling classroom management strategies in the out-of-doors and in the computer laboratory has been a valuable component added over the years to our GT institutes. Finally, the five steps have evolved over time, with Step 1 getting teachers excited and motivated, Step 2 being something teachers can do on their own school grounds, Step 3 expanding the scale to the state, and Steps 4 and 5 applying GT to national and global data sets. Step 2 has been particularly successful because it uses a technique called Problem-Study Framework (Hagevik, 2008), with a 6-week curriculum unit, lessons, and assessments provided. These materials are teacher developed and designed to model inquiry-based instruction.

In our GT institutes, teachers usually are initially frustrated and feel very uncomfortable. Then when they try the GT lessons in their classes, they see their students learning the technology much faster than they seem to be able to do. In addition, there are other frustrations that have been reported, such as not being able to use the computer lab, not being able to get the software installed on the computers, not being able to download data, and not being able to save their students' GT projects on school computers. It takes persistence on the teachers' part to use GT in the classroom. This is why professional development programs need to provide ongoing support in a community of learners in order for teachers to be successful. Eventually, as they continue to incorporate GT technologies over time, teachers become confident and can support others who experience the same initial struggles when starting to use GT. A teacher leader component, especially in GT professional development, is so important. Teachers can and do develop their own geospatial technology programs in their schools. Not only do the teachers report that they "will never look at data and their teaching the same," but their students have benefited through awards such as science competitions, paid summer internships, and college scholarships.

The 5-Step GT program has proven to be sustainable over time and continues to grow as teachers and GT teacher leaders share their new knowledge with others in their own school districts. The model incorporates strategies of effective professional development that fosters implementation, such as increased knowledge and pedagogy, collegiality, active learning, coherence, and sustained support (Desimone et al., 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001). In the 5-Step GT model, there is a mix of scientific knowledge taught by scientists and GT professionals and pedagogy as modeled by other teachers through the leadership component. Collegial interactions are encouraged throughout the school year and continue as teachers choose to repeat steps as it fits into their curriculum. The learning that occurs in the professional development is active, and there is time to plan how they will implement new knowledge into their teaching with continued support.

As the program has grown, it has become more "localized" (Penuel, Fishman, Yamaguchi, & Gallagher, 2007). We have found that the teachers and students initially are interested in their own schools and their own schoolyards. After beginning with where they live, teachers and students ask broader questions, thus providing the teachers with larger data sets for their use has been a key component in the program's success. Teachers are connected with county, city, and national GT organizations early in the program that not only provide support but also offer them opportunities such as summer internships for themselves and/or for their students. As teachers become connected to these local organizations, they have found ways to contribute to their work by sharing data and/or findings with them. In some cases this has translated into community action. The five steps of the GT program are designed to support and encourage these types of interactions. The 5-Step GT program has been sustainable because it provides a flexible program for teachers to learn and grow with continued emotional and professional encouragement and support over time by their peers, the university, and many science and GT professionals.

Critical aspects of the program were the importance of time, ongoing support, flexibility, and the promotion of a supportive learning community. The 5-Step GT program went beyond content knowledge and included self-confidence and self-efficacy. Approaching GT professional development from a personal teacher development perspective empowered teachers who overcame the inherent difficulties of the technology to take on new roles, as they became leaders in their schools.

All 12 teachers reported integrating GT into their science classes, and many received grants and taught other teachers about GT. Careful consideration and research into the potential of high-quality professional development is critical. Reforms in science, technology, mathematics, and engineering (STEM) education, now a national priority, need new and creative approaches to teaching science such as using geospatial technologies in the classroom.

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Part II
Designing and Implementing Innovative and Effective Curricular Materials

Chapter 12
The Data Sets and Inquiry in Geoscience Education Project: Model Curricula for Teacher Capacity Building in Scientific Inquiry Tasks with Geospatial Data

Daniel R. Zalles and Amy Pallant

Keywords Curriculum development • Visualizations • Data-based inquiry • Geoscience

12.1 Introduction

In the professional science education community (American Association for the Advancement of Science, 1993; Committee on Support for Thinking Spatially, 2006; National Research Council, 1996), there is strong advocacy for science teachers to use inquiry-based teaching methods that, among other things, (1) foster in students an understanding of the systemic nature of scientific phenomena; (2) immerse students in epistemically appropriate problem-based inquiry investigations with authentic real-world data and representational tools, such as geographic information systems and other geospatial technologies; (3) challenge students to solve content domain-specific problems; and (4) shift from an assessment paradigm that rates students highly for correct answers toward one that rates students on their ability to construct logical, empirically grounded arguments for their conclusions. Yet attempts to implement problem-based, inquiry-based curricula in classrooms have been challenging. For example, students lacking sufficient background knowledge for carrying out the inquiry are sometimes lost in complex procedures and sometimes have trouble connecting their data to the their driving questions and conclusions (Edelson et al., 1999; Krajcik et al., 1998; Schauble, Glaser, Duschl,

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Schulze, & John, 1995). Curriculum developers and teachers interested in either designing or implementing problem-based inquiry-based data-centered curricula need examples of curriculum designs that mitigate these types of problems.

In order to be conducive to classroom adoption, the curricula should also contain educative characteristics (Ball & Cohen, 1996; Davis & Krajcik, 2005; Shulman, 1986) that can help teachers develop their own skills and help foster the implementation of effective inquiry tasks. Educative characteristics are those that contribute to the teachers' own expertise in the content area and its accompanying pedagogy. Examples of ways curricular designs can be educative include attention to (1) making goals evident, (2) designing the learning tasks to support the building and strengthening of important skills and understandings, and (3) accompanying the learning materials with assessments and item-by-item rubrics that have proven to be fair and consistent and that have been tested for inter-rater reliability.

Curriculum and assessment materials produced by the Data Sets and Inquiry in Geoscience Education (DIGS) project (NSF GEO 0507828; Quellmalz, Gobert, & Zalles, 2005) fulfill these principles of data-driven inquiry into scientific phenomena. They also do so in a theoretically grounded manner that scaffolds teachers' abilities to be effective implementers. In February 2008, DIGS was chosen as the Resource of the Month by the Digital Library for Earth System Education (DLESE) (www.dlese.org). This chapter is devoted to describing characteristics of DIGS that contribute to teacher professional development along the lines of the principles and practices articulated above. The DIGS final report (Zalles, Gobert, Quellmalz, & Pallant, 2007) contains detailed information about how DIGS was developed, reviewed, and pilot tested and about how the pilot assessment results were examined to ascertain the technical qualities of rubrics and other assessment instruments.

The goal of the DIGS project was to develop a proof-of-concept set of project-based curriculum modules comprising units and assessments in which students use real visualizations and data sets to conduct extended inquiry (Gobert, Pallant, & Daniels, 2010; Quellmalz et al., 2005; Quellmalz & Zalles, 2009; Zalles et al., 2007). DIGS includes piloted problem-based curriculum modules on two very different topics in a typical secondary-level science curriculum: plate tectonics and climate change. The modules, which comprise units and assessments, use presorted authentic data for scripted yet open-ended investigations. Implementation supports are provided through scoring guides, teacher directions, and all-inclusive Web access for teachers and students. As befits the differences in research on the two topics, the modules, On Shaky Ground: Understanding Earthquake Activity along Plate Boundaries and The Heat Is On: Understanding Local Climate Change, present data-centered inquiry tasks that vary in the amounts of structure inherent in the problems students are asked to solve. The Plate Boundaries module reflects a relatively well-defined understanding of relationships between earthquake patterns and movement along crustal plate boundaries. In contrast, the Climate Change module poses relatively ill-structured problems (King & Kitchener, 1994) that befit the more difficult tasks of differentiating climate change from natural weather variability over relatively short time spans and finding data that provide evidence that can support arguments about causation.

Both modules incorporate global geospatial data: a geographic representation of earthquake magnitude, location, and depth in one module, and a set of raster data sets showing worldwide distributions of carbon emissions and recent decades of mean temperature changes in the other. Both modules also ask students to draw evidence-based conclusions, which case-based research on secondary and postsecondary curricula implementation suggests is likely to contribute to more effective use in classrooms, as long as the classroom culture is receptive to project-based pedagogy (Squire, MaKinster, Barnett, Luehmann, & Barab, 2003).

Each module's unit and performance assessment comprises multiple parts, and each part contains items that pose different questions to the student. Each item is aligned to national science inquiry standards (National Research Council, 1996). Each performance assessment requires that students carry out near transfer of skills and understandings that they exercised in the unit to similar yet contrasting problem settings. In these assessments, scaffolding guides the tasks, much like in the unit, leaving the students to analyze the data and visualizations in order to solve a different open-ended challenge. The challenges are designed to determine students' understandings of the focal phenomena as the students apply their understanding to new data sets. To ensure that the assessment results are valid and reliable indicators of student learning outcomes, constraints are imposed on how the students carry out the tasks. "Specification shells" available to the teacher trace the alignment between the broad inquiry-based reasoning skills called for in the unit and assessment and the national standards (Quellmalz & Hoskyn, 1997).

12.1.1 Overview of the Plate Boundaries Module

The Plate Boundaries module (Gobert et al., 2010) simulates earthquake occurrences over centuries with varying geographic location, depth, and severity, using real data from the United States Geological Service (USGS). Students use a time-based simulation tool called Seismic Eruption[1] to explore the relationship of the earthquakes to the characteristics of plate boundaries in the Earth's crust. The tool simulates multiple decades of three-dimensional data about earthquakes around the world. The development of this unit was informed by research on a curriculum unit developed earlier by Gobert and Pallant called "What's on your plate?" (NSF-REC# 9980600; Gobert & Pallant, 2004), which was implemented in several middle and high school classrooms in California and Massachusetts. The earlier unit made use of two main pedagogical principles: to make thinking visible and to help students learn from one another. Both principles were derived from an inquiry-based framework (Linn & Hsi, 2000). With these pedagogical principles as a guiding framework, that curriculum provided rich, iterative model-based activities for students to learn with their peers on the opposite coast, plus criteria for them to critique their

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[1] Seismic Eruption. Version 2.1. Level 2006.05. © Alan Jones, 1996–2006. Freely available for downloading from the Web at http://www.geol.binghamton.edu/faculty/jones/#Seismic-Eruptions

peers' work. The goal was to deepen students' understanding of the plate boundaries domain as well as the nature of scientific models by engaging them in an authentic context demanding that they construct and reason with models and critique their peers' models.

The DIGS Plate Boundaries module differs from "What's on your plate?" in the degree to which students are engaged in inquiry using data sets. In the Plate Boundaries module, there is some modeling, but the primary focus is on engaging inquiry with the accompanying real data sets. This engagement reifies the students' prior knowledge about the relationship between plate boundary types and earthquake characteristics. In the Plate Boundaries module, students hypothesize about the likelihood of earthquakes at locations around the world; observe and summarize earthquake patterns along divergent, convergent, and transform boundaries; compare earthquake depth, magnitude, frequency, and location along the different plate boundaries; analyze earthquake data sets from the United States Geologic Survey database in data tables and in map representations; draw and analyze cross sections of plate boundaries; and relate and communicate interactions of the plates to the emergent pattern of earthquakes (Gobert et al., 2010). The student tasks in the unit are as follows:

1. In Part A, students predict the risk of large-magnitude earthquakes occurring near three cities around the world. They assign a number to each city using a Likert scale that represents the risk of a major earthquake hazard. The students are asked to explain their reasoning.
2. Parts B and C build students' capacity to make accurate predictions. The students first familiarize themselves with the Seismic Eruption tool and then examine maps that show earthquakes worldwide and cross sections of the crust to see what types of patterns the earthquakes make below Earth's surface. Students choose the locations to investigate rather than receive assigned locations. This gives them some sense of ownership of the task, which research on other inquiry-based, problem-based, curriculum implementations suggests can contribute to greater student motivation (Edelson et al., 1999). This practice also makes possible more fruitful sharing opportunities with classmates.
3. In Part D, the students print screenshots of cross sections that they take along each of three types of plate boundaries – convergent, divergent, and transform.
4. In Part E, students use these cross sections to answer questions about patterns and characteristics of the earthquakes they observe (e.g., comparing magnitude, depth, frequency, and location). Then they explain how the movements of plates at each boundary might account for the patterns.
5. In Part F, the students identify the type of boundary represented on numerical tables rather than the prior maps and provide three pieces of evidence to support each of their claims. The goal is to strengthen student understanding by presenting them with these alternative table-based representations.
6. In Part G, they revisit and, if necessary, revise their conjectures from Part A.

The Plate Boundaries module performance assessment presents a near-transfer task: students apply what they learned about earthquake behavior at certain types

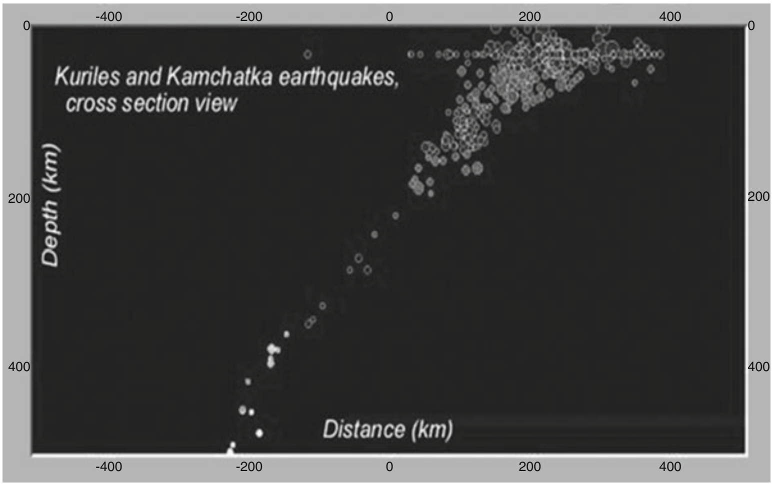

Fig. 12.1 Example cross-sectional view along a subduction boundary

of boundaries to three other types of boundaries that were the focus of the unit. To summarize, students hypothesize about similarities and differences among the three new boundary types, identify the boundary types at new locations from cross sections, rate the broad characteristics of earthquakes at the boundary types, sketch the boundary characteristics, identify where earthquakes are likely to occur at each boundary, predict the likelihood of an earthquake of a certain magnitude at a certain boundary location, and then explain their reasoning.

Figure 12.1 displays an example of an image from Seismic Eruption showing a cross-sectional view of earthquakes along the subducting plate boundary near Kuriles and Kamchatka. Each circle represents the epicenter of an earthquake, and the size of the circle represents the magnitude of an earthquake. The students can connect the data to their understanding of the plate relationships along the boundary.

Figure 12.2 shows a two-dimensional overhead view from the Seismic Eruption tool of earthquake activity juxtaposed with the locations of plate boundaries. In the tool, different colored lines indicate the crustal plate boundaries, which are the actual image is in color coded by typology. Divergent boundaries are colored red, transform boundaries are blue, convergent boundaries are yellow, and diffuse boundaries are white. Students can discern the boundary subtype by virtue of its location (e.g., a red boundary in the middle of the ocean would be an oceanic-to-oceanic divergent boundary).

12.1.2 Overview of the Climate Change Module

The Climate Change module presents authentic data about factors and conditions that relate to the broad question of whether the climate is changing in particular cities. As students do these "case studies" about local climate change, they are

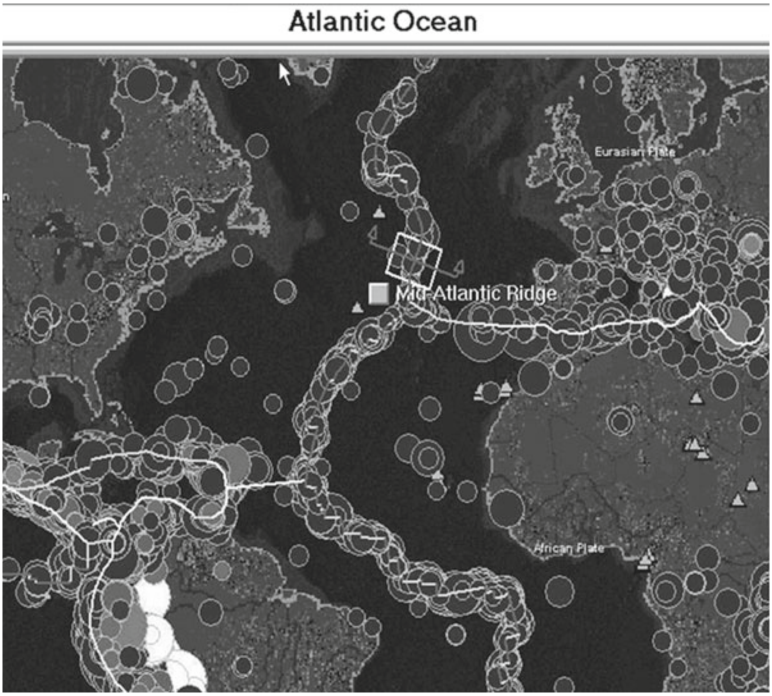

Fig. 12.2 Examples of overhead view from Seismic Eruption tool

introduced to a range of appropriate inquiry tasks. The driving purpose is to prompt the students to think critically about what the data do and do not indicate about climate change and to consider contributing factors. In the process, the students wrestle with the challenges that accompany the analysis of real publicly available data sets, with all of their limitations, for drawing evidence-based conclusions about the complex phenomenon of climate change. The student tasks in the unit are as follows:

1. In Part A, students informally sample data from large year-to-year, month-to-month air temperature data sets to critically examine whether actual climate change trends are evident rather than just natural weather variability. These data are presented to them in a Microsoft Excel™ spreadsheet. A sampling plan is not given to them. They must decide its size and shape. For example, students must decide whether they should examine the average of every year, or every 3 months, or every month for every fifth year, etc. Then they create Excel bar graphs to display the data they selected for their sample.
2. In Parts B and C, students use GIS-based maps, bar graphs, numeric data tables, and satellite images to compare the change trends in Phoenix with larger geographically distributed temperature-change trends and investigate whether there is evidence of a relationship between the temperature data and data about human

influences on the environment (e.g., carbon emissions, pollutants regulated by the Environmental Protection Agency, and increases in population and developed area). In the process, they apply their understanding of (1) how some but not all EPA-regulated air pollutants induce a greenhouse effect in the atmosphere, (2) how readings of anthropogenic carbon emissions in the atmosphere are not the same as readings of carbon accumulation, (3) how there is lack of correlation between areas of the world exhibiting the greatest warming and areas with the most human induced carbon emissions (which reinforces understanding of the Arctic melt feedback loop), and (4) how the growth in size of a developed urban area is more likely to cause increased urban heat island effects than increased greenhouse effects, although the two are systemically related.

3. In Part D, students are prompted to think critically about what can and cannot be known from the available data, recommend courses of action to address warming, and propose a research study to detect effects. They rate their confidence in their conclusions and propose a research strategy for evaluating whether the actions they recommend have the desired effect on the climate. For this, they describe what data they would want to collect and why, where they would propose to collect the data, and how often data should be collected. By this point in the unit, the students should recognize that the trends in the focal city of Phoenix are more evident at night than during the day and that these variances among the data indicate at least in part urban heat island effects. Yet in a supplemental extension activity, they learn that scientists are still struggling to explain why some fast-developing communities exhibit greater nighttime temperature increases than others and that urban heat island effects are only one factor.

The performance assessment for the Climate Change module requires students to apply the methods and findings from the investigation of the climate data for Phoenix to climate data for Chicago. The Chicago data show less evidence of trends in temperature change, and this is most evident in comparing the nighttime minimum temperature fluctuations between the two cities. Chicago also exhibits less urban development and population growth than Phoenix.

Representations of real data investigated in the Climate Change module include time-based tables collected from the Global Historical Climate Network and the US Geophysical Data Center. These data show decades of monthly high and low near-surface temperature extremes at specific weather stations. Students also investigate time-based tables of data from the US Environmental Protection Agency showing (1) air pollution emissions near the same weather stations, (2) GIS-generated geospatially represented data on globally distributed carbon emissions and temperature changes from scientific research studies, and (3) satellite images of changes in land masses from the USGS. Pilot testing revealed how GIS-based geospatial data was particularly engaging to students when they used global data representations to observe how worldwide distributions of temperature changes correlate poorly with worldwide distributions of human induced carbon emissions (Zalles et al., 2007).

12.2 Professional Development Frameworks

The DIGS modules are grounded in broad curriculum models of epistemically appropriate case-based data investigations that reflect the cognitive dimensions of knowledge in their respective scientific disciplines (Manduca, Mogk, & Stillings, 2002). For teachers, the modules therefore exemplify (1) how scientific ideas in the instructional program can be explicitly related to real-world phenomena and to learning activities, (2) how driving purposes that stimulate student thinking and expression can be articulated, and (3) how scaffolding can be provided to help students understand presorted data and visualizations and support them in generating explanations based on evidence.

In addition, the modules have the following components that are compatible with recommended professional development strategies (Loucks-Horsley, Hewson, Love, & Stiles, 1998): (1) facilitation of teacher immersion into inquiry activities, (2) provision of adaptable materials and low-risk opportunities for teachers to try out new instructional practices in a minimum of class time, and (3) assessment strategies for differentiating among forms and levels of student thinking. The DIGS materials are both educative and consistent with these professional development recommendations.

12.3 DIGS Practices That Support Professional Development

The DIGS Plate Boundaries module and Climate Change module will be used to illustrate how well-designed curricula can contribute to teacher professional development by exemplifying some of the ways in which student inquiry with real data sets, tools, and data representations can be implemented effectively. Specifically, the DIGS modules:

1. Exemplify contrasting curriculum models for data-centered inquiry
2. Exemplify how scientific ideas can be related to real-world phenomena and learning activities
3. Present driving purposes to the student that stimulate thinking and expression
4. Contain scaffolds that help students understand data and generate evidence-based explanations
5. Facilitate teacher immersion into inquiry activities
6. Build understanding of differences between design criteria for effective learning tasks and parallel assessment tasks
7. Provide through their adaptability low-risk opportunities for teachers to try out inquiry-based instructional practices

Each of these will be explored in more detail below as the discussion turns to the affordances of each module.

Probabilistic Systems Well-structured problems representing more probabalistic natural systems	**Complex Systems** Ill-structured problems representing less probabalistic natural systems
Using multiple cases....	Using single cases...
Render conjectures about initial cases	Look for patterns in individual data sets
↓	↓
See relationships between variables in new cases, using different representations	Draw conclusions about representativeness to decide if trend is evident or just natural variability
↓	↓
Analyze and synthesize data from more new cases to classify them and detect patterns across them	Look for trends across data sets to see if evidence exists of correlations between variables
↓	↓
Revise conjectures about initial cases as result of understanding factors in probability assessment	Decide what evidence there is, if any, of causal relationships and suggest further research
DIGS Plate Bounadaries Module	*DIGS Climate Change Module*

Fig. 12.3 Curriculum models for data-centered problem-based scientific inquiry

12.3.1 *Contrasting Curriculum Models for Data-Centered Inquiry*

It is instructive for the professional capacity building of teachers and curriculum developers to elucidate the design principles that underlie a curriculum. To do so helps teachers better understand and implement the curriculum and helps curriculum developers better generate ideas for student activity structures (Linn, Bell, & Davis, 2004a). Case-based, problem-based, data-centered inquiry lies at the heart of the DIGS curricular designs. The material focuses on what scientists know and do not know about different natural phenomena and how they interpret data about the phenomena. Figure 12.3 displays a flow chart of two models of curriculum design that the DIGS modules instantiate. The Probabilistic Systems model presents a type of curriculum design for investigating natural systems for which there are widely accepted and empirically verifiable assumptions about cause-and-effect relationships. Curricula falling within this model would be designed to build understanding about patterns and encourage speculation about the relatively well-known cause-and-effect relationships in real data sets and data representations. The relatively well-understood relationship between crustal plate movements and earthquakes is an example of a topic that lends itself well to such designs. Different interactions of plates along plate boundaries (the independent variable) cause different earthquake patterns (the dependent variable). Students can reify this understanding by observing its representation in historical simulations of real, geographically situated earthquake data and the relationship of these data to scientists' abilities to predict the likelihood of future earthquake magnitudes and locations. In addition to studying earthquakes along plate boundaries, examples of science topics that exemplify probability patterns in data include predator–prey relationships and sunspot occurrences over time.

The Complex Systems model in Fig. 12.3 refers to natural systems within which there are less well-understood relationships between variables. Curricula designed to build understanding of such less-probabilistic systems lend themselves to exploring uncertainty and emphasize the importance of planning and executing tasks that may reduce the uncertainty. Researchers refer to the problems that drive the student investigations in these curricula as ill-structured (Hmelo-Silver, 2004). In climate science, for example, different interdependent phenomena that characterize the Earth system (e.g., energy budget, global atmospheric circulation, oceanic circulation, atmospheric ocean interaction, greenhouse effect) are the independent variables scientists observe as affecting climate (the dependent variable) in complex, nonlinear ways. The presence of feedback loops convolutes simple causal theorizing. Besides climate change, examples of topics that exemplify less predictable relationships and lower probability patterns include weather prediction and relationships between Alzheimer's disease and different pathologies in human brain structures.

Both models are about posing problems, scaffolding the investigation of real data about real cases, and extrapolating broad conclusions from those investigations. The Probabilistic Systems model, instantiated by the DIGS Plate Boundaries module, provides the student with the opportunity to examine real data showing predictable patterns. In the module, the data are drawn from earthquake characteristics at different plate boundaries. The Complex Systems model, instantiated by the DIGS Climate Change module, provides students with the opportunity to investigate complex relationships among variables manifested in real data about a single case. In this module, that case focuses on climate change in a particular city.

Critical to these curriculum models is the connection between learning tasks and culminating assessment tasks. Both DIGS modules exemplify how case-based approaches lend themselves to performance assessments that provide opportunities for students to demonstrate carryover of their learning in near-transfer tasks about similar yet not identical new cases.

These curriculum models have educative value for teachers. Not only do they show teachers how inquiry with real data can fit into their lessons and assessments, but they also provide a framework the teachers can use to better understand the epistemic differences between research methods practiced on different scientific phenomena and how the research methods and principles can be made evident to students with appropriate scaffolding.

12.3.2 Relating of Scientific Ideas to Real-World Phenomena and Learning Activities

The DIGS modules exemplify how critical investigations of relationships between variables in real data sets can serve to strengthen student understanding of key scientific concepts emphasized in standards. Research shows that similar curriculum projects which connect key scientific concepts to data-centered inquiry tasks can be successfully implemented in K-12 classrooms (Bodzin, Anastasio, & Kulo, 2009; Edelson et al., 1999; McLurg & Buss, 2007). Key scientific concepts underlying the Climate Change module are weather and climate, recognizing seasonal variation, and differentiating among impacts of air pollutants on air quality and air temperature. The key concept underlying the Plate Boundaries module is recognizing how movements along plate boundaries are related to patterns in earthquake depth, location, and magnitude.

The differences between the relative certainties and uncertainties in the data influence the learning goals of a data-centered, inquiry-, and problem-based curriculum. The main learning goal of the Plate Boundaries module is to have students recognize how the real data they investigate confirm what is known about the characteristics of earthquakes along plate boundaries and to apply this to understanding what can and cannot be predicted regarding the location and occurrence of future earthquakes. In contrast, the Climate Change module's main learning goal is to have students appreciate why nuanced conclusions are appropriate in climate science and why well-designed research studies can help reduce uncertainty and expand the knowledge base.

Consequently, the modules provide the teacher with epistemically different strategies for teaching students to recognize and express different levels of certainty about what they observe in the real data. On one hand, the modules address the challenges of understanding data and observations about contrasting natural phenomena. On the other hand, the modules reflect the fact that there is more certainty about causes of earthquake patterns along different plate boundaries than there is about what amount of weather variability constitutes climate change.

12.3.3 Driving Purposes That Stimulate Thinking and Expression

The two DIGS modules are examples of how project-based curriculum designs call for driving purposes (Blumenfeld et al., 1991; Savery & Duffy, 1996; Squire et al., 2003). But the modules are distinctive in that the purposes for each are quite distinct due to the epistemic differences between their topics. The Plate Boundaries module's driving purpose is to build students' ability to posit and then critically reexamine conjectures they made at the unit's outset about the likelihood of large-magnitude earthquakes occurring at three world cities near different types of plate boundaries.

In contrast, the Climate Change module poses its driving purpose to students in the form of a question: is Phoenix's climate getting warmer and, if so, why? The students then receive an overview of the data they will investigate to answer the question. Hence, although both are case based, the Plate Boundaries module is driven by a conjecture-testing activity that bookends the other activities, whereas the Climate Change module is driven by an overall research question. Questions presented along the way in both modules serve to support students as they work toward fulfilling these driving purposes.

12.3.4 Scaffolding for Students to Understand Data and Generate Evidence-Based Explanations

The DIGS modules scaffold learning tasks by breaking the driving problems down into smaller sequences of subproblems, which help teachers and students design inquiry-based investigations, analyze and synthesize data, and make evidence-based conclusions. Embedding scaffolding in active learning tasks is a longstanding characteristic of many problem-solving instructional programs (Halperin, 2003). Advances in how to scaffold scientific inquiry tasks have been made by various educational technology researchers who have postulated frameworks for embedding different types of scaffolds into instructional software (Linn, Bell, Davis, & Eylon, 2004b; Quintana et al., 2004).

Responding to the relatively well-known cause-and-effect relationships between crustal plate boundaries and earthquakes, the Plate Boundaries module provides scaffolds that help students pose and then revisit their initial conjectures about the probability of large-magnitude earthquakes occurring in certain cities in light of their geographic locations. In between, students observe and analyze earthquake data around the world as an exercise in seeing how the data enable scientists to characterize the patterns of earthquakes along different plate boundaries. Their analyses are scaffolded in the sense that the students must identify the patterns before explaining the plate characteristics that account for them.

In the Climate Change module, students unpack the layers of the complex "story" of climate change at a local level. They do so with the help of scaffolding in the form of staggered presentation of the data sets, question sequences that guide interpretation and analysis of the data, and strategically placed conceptual information about the key phenomena the students need to consider in their analyses, such as urban heat island effects and the greenhouse effects of different air pollutants. An alternative and less scaffolded design would have been to simply introduce the driving purpose (e.g., to investigate and draw conclusions about the locality's climate change), make all the data sets available concurrently, and provide no questions that guide data interpretation and analysis. Unfortunately, research has shown that such designs can lead to uneven implementation because students end up making inadequate choices about what data and tasks to attend to (Squire et al., 2003).

To help focus the students on discerning trends in temperature data, scaffolding in Part A of the module is presented in the form of claims and counterclaims. Students need to respond to such information in order to determine whether the multiple decades of high and low daily temperature data exhibit a sufficient trend that suggests climate change. Focus in Part D of the module, where students make their final conclusions and arguments, is scaffolded through Microsoft PowerPoint™ templates that the students can use to compose their answers and present to their classmates. The templates are designed so that each slide addresses a different facet of the investigation that the students are supposed to address.

In a related manner, the differences between the characteristics of available data influence how tasks need to be structured and scaffolded. The DIGS modules exemplify how developers of data-centered curricula can accommodate the benefits and constraints of the data sets available to them, what data comparison and synthesis tasks are feasible in light of those characteristics, and what types of scaffolding should be embedded to support those tasks. The data used in the DIGS Plate Boundaries module easily permit analysis and synthesis because the data are comprehensive in the time period and spatial area they cover (i.e., the entire world), come from one database (maintained by the USGS), share a common metric, and are available through one specific software spatial visualization tool (Seismic Eruption). Hence, the Plate Boundaries module's goal of having the students build a deeper understanding of earthquake behavior at different crustal plate boundaries is sufficiently achievable with this one comprehensive data set.

In contrast, the Climate Change module's data sets are unconnected in origin, use different metrics, and come from different government agencies (Environmental Protection Agency, National Climatic Data Center, USGS) and research projects. The reliance in this module on such data sets is to be expected given the fact that the module looked at different types of measures that may be phenomenologically related yet focus on different factors (e.g., air temperature, air pollution, population, urbanization) related to climate. For the learner, however, these characteristics make the module's integrative data tasks more challenging. To meet these challenges, the module helps students synthesize meaning from these data sets by scaffolding the synthesis process. For each data set, students rate on a common metric the intensity of the trend exhibited in the data (e.g., greatly increased, moderately increased, no change, moderately decreased, greatly decreased) and note the start and end dates of when the data were collected. The ratings provide a common ground for comparison and synthesis.

12.3.5 Teacher Immersion into Inquiry Activities

DIGS supports educative teacher immersion into the same inquiry activities they assign to their students via the sequential nature and specificity of the task structures. These structural characteristics help teachers more easily prepare for implementation by building their capacity to understand exactly what their students

Table 12.1 Section of specification shell from Climate Change module

Unit task #s	Assessment task #s	Task description	Technology tools and visualizations	Alignments to NSES inquiry standards
A1–A4	A1–A5	Create graphs and analyze local temperature trends	Excel spreadsheets of GHCN temperature data of the focal city	1. Use technologies to collect, organize, and display data 2. Critique explanations according to scientific understanding, weighing the evidence, and examining the logic 3. Review, summarize, and explain information and data
B1–B4	B1–B2	Analyze global distribution of temperature changes	GIS image of 30-year mean temperature differences	Review, summarize, and explain information and data Plan method (only covered in item B4 in unit)

will experience. This capacity building also contributes to the teachers' greater understanding of the science content. Furthermore, the sequential nature of the activities serves to scaffold the teachers' performance of the tasks in a way that allows them to build their knowledge incrementally. For example, in the Climate Change module, this incremental knowledge-building, one phenomenon at a time (e.g., air temperature, air pollution, population), culminates in their ability to synthesize meaning across the different data sets and render culminating conclusions.

Educative teacher immersion in the inquiry activities is also supported through alignments made visible between the DIGS tasks and curriculum standards. These alignments show the teacher how the activities are grounded in the high-level skills and understandings typically expressed in the standards. The alignments are evident on the DIGS website (http://digs.sri.com). Alignment tables on the website show which national science standards are aligned with which tasks, and specification shells show parallel information by order of task rather than by standards coverage. Table 12.1 shows an example of alignments presented on the specification shell from the Climate Change module.

The specification shells also summarize key information about the modules, including a summary of sequence of activities, focal concepts, focal inquiry skills, driving questions, types of data representations, data sets, and focal variables (Quellmalz, 2002).

Lastly, educative teacher immersion is also supported by features of the DIGS assessments: item-by-item scoring, illustrative examples of answers at each score point, and explanations for scores that provide a frame of reference for teachers to gauge their own understanding of the material and the understanding of their students. Each item in the assessments is accompanied by a scoring rubric, examples of student work at each scale point in the rubric, and explanations of why each example was assigned a particular score. Each item is aligned to at least one national science standard. The rubrics contain (1) scoring criteria, (2) descriptions of what response qualities constitute a score at each scale point, (3) illustrative examples of

Prompt: Agree or disagree with this statement: “The data on Maps 1 and 2 provide evidence that LOCAL COMMUNITIES can have a direct and powerful impact on their LOCAL CLIMATES. In a sentence or two, write if you agree or disagree and describe what you noticed on both Map 1 and Map 2 that supports your answer.

National standard: Critique explanations according to scientific understanding, weighing the evidence, and examining the logic
Scoring criteria: Demonstrated ability to make a data-based conclusion about relationships between raster map variables

Scale for the constructed response:

2. disagrees with claim, and supporting explanation shows understanding of the lack of a correlation on the maps between carbon emission rates and mean temperature rates
1. focuses on relationship between carbon emissions and climate change, and hence shows some understanding of underlying data concepts or scientific principles, but draws vague or erroneous conclusions; may be either agreeing or disagreeing with the claim)
0. completely insubstantial, inaccurate, or confused

<u>Illustrative examples of student work</u>

Score of 2:
False, the Eastern Seaboard of America emits far more carbon into the atmosphere, yet at the same time, they are warming much less than the Western portion of America, which had less carbon emission yet warmed up the most out of continental America.
Explanation of score:
The answer shows correct interpretation and synthesis of the data from the two maps.

Score of 1:
I agree with the statement because the moderately high temperature in Chicago expressed in the first map correlates with the relatively high carbon emissions expressed in the second map

Explanation of score:
The answer shows understanding of the concept of correlation, but the interpretation of the data on the temperature map is off-track and hence wrongly factored into the conclusion.

Score of 0:
Yes I agree because wherever there is the most amount of industry, we can see from the map that these are the places or cities where the most amount of carbon is being emitted.
Explanation of score:
The answer poses a conclusion not supported by the maps, which are not about industries and do not show a clear relationship between rising temperatures and carbon emissions.

Fig. 12.4 Item example from Climate Change assessment scoring guide

student responses at each scale point, and (4) an explanation for each score. These scoring materials are in scoring guides on the DIGS teacher-only Web pages for each module. Figure 12.4 shows an example of a Climate Change assessment prompt, rubric, and set of exemplars from pilot test student participants (consult the scoring guide for the maps referred to in the prompt).

12.3.6 Differences Between Design Criteria for Effective Learning Tasks and Parallel Assessment Tasks

Both teachers and curriculum developers need models of how assessment tasks may need to be structured differently than learning tasks in order to yield valid and reliable data about how much the students have learned. The DIGS performance assessments provide examples of how unit tasks designed for learning can be adapted for assessment when sufficient constraints are imposed on their structure and administration. The constraints should ensure that the assessment tasks function as valid and reliable indicators of student proficiency with the focal knowledge and skills.

In the following example from the Climate Change module, the unit activity is open ended, as it is designed for small-group brainstorming in which any idea is welcome for expression and critical review. The assessment activity, in contrast, is constrained to ensure that student responses truly address the focal learning constructs and are therefore interpretable as demonstrative of proficiency on those constructs. In order to have them express a particular recommendation in a scientifically grounded way, the students are instructed, "If Phoenix is warming, recommend what the government and people of Phoenix might do to slow the warming down and give scientific reasons why what you recommend could be effective." In the parallel assessment activity, however, students are given a set of choices from which they must select but then write a justification for their selection. Specifically, they are told that to try to cool down the local climate, Chicago's City Council is considering enacting certain policies. Students are directed to select one policy that primarily tackles carbon emissions and another that primarily tackles urban heat island effects, then justify their selections.

Some parallel activities in the Plate Boundaries unit and assessment also exhibit these characteristics. For example, in Part B of the Plate Boundaries assessment, the more constrained task of matching cross-sectional views of earthquake behavior to plate boundary locations parallels the more open-ended task that asks students to select their own locations for analysis. In addition, the assessment task of describing characteristics of earthquakes on different boundary types is constrained to selection from a set of choices about the characteristics, whereas in the unit the students describe boundary characteristics in an open-ended manner.

12.3.7 Adaptability

Curriculum implementation research suggests that curriculum projects need to be adaptable to different teaching styles and classroom cultures in order to be capable of widespread implementation (Barron et al., 1995; McLaughlin & Marsh, 1978; Squire et al., 2003). The more that a curriculum developer can do to make the curriculum adaptable, the more it reduces the risks to the teacher that come with implementation. The DIGS curriculum modules are adaptable to different implementation conditions and teaching preferences. For example:

- Different activities are identified as either core or supplemental and thus accommodate different class time constraints.
- Some of the tasks, which individually may consume only a fraction of a class period, can be used alone, especially data analysis tasks that happen to be centered around one particular data set or representation.
- Teachers can vary their delivery of many of the unit activities to the students, selecting hands-on individual work, small-group collaborations, or class discussions.

The DIGS data sets provide for a wide range of potential geographic foci. Because of this variety, teachers can refocus the learning and assessment tasks on geographic settings of their choice, including their own community. Such flexibility provides another distinguishing type of adaptability. In the Climate Change module, the same Web-based, publicly available data sets about Phoenix and Chicago can be mined for data about other communities, as can the historical earthquake data in the Plate Boundaries module. Teachers concerned that students might not be interested in analyzing data about unfamiliar places can take heart in the likelihood that their students will be more motivated when looking at their own community's data.

12.4 Recommendations for Practice

Curriculum developers interested in conducting inquiry tasks around data-centered science problems can use the two curriculum design models expressed in Fig. 12.3 as frames of reference for determining what types of learning tasks would be most responsive to the epistemic characteristics of inquiry in different science topics. Following identification of the epistemic characteristics of our knowledge of the topic, key questions guiding curriculum development decisions are, to what extent:

- Can the topic be accurately characterized by probabilistic relationships or complex relationships between variables?
- Can age-appropriate data-centered learning and assessment tasks be designed around the topic that build in students deep understandings of those relationships?
- Do the characteristics of the topic require rating students on how well they can recognize what we do not know as well as what we do know from existing data?
- Does the topic permit assessment of whether students can draw unequivocally correct conclusions about what the data indicate or simply around how well they can pose strong evidence-based yet debatable arguments?

Providers of teacher professional development can present the DIGS modules as examples of curriculum designs that are responsive to different epistemic demands of data-centered inquiry within greater and lesser-probabilistic science topics.

Then, the providers can encourage their teachers and teacher candidates to practice answering the above questions in the context of different science topics.

Teachers thinking of using the DIGS modules in their classrooms should try out the different components of the DIGS modules and their assessment items in ways that fit available class time and their own comfort in implementing problem-based, case-based inquiry with real data. Teachers can also build their capacity with the foundational curriculum models in which the DIGS modules are rooted. They can think about how to design their own units and assessments on science topics. If teachers are not inclined to develop their own curricula, they can at least use the models to influence their adoption and adaptation decisions about already-developed curriculum resources. This exercise would be educative because using the models to make these curriculum decisions stimulates deep consideration of the epistemic qualities of our accumulated scientific knowledge about these topics.

12.5 Recommendations for Research

Research should be conducted on the impacts of classroom adoption of the application of foundational curriculum inquiry models exemplified by DIGS compared with implementations of other curricula that share common goals. Pre-/post-measures can be designed to measure impacts in experimental or quasi-experimental studies. However, designing these measures to be equally capable of detecting intervention group and control group impacts is challenging. This challenge can be confronted by articulating a theory of change that expresses the hypothesized added value of the treatment provided in the intervention situation as an improvement over the treatment provided in the control situation. If the hypothesized change justifying the intervention is expressed in terms of learning outcomes that are not addressed in the control situation, looking at relative changes in those outcomes across the groups is not a fair comparison. If, however, the hypothesized change addresses a common goal, the outcome measures become responsive to what is implemented in both the intervention and control groups. This type of comparison is possible if the outcomes are greater understanding of the science topics rather than student inquiry skills and if the differentiator of added value is deeper understanding about those topics, because the control group may not even be attempting to build inquiry skills.

Research also can be conducted on the extent to which other adoptions of data-centered inquiry curricula prove educative and capacity building for teacher professional development. Again, in experimental or quasi-experimental designs, teachers can be assigned to intervention and control groups. Intervention teachers can review and practice the DIGS modules or other modules rooted in the curriculum models, and control teachers can review and practice other curriculum materials that are hypothesized not to be inclusive of the educative, capacity-building components of the intervention curricula. Pre-/post-outcome measures can be designed to measure increases in teacher understanding of science and pedagogical issues surrounding science education.

Lastly, research should be conducted on the extent to which professional curriculum developers who are charged with developing data-centered, problem-based, inquiry-based curricula improve their capacity to do so by (1) identifying the topic's epistemic characteristics, (2) using the questions presented in the Recommendations for Practice to guide broad development decisions, and (3) comparing and contrasting the models introduced in Fig. 12.3 as foundational design alternatives.

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Chapter 13
Designing Google Earth Activities for Learning Earth and Environmental Science

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Keywords Environmental science • Educative curriculum • Spatial thinking • Earth science

13.1 Designing Google Earth Activities for Learning Earth and Environmental Science

Geospatial technologies including geographic information systems (GIS), global positioning systems (GPS), global visualization tools (such as Google Earth, WorldWind, ArcGIS Explorer), and Web-based 2D and 3D visualizations of Earth's landscapes, oceans, and associated geographic data have become readily accessible, widely available, and more apparent in our daily lives than ever before. These tools allow for visualizing, mapping, organizing, and analyzing multiple layers of georeferenced data. Geospatial technologies have proven to be a valuable tool for

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understanding the environment and of making responsible environmental decisions (Carrarra & Fausto, 1995; Heit, Shortried, & Parker, 1991; National Research Council, 2006). The ability to use, analyze, and interpret images and maps is becoming more and more important in many scientific and industrial fields. In addition, some contend that the ability to use images and spatial technologies intelligently and critically is becoming a requirement to participate effectively as a citizen in modern society (Bednarz, Acheson, & Bednarz, 2006).

Recent education reform initiatives emphasize the significance of developing thinking skills, data analysis skills, understanding real-world applications, and utilizing the power of technology in teaching and learning (International Society for Technology in Education, 2000; National Research Council, 1996; North American Association for Environmental Education, 2000). Integrating geospatial technologies that focus on the development of spatial thinking skills may provide a platform for effectively achieving these education goals and as a beneficial byproduct, environmentally literate citizens (Geography Education Standards Project, 1994). There have been many challenges, however, to implementing geospatial technologies in K-12 classrooms. These include technical issues pertaining to the interface design of software, time for classroom teachers to learn to use the software, lack of existing basal curriculum materials that integrate geospatial technologies, and lack of time to develop learning experiences that integrate easily into existing school curricula (Baker & Bednarz, 2003; Bednarz, 2003; Kerski, 2003; Meyer, Butterick, Olin, & Zack, 1999; Patterson, Reeve, & Page, 2003). While we acknowledge these barriers, new Web-based geospatial tools such as Google Earth and instructional resources integrated with appropriately designed instructional materials show much potential to be used with diverse learners to promote spatial thinking (Bodzin & Cirruci, 2009).

We have developed middle school curriculum modules that use Google Earth as a primary tool to promote learning of earth and environmental science concepts as part of a school-based reform initiative that was initially supported by a NASA Explorer School grant. Google Earth is a relatively new geospatial technology that is changing how people can interact with remotely sensed aerial and satellite images. Many scientists are currently using Google Earth to visualize data for studying a variety of environmental issues including sea ice distribution patterns and local weather phenomena (Butler, 2006). Google Earth is a virtual globe that contains and integrates a wide arrangement of remotely sensed and modeled images created with satellite and aircraft data at different points in time. Aerial photography and satellite image data have various resolutions, and depending on the user's virtual angle above the Earth, one is able to observe an earth feature from any direction or angle with an easy to use interface. One can zoom in on many major urban areas where the resolution may be about 1 m/pixel, permitting users to identify roadways, buildings, vegetation, and small water bodies. In areas where such high resolution is not available, the resolution is typically 15 m/pixel, enabling users to identify physical features such as volcanoes, canyons, and ski slopes. A fully functioning version is free and available for

Linux, Macintosh, and Windows operating systems (http://earth.google.com/intl/en/ download-earth.html). The free version of Google Earth is currently being used in secondary classrooms for virtual explorations of geologic features to enhance learner understandings of geologic processes (Fermann, 2006; Stahley, 2006). While Google Earth is a less robust tool than GIS for performing spatial analysis, it is also a much less complex tool to learn. Its basic tool set features are easy to use, enabling teachers to adopt it in their classrooms without having to spend significant time learning many procedural steps as is common with GIS applications. As a result, Google Earth has been adopted in a variety of classroom contexts including urban elementary school learners to assist with inquiry-based investigations (Bodzin, 2008). A variety of third-party users release additional applications to enhance the effectiveness of the tool through an online Google Earth community (see http://earth.google.com/). Another version of Google Earth with enhanced features, such as 3D modeling tools, is available for commercial applications for a modest cost.

13.2 Curriculum Materials Design

Our curriculum modules are designed to align instructional materials and assessments with learning goals (Wiggins & McTighe, 2005). We use national and state standards (American Association for the Advancement of Science (AAAS), 1993; Geography Education Standards Project, 1994; National Research Council, 1996) to provide guidelines for the science and geographic content in addition to the science inquiry and spatial skills that schools must focus on. The curricula include educative curriculum materials, that is, curriculum materials designed to promote teacher pedagogical content knowledge in addition to student learning (Davis & Krajcik, 2005). In designing such materials, curriculum developers and researchers recommend providing baseline instructional guidance for teachers and implementation and adaptation guidance (Ball & Cohen, 1996; Davis & Krajcik, 2005). Educative curriculum materials also provide rationales for instructional decisions. If teachers understand the rationale behind a particular instructional recommendation, they may be more likely to enact the curriculum in keeping with the developers' intent (Davis & Varma, 2008).

Our materials are designed to promote teacher learning of spatial thinking skills that are geographic (see Gersmehl & Gersmehl, 2006) in addition to supporting teachers' learning of earth and environmental science subject matter (Schneider & Krajcik, 2002). The instructional materials are designed to provide additional supports for teachers who work with diverse learners. They include tools that enable access to learner ideas and attitudes that students bring to the classroom. The materials include an instructional design model (Appendix) to provide teachers with an understanding of the rationale to how materials are intended to be used with classroom learners.

We use a design partnership model for the development of the materials that includes science educators, scientists, instructional designers, and classroom teachers. Our partnership model focuses on collaborative design and implementation of curricula in keeping with models of school-based reform (Shear, Bell, & Linn, 2004). Our partnership is a mechanism for leveraging the diverse expertise of each contributor. Such partnerships facilitate the transition between the designed curriculum and the implemented curriculum in the classroom. These collaborations also promote the learning of each partner in a process of codeveloping the curriculum and instructional practices that will be implemented in the classroom (McLaughlin & Mitra, 2001).

Each partner brings a unique perspective to the design and development of the modules and activities. The science educator provides the group with science-specific pedagogical content knowledge and knowledge of instructional designs and frameworks that were successfully used in past science curriculum projects for diverse learners (see, e.g., Bodzin, Waller, Edwards, & Kale, 2007; Bodzin & Anastasio, 2006; Bodzin & Shive, 2004). The scientists contribute to the design process by ensuring that the content is current, valid, and essential to the students' enduring understandings of the discipline. The instructional designer assists the group with ensuring that the overall design framework conforms to proven educational technology instructional design theories such as incorporating facets of Gagné's nine significant events model (Gagne, Briggs, & Wager, 1992), Gardner's theory of multiple intelligences (Gardner, 1999), incorporating constructivist models to enhance the social process (Jonassen, 1994), and ensuring cognitive flexibility of learning, knowledge representation, and knowledge transfer (Spiro & Jehng, 1990). The classroom teacher keeps the group grounded in the fidelity of implementation realities of the classroom. During an iterative development process, the teacher helps the group to address many implementation issues including curriculum time and scheduling constraints (such as classroom time required state testing), designing instructional materials for students with special needs and below average reading abilities, and computer and network issues that commonly occur in school settings.

In this chapter, we first present an overview of two instructional middle school modules, the 4-week *Environmental Issues: Land Use Change* (http://www.ei.lehigh.edu/eli/luc/) unit and the 8-week *Energy* (http://www.ei.lehigh.edu/eli/energy/) unit. Both curricular units use Google Earth as an instructional learning tool and were developed as part of our partner NASA Explorer School's 8th grade science curriculum. Next, we describe a series of design principles that we use as a guide in the development of instructional activities to promote earth and environmental science learning. We include examples from *Land Use Change* and *Energy* to discuss how we incorporate our design principles into our learning activities. In our presentation of the design principles, we include recommendations for other curriculum developers interested in using Google Earth as a learning tool. We conclude the chapter with implications for the professional development of teachers who implement curriculum materials that use Google Earth as a learning tool.

13.3 Environmental Issues: Land Use Change

Urban area expansion and population growth through commercial, industrial, and residential development results in a loss of natural vegetation, agricultural lands, and open space (Alberti, 2005). For the first time in human history, a majority of the world's population now resides in cities. Such growth is often accompanied by a general decline in the extent and connectivity of wildlife and wetland habitat. Land cover and land use changes can be substantial but are difficult to grasp when they occur incrementally (Laymon, 2003).

The 4-week *Land Use Change* module is designed to assist students in understanding land use change concepts including environmental issues that are typically associated with sprawl and development such as urban heat island effects and to promote the learning of essential skills used in interpreting remotely sensed images. Urban heat islands occur as a result of increased heat production and diminished heat dissipation due to city structure. More solar energy is absorbed and retained creating a "hot spot" as compared to nearby suburban and rural areas that have more vegetation. To understand concepts involved in the formation of urban heat islands, students use Google Earth to investigate how shopping malls change natural environments. The module begins with a student investigation of the spatial and environmental aspects of a shopping mall in Huntsville, Alabama. Students learn to use basic elements of aerial photo interpretation (including tone, size, texture, pattern, shadow, site, and association) to aid in identifying objects in aerial photographs, enhancing their three-dimensional visualization skills. Next, students use Google Earth to complete a geographical case study of Atlanta's urban heat island effects and the consequences of urban deforestation in the greater Atlanta area. In the instructional activities, students learn how communities can use certain heat island reduction strategies to reduce the impact of an urban heat island effect. They also interpret land use maps of the greater Atlanta area to understand environmental issues that are typically associated with sprawl and land development.

Student investigations continue with a case study of the Lehigh Valley area in Pennsylvania using Google Earth to identify various man-made and natural land features (Fig. 13.1). Next, they compare the land use types around five different shopping mall areas using Google Earth as they examine the significance of mall locations. Shopping malls use a lot of land and stand out on the landscape. They are large enough to appear on aerial photos and satellite images and contribute to heat island effects in an area. Malls affect other places in a community and encourage dependence on automobiles. Wherever malls are built, there are environmental consequences as vegetation, and wildlife habitat is fragmented and lost. Shopping malls are found in large and small communities and are a part of everyday life for most middle school students in the USA. Studying mall locations helps learners examine changes in ecosystems that are associated with sprawl and development.

In the next learning activity, students use remotely sensed images to recognize land use patterns of diverse areas in our world. They examine and interpret time-sequenced satellite data and aerial photographs of urban areas to interpret

Fig. 13.1 Image from Google Earth displaying locations of an active limestone quarry (*left* pushpin) and an abandoned flooded quarry (*right* pushpin). The lake level in the abandoned quarry is the local groundwater table; pumping has lowered the groundwater table in the active quarry

geographic growth patterns. In addition, they examine landscape changes over time through analysis and interpretation of satellite data images and aerial photographs. By studying diverse areas, they learn about the nature and consequences of human–environment interactions.

In the culminating activity, students recommend a plan for locating a new Walmart Supercenter in the greater metropolitan Lehigh Valley area to have minimal impact on the environment. Students use Google Earth to analyze and evaluate features of different land areas for proposed development sites. Lastly, they develop a proposal to apply “smart growth” principles to their planning decisions and communicate their plan in a simulated planning commission meeting.

13.4 Energy

The 8-week *Energy* module takes advantage of geospatial learning tools including Google Earth and GIS to promote student understandings that there are many sources of energy to power society and they each have impacts on the environment. In the learning activities, students investigate the underlying physical science concepts pertaining to the production of energy from different sources, learn how energy is used for electricity production, and enhance their geography knowledge by investigating the spatial relationships of energy sources among our planet. Students also examine energy use and inefficient practices and consider ways to sustain the future of our environment with alternative energy sources. The learning activities address common student misconceptions and knowledge deficits about energy concepts. This section describes the learning activities that incorporate Google Earth to investigate renewable energy sources.

Fig. 13.2 The Bay of Fundy (Image from Google Earth)

In the first renewable energy activity that uses Google Earth, students are presented with the driving question: *Where is the best place to locate a new solar power plant*? First, students locate and tour existing solar power plants around the world. They examine the ground cover area and measure perimeters of each solar power plant with the Google Earth measuring tool, thus become introduced to quantitative geospatial analysis. The investigation continues as students analyze newly planned solar power plant locations and a 30-year average world insolation dataset with MyWorld GIS to evaluate the suitability of the locations for construction.

Students learn about harnessing wind energy as they use Google Earth to investigate *Where is the best place to locate a new wind farm?* They view seven different wind farms around the world to examine land cover, topography, perimeter, and wind power classes at each location. In this activity, students determine the optimal characteristics of a location to develop a new wind farm. The activity continues by examining sixteen proposed wind farm locations in Pennsylvania using MyWorld GIS.

Students learn about tidal power as they explore locations with high tidal ranges with Google Earth. In the learning activity, they examine the funnel shapes of the Bay of Fundy (Fig. 13.2), Severn Bay, and the Baltic Sea – areas with very large tidal ranges that make these locations advantageous for the placement of tidal power plants. Students then compare the water body shapes of these areas to those with low tidal ranges such as the Gulf of Mexico.

The next Google Earth activity has students examine and compare the characteristics of five different hydroelectric dams and their surrounding areas. Students examine the location of each dam, the height, and the dam capacity, then measure

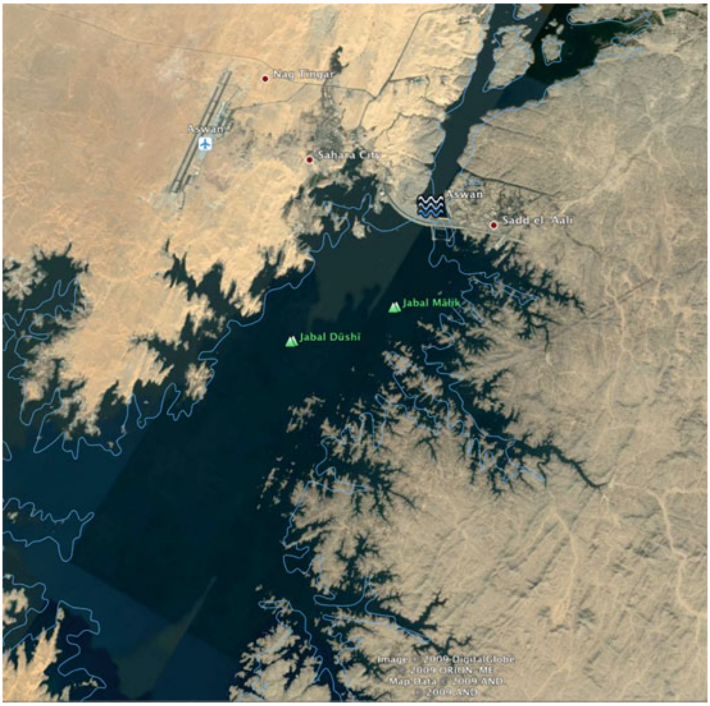


Fig. 13.3 The upstream Nile reservoir and downstream Nile River separated by the Aswan Dam (Image from Google Earth)

the width of the dam and distances from each dam to nearby population centers. The shape and size of each dam's reservoir is compared to the shape and size of the river on the downstream side of the dam (Fig. 13.3). The activity continues as students use MyWorld GIS to query and examine features of the 1,184 most productive hydroelectric dams in the USA. The activity concludes as students use Google Earth to investigate specific features of five major Pennsylvania hydroelectric facilities on the Allegheny and Susquehanna Rivers, including a pumped storage generating station facility.

The final renewable energy resource activity, *Where is the best place to locate a geothermal power plant?* has students use Google Earth to explore "hot Earth" areas in Iceland and in the USA. Students use Google Earth to identify Earth features that are evident of geothermal activity. These include locations of geysers, fumaroles, natural hot spring areas such as the Blue Lagoon in Iceland (Fig. 13.4), lava fields, volcanic mountain features, and a chain of volcanic islands that marks the boundary between the Pacific and North American tectonic plates. Students then examine population centers in the northwest USA and areas where the Earth is hot to determine an optimal location to place a geothermal power plant.

Fig. 13.4 The Blue Lagoon area and Svartsengi geothermal power plant in Iceland (Image taken from Google Earth)

13.5 Design Principles

Design principles speak to the pragmatic aspects of practice while also informing theories of learning (Bell, Hoadley, & Linn, 2004). Like other design principles used in education (Kali, 2006), our principles are designed to focus not only on local classroom implementation but also for more generalized classroom learning environments. These design principles are a product of a series of design-based research studies conducted in diverse educational settings over the past 6 years whose primary aim has been to promote innovation in earth and environmental science learning. It is our intent that the ideas presented in this section will serve as recommendations to curriculum developers who intend to use Google Earth in their design and development work.

13.5.1 Design Curriculum Materials to Align with the Demand of Classroom Contexts

Schools across the USA have made significant investments in technology such as high-bandwidth wireless networks and widely available laptop computers in classroom instructional settings. We acknowledge that one instructional model or distinct set of learning activities may not accommodate every learner, classroom teacher's pedagogical style, or classroom learning environment. Activity structures from available curricula, whether designed by commercial publishers or from educator developers, vary significantly. We recognize that developers of such activities have an intended target audience and that audience may not have the same prerequisite skills or content background of other classroom learners. In addition, such curricula may not take into consideration teacher time constraints on curriculum implementation and mandated academic year content coverage. We develop our learning activities in ways that teachers may customize the instructional sequence and still meet the learning goals of the units. We incorporate design features in instructional materials so that low-level readers and low-ability students can understand scientific concepts and processes in addition to learners whose cognitive abilities are at or above the intended grade level. For example, we provide animations and images on many content Web pages to help learners visualize scientific concepts that occur over time such as the formation of fossil fuels. In addition, we design activities to promote active learning with Google Earth to promote high learner engagement with this learning tool.

13.5.2 Design Activities to Incorporate Two Main Properties: Scalability and Portability

Scalability refers to the need for the investigative experiences addressed by the learner to be small enough that they can derive conclusions in a reasonable length of time, but also be of sufficient detail that by completing them, the students will make connections to larger and more complex environmental problems. Portability means the problems addressed in the activities should involve concepts and practices that are applicable to diverse locations and situations, allowing learners to extrapolate their derived understandings to problems other than those to which they were exposed (Bodzin & Anastasio, 2006). We structure learning experiences in ways that allow students to see connections from local to global and between the specific cases and generalized settings in order to maximize educational value (Bednarz, 2004). For example, in *Land Use Change*, a case study of a shopping mall area in Huntsville is used to introduce students to urban heat island effects. The concepts learned are then later applied to examining the land uses and infrastructures of shopping mall areas in the greater Lehigh Valley area. The understandings gained from these activities are then later applied to finding a location for a new Walmart Supercenter that will have minimal impact on the environment.

13.5.3 Use Motivating Contexts to Engage Learners

It is important to provide middle school learners with a motivating entry point to set the stage for their investigations. Using a locally relevant problem or real-life occurrence that a student can easily experience is important to engage students in learning (Bodzin & Shive, 2004). Such motivating contexts, such as examining a shopping mall environment – a location where middle school age students often spend their free time – provide students with reasons to want to learn more about a particular environmental issue such as how new development impacts land use change.

13.5.4 Provide Personally Relevant and Meaningful Examples

To make earth and environmental science learning accessible, we seek out and include examples that are personally relevant to students. By including issues pertaining to students' everyday experiences, we make science learning meaningful and relevant. In our implementation studies, we have found that students become more motivated to understand environmental issues when they recognize that the issues involved are directly connected to their daily lives. In *Land Use Change*, we have students use Google Earth to examine land features in their community and consider the environmental impacts of a new building construction project in their area. In *Energy*, the use of Google Earth to analyze nearby area locations for placing renewable energy power plants provides learners with a meaningful context for considering the environmental impacts of these new facilities.

13.5.5 Promote Spatial Thinking Skills with Easy to Use Geospatial Learning Technologies

Instructional activities should include easy to use tools to support spatial thinking and reasoning activities. We identify readily available remotely sensed aerial and satellite images from Google Earth as tools to be used to support such learning. Remotely sensed images have been used in educational settings as tools for learners to identify and interpret land cover features and view changes on the Earth's surface over time (Huber, 1983; Kirman & Nyitrai, 1998; Klagges, Harbor, & Shepardson, 2002). We compose screen placemark images at specific sizes and scales to help learners understand the scale and spatial distribution of Earth features and guide learner attention by automatically delivering sequential image examples that reinforce the educational concepts. For example, in a MyWorld GIS investigation of hydroelectric power dams, we start nationally, then zoom to Pennsylvania, and finally the Susquehanna River. Then we sequence a Google Earth exploration of energy generating hydro and nuclear power plants on the same river, bringing the students to their home region and recognizable geography. Our materials instruct students and teachers to display certain layers, such as the *Terrain* layer to emphasize natural geographic features such as mountain ranges and canyons. In addition, we develop files using Google Earth tools such as polygons and image overlays to assist students with understanding the spatial relationship among different features. For example, in *Energy*, we created colored polygons to enable learners to see greater metropolitan areas in the northwest USA.

13.5.6 Design Image Representations That Illustrate Visual Aspects of Scientific Knowledge

Earth scientists have years of training and experience with recognizing salient information in visual material. For example, a geologist is more likely to identify prominent information in a satellite image of a volcanic mountain area than a nonscientist. Yet, visualizations can distract learners rather than encourage understanding. We use Google Earth to take advantage of a scientist's craft by designing Google Earth images that clearly display aspects of scientific understanding. For example, when one uses the Google Earth search feature to observe Mt. Fuji, the resulting image display does not prominently illustrate key features that identify Mt. Fuji as a volcanic mountain (Fig. 13.5, left image). When we design our placemark images, we take advantage of the ability to resize, rotate, and adjust the angle of the image to provide learners with an initial image display that highlights prominent physical features. This helps novice learners to better understand the connection between Earth and environmental processes and the landscape. For example, we created the right image on Fig. 13.5 to enhance the prominence of the features that allow a trained eye to conclude the image is of a volcano. The salient observations include that this is a cone-shaped mountain rising above a surrounding plain. The radiating gullies confirm the cone shape. The snow line on the flanks supports the conclusion that the feature has a high altitude, and the numerous switchbacks in the flanking roads suggest the feature is steep. The tilted image better shows the crater depression on the crest. When taken together, the crater-topped, steep, high, conical mountain is correctly interpreted to be a volcano, a characteristic of empirical science inquiry.

13.5.7 Develop Curriculum Materials to Better Accommodate the Learning Needs of Diverse Students

Today's classrooms are quite diverse with learners of varied cognitive abilities, language skills, and special learning needs. We incorporate design features in our instructional materials to accommodate varied learning needs. We reduce the complexity of examples and visualizations by eliminating details that may distract learners from understanding the main concepts. In our instructional materials, we keep language simple and use graphical features in the instructional materials to help learners understand content as well as procedures for using geospatial learning tools. For example, Fig. 13.6 shows how large numbered red arrows are added to a screen capture of the *layers* window of Google Earth to help students understand image display procedures. Bold and italicized text fonts are used to draw learners' attention to keywords in the procedure.

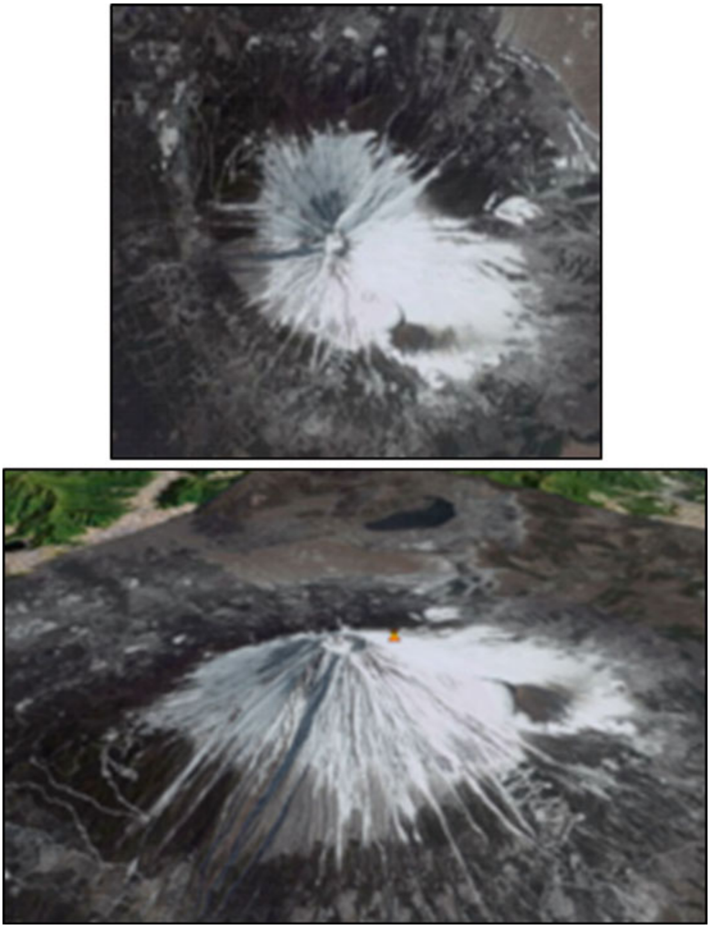
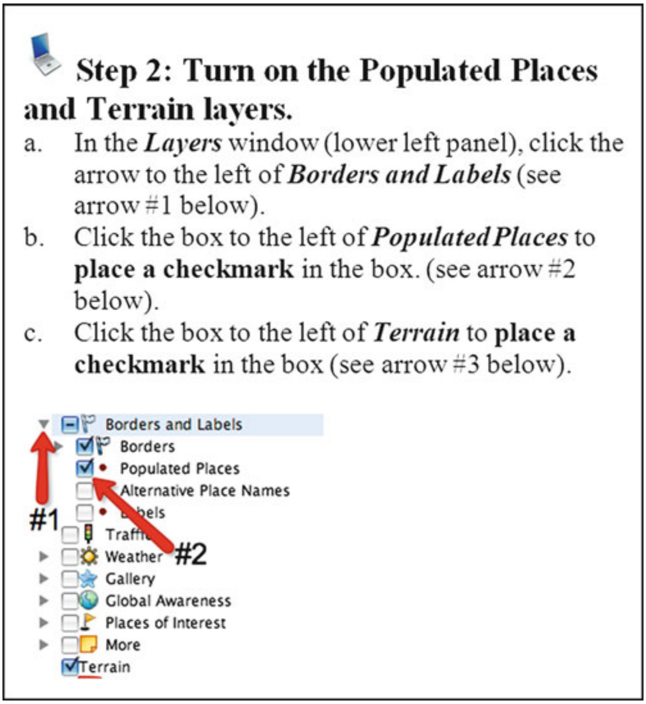


Fig. 13.5 The *top* image shows Mt. Fuji as displayed with the Google Earth search feature. The *bottom* image is created to display prominent volcanic features by tilting the viewer's perspective

13.5.8 Scaffold Students to Explain Their Ideas

Many students have problems being successful with open-ended investigations and complex activities where data are analyzed and evidence is carefully considered to formulate conclusions. We design materials with embedded prompts in the learning activities to help students focus their observations. Such prompts help learners articulate their thoughts and think critically about observed phenomena. Table 13.1 includes some examples of prompts used in the *Exploring Hydroelectric Dams with Google Earth* activity designed to help learners examine and think about features of



Step 2: Turn on the Populated Places and Terrain layers.

a. In the *Layers* window (lower left panel), click the arrow to the left of ***Borders and Labels*** (see arrow #1 below).

b. Click the box to the left of ***Populated Places*** to **place a checkmark** in the box. (see arrow #2 below).

c. Click the box to the left of ***Terrain*** to **place a checkmark** in the box (see arrow #3 below).

Fig. 13.6 Google Earth procedure from the *Exploring Hydroelectric Dams with Google Earth* activity that provides graphical features and specialized text font

Table 13.1 Select prompts used in the *Exploring Hydroelectric Dams with Google Earth* activity

Do all dams have the same *shape*? Do all dams have the same *length*? Do all the dams have the same *height?* What do they look like?
Is the *area surrounding* each dam similar or different? What does the area around each dam look like?
Why do you think dams are built on rivers?
What are the *advantages* of building a dam near a *large population area*?
Which dams were built *furthest away* from large population areas? Why do you think these dams were built in these locations?
What does the river look like on each side of the dam? How are the *shape* and *size* of the reservoir different from the shape and size of the river on the downstream side of the dam? Is the water area larger and wider on one side of the dam? By looking at which side of the dam has a larger body of water, can you tell which way the river flows? Remember the reservoir is located on the upstream side of the dam. Water flows downstream.
What are some *advantages* of having one side of the dam contain a *much larger volume of water* than the other side?

hydroelectric power dams. The prompts in Table 13.1 are designed to help students focus on key features of dams and the area surrounding them such as reservoir shape and size and proximity to populated areas.

13.5.9 *Use Icons That Portray the Real-World Concept*

Google Earth provides different icons that can be used as placemarks, and it also allows for using custom icons. Instead of using the default pushpin, we use icons (images) that depict the concepts being learned. This might help the learners to form an association between the icon and the concept it represents which may enhance recall. In Fig. 13.7, for example, we used the sun icon to put placemarks at locations of solar power plants and the water icon to put placemarks at locations of hydroelectric dams. This may help learners recall that solar energy comes from the sun and hydroelectricity comes from the force of moving water. According to Paivio (1971), images act as mediators in learning and memory tasks and can be amazingly effective as memory aids.

13.6 Educative Curriculum Materials as a Form of Professional Development

As discussed in Chap. 14, teacher professional development is highly effective when designed to accompany particular curriculum materials. We contend that the use of educative curriculum materials in and of themselves provides a form of professional development since they include designs to promote teacher learning and support teacher decision-making for implementing curriculum materials. These materials may be used independently or with other forums for teacher learning such as face-to-face or Web-based professional development experiences. Remillard (2000) describes using curricular materials to “speak to” teachers about rationales behind instructional decisions. Since the classroom teacher is the agent who ultimately decides and structures what is to be taught, educative curriculum materials should help teachers to understand how Google Earth fits contextually within the instructional design of the curriculum. For example, in both the *Land Use Change* and *Energy* curricula, Google Earth is used to explore concepts through geospatial-supported investigations. Consequently, our instructional materials are designed to help teachers learn how image displays in Google Earth, when used with overlay features such as terrain, roads, and 3D buildings in urban areas, provide support for students to identify and interpret land cover features.

Educative curricular materials can be used to help teachers promote spatial thinking skills. When using Google Earth to promote spatial thinking skills, there is a need for explicit instruction in spatial analysis to help diverse learners understand visual representations in remotely sensed images. Much structure is needed to guide students to observe spatial patterns in land use, especially in areas that are unfamiliar to them. Furthermore, unlike adults who have developed better locational skills as automobile drivers, middle school students typically have a myopic view of their world, so spatial locations are more difficult for them to comprehend. Our Google Earth activities allow learners to view their world close-up as they normally encounter it and to pan back to see relationships between things they only know previously

Fig. 13.7 The sun icon was used as a placemark at the Kramer Junction solar power plant in the *top* image. The water icon was used as a placemark at the Three Gorges hydroelectric dam in the bottom image (Images from Google Earth)

in isolation. In our curriculum materials, we provide instructional recommendations encouraging teachers to model the processes of analyzing and interpreting such relationships to their students. In addition, we design educative curricular materials to help teachers provide appropriate scaffolds to students when they examine images with different land use types, especially in areas that include environmental contexts that are unfamiliar to students.

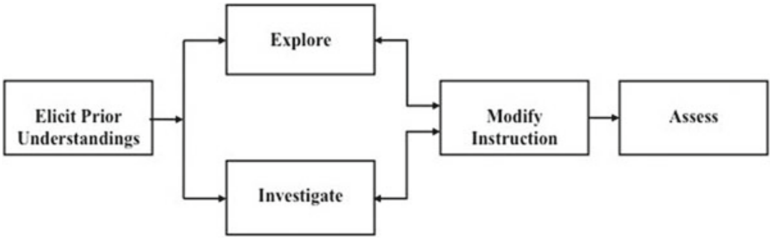
13.7 Final Thoughts

Google Earth, when accompanied with appropriately designed learning and support materials, can be used as an effective tool for learning about the Earth and the environment. In educational learning environments, Google Earth can be used to foster certain spatial thinking skills with diverse learners. Google Earth is a freely available, powerful, user-friendly tool that can be used to examine and investigate natural and man-made features on the Earth's surface, helping learners to visualize and understand processes that occur on our planet. Working together, science educators, scientists, designers, and classroom practitioners can design and develop instructional materials that present earth and environmental content and concepts in appropriate and engaging ways for learners.

Acknowledgments We wish to give special acknowledgment to Lori Cirucci, Dork Sahagian, and Tamara Peffer, our partners in this effort. This work was supported in part by a NASA Explorer School grant and the Toyota USA Foundation Web-enhanced Environmental Literacy and Inquiry Modules for Middle School Learners (WELIM) grant.

Appendix

Energy unit instructional design model



Elicit Prior Understandings

At the beginning of the unit, the teacher evaluates what students know through a concept map, content knowledge, and attitude and behavior pretests.

Explore and Investigate

Students explore and investigate concepts through geospatial-supported investigations, laboratory experiments, and other curricular materials to help them acquire desired knowledge, skills, and attitudes.

Modify Instruction

The teacher adjusts instruction as needed based on students' responses to the learning activities (formative assessment).

Assess

At the end of the unit, the teacher evaluates students through their completed artifacts and summative assessment. These include energy policy presentations, concept maps, and content knowledge, attitude, and behavior posttests.

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Chapter 14

Designing Geospatial Exploration Activities to Build Hydrology Understanding in Middle School Students

Louise Yarnall, Philip Vahey, and Karen Swan

Keywords Water cycle • Preparation for future learning framework • Curriculum design • Data literacy

14.1 Introduction

In both environmental science education and policymaking circles, water plays a central, unifying role. Yet in educational and professional practice, there are few opportunities to appreciate and understand the broad scientific and social importance of water. The water cycle has been characterized by hydrologists as "the bloodstream of the biosphere," an analogy that captures the highly interdisciplinary quality of the study of water (Falkenmark, 1997). While early understandings of what we now call "the water cycle" go back to Aristotle's time, modern science has deepened our understanding of this cycle and revealed how water and water-related phenomena touch on many scientific and social aspects of life. The study of water is linked to physics, chemistry, geology, ecology, geography, and biology, as well as to politics, economics, and culture (Brody, 1993).

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14.2 Theoretical Framework

Despite the centrality of water to life, the scientific models that describe its function in the biosphere are not well understood by students and laypeople. In his review, Brody (1993) described multiple studies documenting many common student misconceptions about osmotic and diffusion processes, evaporation, condensation, kinetic molecular theory, and water pollution. These misconceptions persist through 12th grade for most students. Science education researchers have theorized that such misconceptions emerge from educational approaches that fail to engage students in constructing their own understanding of scientific ideas (Bransford, Brown, & Cocking, 2003). As an alternative, K-12 education researchers have recommended inquiry-based instruction that encourages students to reason about data and construct scientific models (Krajcik et al., 1998; Lehrer & Schauble, 2002).

Some research has focused on using technology, such as geospatial tools, to support such reasoning and knowledge construction. These representations are believed to help students see abstract scientific concepts better through the computational tools' dynamic and interactive features (Konold & Miller, 2005; Morgan, MaKinster, & Trautmann, 2009). In practice, however, it is challenging to implement widespread adoption of computational geospatial tools, particularly at the middle school level. Beyond the technical hurdles of this enterprise is an even more challenging reality: middle school teachers with lower levels of content knowledge tend to rely heavily on textbooks (Lee, 1995). The common use of textbooks fosters a set of instructional practices that run directly counter to the kinds of inquiry-based approaches consistent with computational geospatial tools. Project 2061 rated middle school science textbooks as "poor" to "fair" in promoting inquiry-based instructional strategies, such as acknowledging student's preexisting ideas, engaging students' interest in personally relevant scientific phenomena, providing opportunities for students to develop and use scientific ideas, promoting student thinking, and, notably, representing scientific ideas (Kulm, Roseman, & Treistman, 1999; Stern & Roseman, 2004).

Rather than focusing on how teachers or students might construct geospatial representations using a computational tool, we focused on examining the challenges and opportunities of selecting geospatial data to spur students' problem-based reflection and hydrological scientific reasoning. We wanted to provide students with the data most relevant to water cycle processes as a means to motivate inquiry. In particular, we wanted to stimulate student reasoning and explanation construction within the context of unequal water distribution among the countries in the Tigris/Euphrates watershed. Furthermore, we sought to have students examine how the use of agricultural and industrial water capture and redistribution technologies causes pollution. We chose geospatial maps as a stimulus to present these thought-provoking real data. Map design experts have described the cognitive dimensions of map reading as iterative and complex: "geovisualization is not a passive process of either seeing or reading maps. It is an active process in which an individual engages in sorting, highlighting, filtering, and otherwise transforming data in a search for patterns and relationships" (MacEachren, Brewer, & Steiner, 2001).

In our design of geospatial representations, we applied ideas similar to those identified by cartographic and information design researchers (Bertin, 1983; MacEachren, 1995; Tufte, 2001). First, we used the geospatial design concept of layering to help students make links between critical climate and topographical data, thus prompting them to reason about why precipitation and runoff occur where they occur. We designed this representation in science class to build students' understanding of a watershed, a concept developed throughout an interdisciplinary curriculum for a larger project called Thinking with Data (TWD). A watershed is "a basin-like landform defined by highpoints and ridgelines that descend into lower elevations and stream valleys. A watershed carries water 'shed' from the land after rain falls and snow melts" (Pennsylvania Environmental Council, 2001). Watersheds are critical in understanding that environmental phenomena often occur on larger geographic scales that supersede political and cultural boundaries. Second, we used the geospatial design concept of parallel representations to help students develop the ability to synthesize data from multiple sources. This synthesis helps students create explanations and specifically make links between how a human activity like irrigation can be associated with increased salt concentrations in soil and water.

14.3 Current Practices

Typically water cycle concepts are taught through a combination of a diagrammatic representation of the water cycle occurring over a familiar landscape, a set of vocabulary memorization tasks, and one laboratory activity that illustrates the phase change of water as it condenses from gas to liquid form. In contrast, our TWD project used the water cycle as the frame for understanding issues of water availability and use in the Tigris/Euphrates and selected US watersheds. The TWD project, funded through the National Science Foundation's Instructional Materials Development program, sought to create a set of related curriculum units that would build students' data literacy across all the subjects of the middle school curriculum – social studies, mathematics, science, and language arts (http://www.rcet.org/twd/index.html). Our materials were tested in two suburban middle schools in northeast Ohio and built upon their local curriculum standards. Since study of the ancient river civilizations of the Tigris and Euphrates was a central focus in the social studies curriculum, we designed our lesson sequences around data drawn from this watershed – the area that is now the modern countries of Turkey, Syria, and Iraq. Although our curriculum materials cover all four subjects, this chapter focuses only on the science materials and in particular on the use of geospatial maps to stimulate student inquiry and reasoning about water cycle concepts. The project began in 2004, but the discussion in this chapter focuses solely on work conducted from 2007 to 2008. This science activity involved 140 seventh-grade students taught by two science teachers in two different schools. Our data in this case study focuses on the experience of one of those science teachers.

14.4 Our Use of Geospatial Exploration Materials

The ideas of layering and parallel representations helped us create geospatial data representations that met the rigorous requirements of our driving pedagogical approach, Preparation for Future Learning (PFL) (Schwartz & Bransford, 1998). In this curricular design framework, the typical sequence of instruction – lecture followed by practice followed by testing – is turned on its head. In PFL, students first review a complex data representation with an embedded driving question and then (1) invent a solution, typically nonnormative, to answer the question, (2) share and compare their solutions, and (3) experience a more formal explanation of the important scientific principles central to answering the question. For shorthand, we described this process in our instructional materials as inventing-sharing-telling. As the theory's title implies, the students are "preparing to learn" important concepts through the steps of inventing and sharing, and they have a greater appreciation for the formal explanation provided in the "telling." In this framework, we posed driving questions to students and then provided the data representations to help them "invent" a coherent answer. In theory, the difficulty the students would experience in crafting an explanation by using the data would prepare them to hear and appreciate the key explanatory science concepts in a teacher's later lecture.

We developed two driving questions to stimulate student reasoning about the underlying water cycle-related causes of unequal water distribution and salt pollution. The first driving question focused on water distribution and sought to have students think about how the water cycle functions over the vast Tigris/Euphrates watershed: "Where does it rain the most?" We provided the students with custom geospatial maps of Turkey, Syria, and Iraq generated in geospatial software. The maps depicted data related to rainfall, such as monthly and annual average air temperatures, evapotranspiration rates, elevation, average hours of sunshine, and biomes. We purposely did not give the students the actual rainfall rates. We provided data about sunshine and biomes as additional contextual information. The students viewed the maps on computers (see Fig. 14.1).

We should note that our underlying curriculum framework pushed us to set relatively complex learning goals. Geospatial watershed lessons described in other research (see Bodzin, 2008) and other chapters in this volume (Bodzin, Chap. 17; MaKinster, Chap. 15) involve using mapping software to make large-scale environmental phenomena more concrete. Students could "fly through" virtual topographical maps, tracing water runoff patterns; they could track how water in a schoolyard stream fed into the Atlantic Ocean; and they could see how local dams changed the shape of water bodies. Using the PFL framework's push for conceptual learning, we wanted students to use the first driving question to invent a data-based explanation about why rainfall occurs more in some places and less in others. Inventing such an explanation involved a few conceptual leaps: seeing the relationship between temperature and topographical elevation and then considering the influence these factors had on water cycle condensation and evaporation.

The second driving question focused on the causes of salt pollution: "Is there a relation between irrigation and salty soil?" To help students answer this question, we provided three different data representations: a table, a bar graph, and a

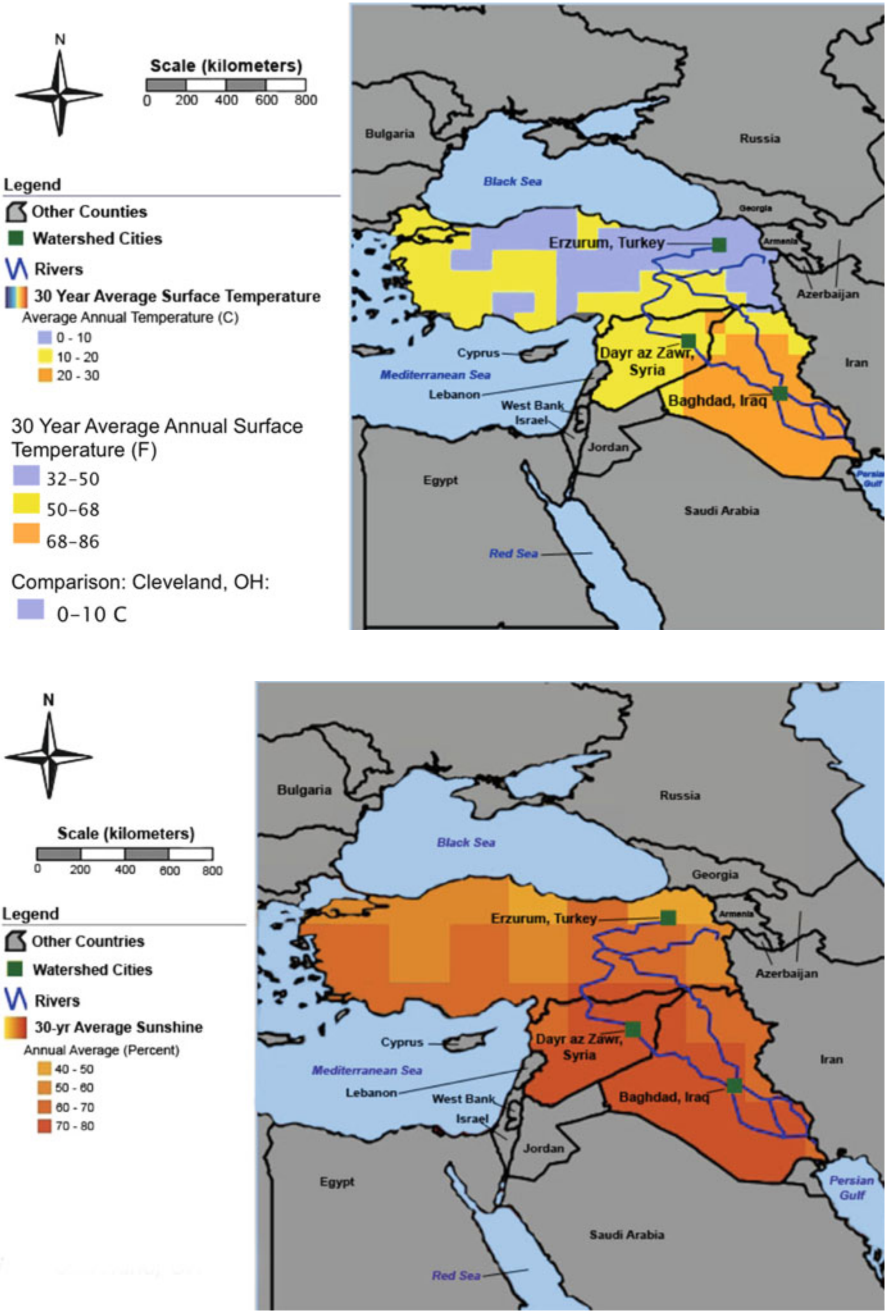


Fig. 14.1 Geospatial exploration activity using layered data. These images engage students in using different layers of geospatial climate and topography data. *Image 1* Example of one layer of data. *Image 2* Example of second layer of data. *Image 3* Example of third layer of data. *Image 4* Example of fourth layer of data. *Image 5* Example of fifth layer of data

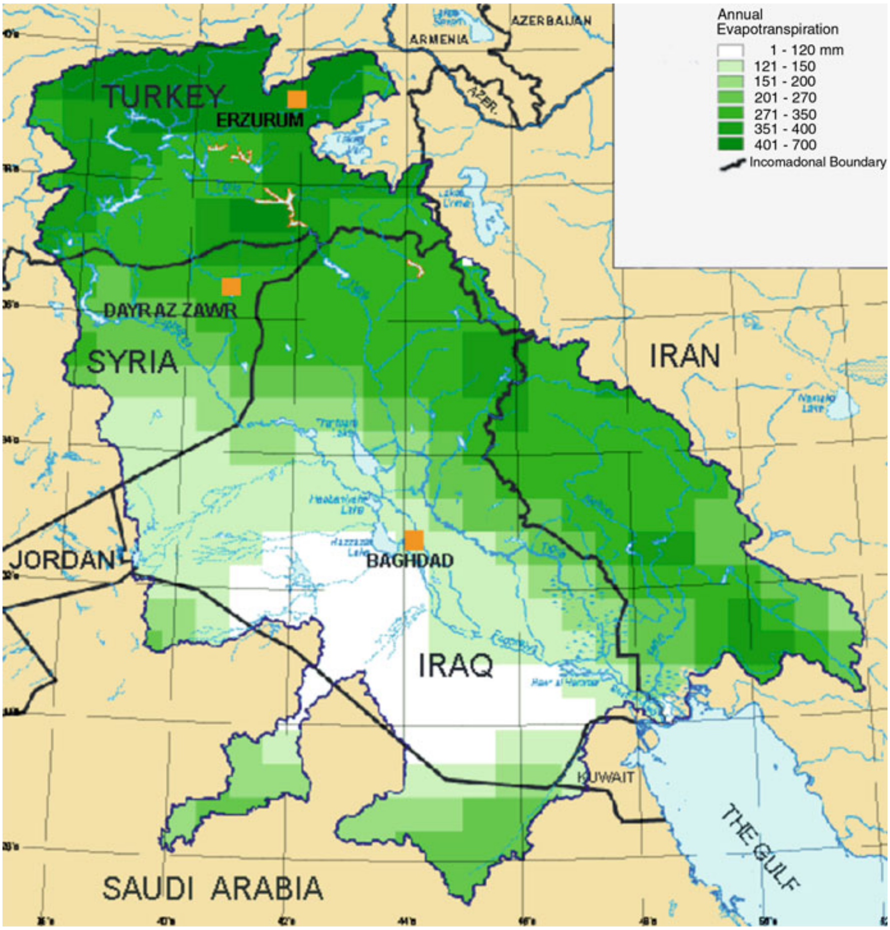


Fig. 14.1 (continued)

geospatial map. The table represented data on amounts of irrigated land and salty soil in Turkey, Syria, and Iraq. To render the raw data in the table comparable among countries (so students could see the relationship between irrigation and salty soil), students needed to compute some percentages, an application of lessons they had learned in the TWD mathematics module which preceded the science module. The geospatial map shows different kinds of land uses in five specific locations in Iraq – irrigated land, rainfed agriculture, desert land, and floodplain. For each location, data in the bar graph displays sodium and chloride measurements taken at different points in the Tigris/Euphrates system. This task also involved a conceptual leap. Students needed to see the relationship between the irrigation of land and higher salt content in the soil. The "telling" portion of the lesson presented how the water cycle, runoff, infiltration, and evaporation contributed to this problem (Fig. 14.2).

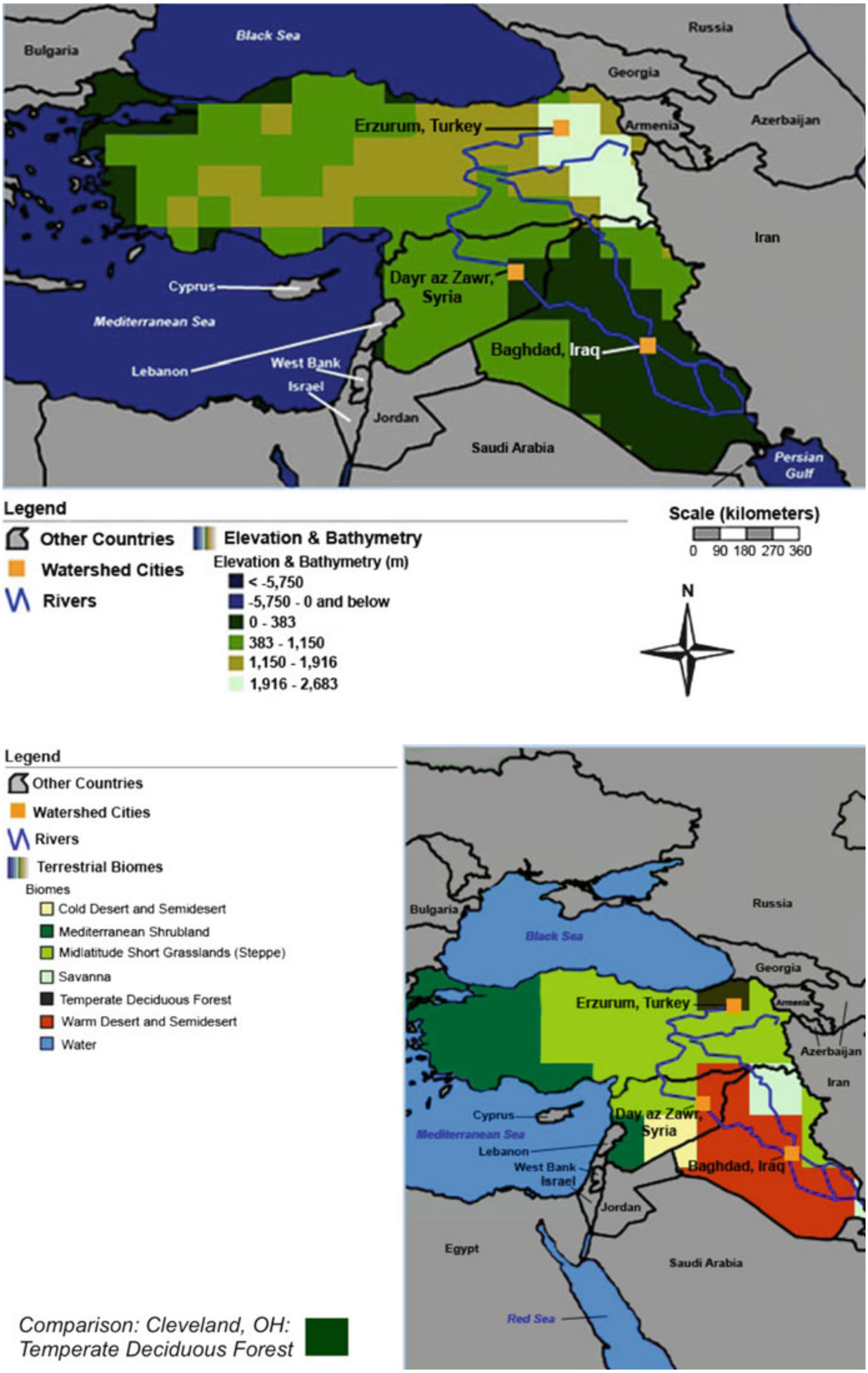
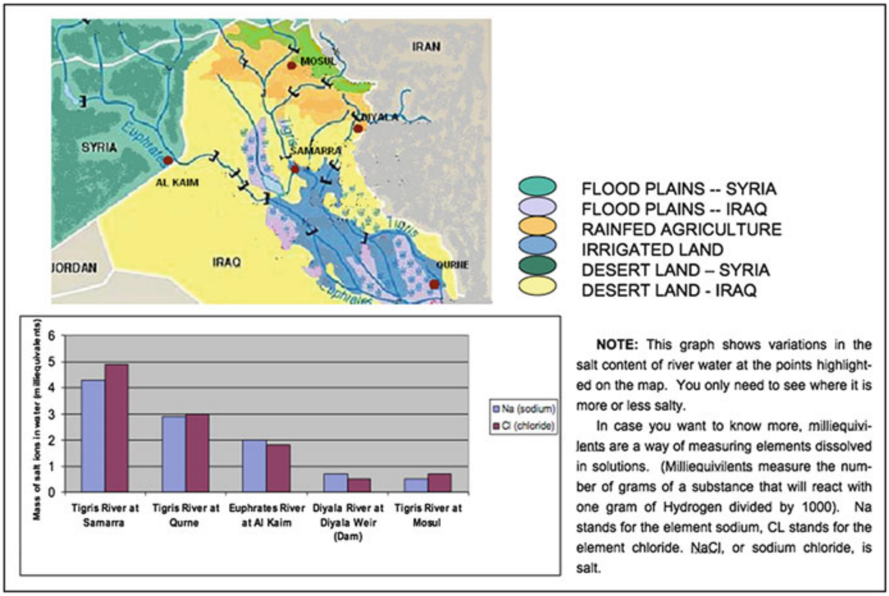


Fig. 14.1 (continued)



NOTE: This graph shows variations in the salt content of river water at the points highlighted on the map. You only need to see where it is more or less salty.

In case you want to know more, milliequivilents are a way of measuring elements dissolved in solutions. (Milliequivilents measure the number of grams of a substance that will react with one gram of Hydrogen divided by 1000). Na stands for the element sodium, CL stands for the element chloride. NaCl, or sodium chloride, is salt.

Fig. 14.2 Geospatial exploration activity using parallel data representations

14.5 Professional Development in Using Geospatial Representations

The professional development program was modest compared to other efforts described in this volume (Bodzin, Chap. 17; MaKinster, Chap. 15). Originally, we planned to have the teachers in all four subjects complete the entire TWD unit activities as two teams, offering them intimate experience with how the TWD unit and its PFL approach builds across classes to develop data literacy. The teachers worked other jobs during summer months, however, so it was not possible to engage in extended professional development.

Instead, two whole-group meetings were held during team preparation times in the spring semester. During these meetings, project staff went over the basic thrust of the program across modules. The project's principal investigator then conducted daylong individual sessions with each teacher during the summer, walking each one through the materials and activities for the science lessons. Similar daylong individual sessions took place between other subject area teachers and the developers of their particular modules. During these sessions, teachers sometimes expressed concerns about the materials and suggested changes. These changes were made. For example, science teachers expressed concern about letting the students independently explore the materials. They doubted students could understand the geospatial maps. They preferred guiding students through the science geospatial maps, either on an overhead projector or on individual computer screens.

The original goal of the professional development was to focus on helping teachers appreciate both how to implement PFL across the different subject areas to improve general data literacy and how to use PFL within each subject to push for deeper conceptual knowledge. In practice, professional development focused on helping teachers feel comfortable with the materials and inquiry-based approaches.

PFL across the different subjects was organized to teach general data literacy knowledge and skills. Social studies students participated in the first and second steps in PFL. They "invented" and "shared" ideas about how to use data on population and water use and distribution to develop a plan for equitably sharing the water from the Tigris and Euphrates rivers among the three Middle East nations. The mathematics lesson added the third step in PFL. While mathematics students again "invented" and "shared" approaches to equitable sharing of water, the mathematics teachers also engaged in "telling" students about two key data literacy approaches: proportionality concepts and per capita computation procedures. With these data literacy tools, students revisited the water sharing problem and came up with a per capita solution and then a percent solution to the equitable sharing of water.

Within this broader framework, the science class served two PFL goals. First, science class offered a place for students to reinforce their general data literacy through application. They applied proportional and per capita analysis to new water-related datasets in the Middle East and the USA. Second, the science class offered an opportunity to use PFL with geospatial map data alongside scientific hydrological concepts associated with the water cycle and salinity to deepen their understanding of regional water distribution problems. The latter is the focus of this chapter.

Finally, in English language arts class, students presented data-based evidence about water problems in different US regions, using both proportional reasoning and scientific concepts.

14.6 Results of Our Use of Geospatial Representations

To analyze how our field test with the science class instructional materials functioned in the classroom, we reviewed data from six sources: observational field notes, a post-unit teacher interview, pretest and posttest science assessments, student classroom work, a post-unit student survey, and pretest and posttest data literacy assessments (the pretest was administered before the first TWD unit in social studies, and the posttest was administered after the last unit in English language arts).

In the field notes, we observed that the science teacher did not fully engage in two of the three steps of the PFL process for either the water cycle or salinity activities – "sharing" and "telling." She fully engaged students only in the "inventing" activities that involved using the geospatial activities to answer a driving question. She ended each of the two activities slightly differently. She ended the water cycle activity after an abbreviated form of sharing, in which students reached a classroom consensus in answering the challenge questions. She did not engage in any of the "telling." She also did not engage students in the "sharing" aspect of the salinity activity, and she ended the salinity activity with only an abbreviated "telling" about how open trench irrigation leads to salt sinking to the bottom of the ditch and increased water evaporation.

Through the observation notes and the teacher interview, multiple reasons for shortening the PFL cycle were uncovered. Technological challenges applied pressure to classroom time. Difficulty in getting school laptops to function consumed time intended for other parts of the lesson. Another reason was the teacher's understanding of PFL itself. She explained that she understood the PFL process to involve two steps: "letting the students flounder" and "guiding them in the right direction." This operational understanding may explain why the teacher did not engage in an elaborated "telling" in either activity. In addition, the students had already engaged with a water cycle unit, and she did not want to devote much time to a deeper investigation of the water cycle. Reinforcing the decision to cut short the "telling" in the water cycle activity was her belief that the students found the water cycle map activity "pretty easy." This ease surprised the teacher, who was among those concerned that students would find it hard to use the geospatial map data. She said she was "impressed" with how logically the students reasoned their way around the water cycle maps and how well they answered the challenge question using topographical and temperature data. While an analysis of the observation notes revealed that students never made the causal relationship between the data and rainfall, the teacher accepted their explanations as satisfactory and chose to end the activity, stating, "This was a great unit in reflecting back on concepts already learned."

Teachers also made choices about how far to go with the hydrological concepts, based on their understandings of their students' needs and on state standards. With respect to the salinity task, the teacher chose to use the materials to help students see "a relation between salt and irrigation" using the associations presented in the geospatial maps. The lesson materials included a "telling" PowerPoint presentation that explained runoff, infiltration, plant capillary action, and accelerated evaporation associated with open trench irrigation and periodic flooding of agricultural lands. The teacher cut short the "telling" section after students took more time than expected with the percentage computations on the salinity exercise. This teacher's focus on the time taken for the lessons might be interpreted as an artifact of learning to manage inquiry activities in the classroom. As Coulter has noted in this volume (Chap. 13), teachers' ability to lead rich geospatial inquiry depends on their interest in the topic, experience with inquiry, comfort with model-based reasoning, and ability to guide student questioning. The teacher said she really "liked" the materials and was not sure how to improve them, but she said specific tips about linking to core scientific concepts in each activity might be helpful.

In the science content assessments, students ($n=85$) showed no significant gains in learning on the water cycle test item, but they did show significant gains in learning in the salinity test item. The water cycle posttest item asked students to figure out what type of biome (mountain, desert, grasslands) would be associated with specific temperatures and rainfall rates in February. To some extent, a ceiling effect might have constrained improvement on this item. In both pretest and posttest, a slight majority of students successfully saw how the temperature was associated with land elevation and correctly saw that the highest precipitation would be associated with the coldest location, the mountains. Yet in both pretests and posttests, a high percentage of students appeared to focus primarily on rainfall totals and not the temperature data, which included an implicit clue to determining land elevation (i.e., it is colder at higher altitudes). Indeed, in the posttest, 36 % of the students thought the grasslands would have higher rainfall than the mountain, compared to 40 % in the pretest. Part of the problem might have been with the item's use of the term "rainfall" instead of "precipitation," which would comprise both rain and snow. Students might have thought rain, rather than snow, would be more likely in the grasslands than the mountains because it was warmer in the grasslands. By contrast, the salinity test item offered results that were more clear-cut. This item asked students to describe the "possible negative consequence" of using open trench irrigation. In the pretest only 6 % of students mentioned evaporation or salinity, while in the posttest 60 % of students mentioned evaporation or salinity. Most of the students mentioned the "salty" soil or water.

The data from the TWD data literacy assessment showed a statistically significant difference between students in the TWD classes and students in the comparison classes ($F(5, 367)=25.204$, $p<.001$). These items had students integrate data in a simple GIS representation, an excerpt from a newspaper article, and a series of quantitative data provided in table form. Students were asked to draw conclusions about the reasons for depleting aquifer reserves in the High Plains Aquifer. The assessment was intentionally designed to require transfer of the processes used in the TWD activities, especially the types of analyses used in the science unit. These results indicate that the science unit may have been more successful in helping students become more competent in the key inquiry skill of mapping and applying data in the creation of causal explanations than in the specific content embedded in the unit.

In reviewing samples of class work from four student teams, we see evidence that students did engage in using data to create explanations that included both everyday ideas and scientific knowledge. In the water cycle activity, the teacher asked students to analyze each geospatial map individually to determine which of the Middle East countries would receive the most rain. In the maps that focused on temperature and elevation, student teams wrote that it "rains more" where it is "cooler" and "higher." Students showed different levels of reasoning about how temperatures are associated with evaporation or condensation. Two teams stated that cooler temperatures are associated with more rain. Two teams stated that Turkey had the most rain because it had the lowest temperature and it was located near "two big bodies of water." In the latter answers, the students are linking cool temperatures with rain, which is a correct association related to condensation occurring at cooler temperatures. Students also make an apparent association with evaporation by the mention of the two bodies of water, although neither team mentions the ideas explicitly, only implicitly. With respect to elevation, we see a similar range of reasoning. One team noted merely that Turkey is higher than Syria and Iraq and did not discuss how that might affect rain. Another team stated that "the higher elevation that you have you get more of the rain." Another team offered the theory that Turkey was "closer to the clouds," which led to more precipitation. A fourth team stated, "the higher elevation usually has colder weather leading to precipitation." This last team correctly associated cooler temperatures with higher elevations and condensation. While these explanations occurred in the "inventing" stage, and so are exactly the range of student responses hoped for, the lack of full engagement in sharing and telling may have contributed to students not further refining their ideas throughout the TWD activities.

This analysis indicates that these maps effectively spurred forms of reasoning associated with scientific concepts, if only implicitly. The maps containing information on sunshine, evapotranspiration, and biomes did not appear to instigate as much scientific reasoning, but they appeared to offer a chance to apply logic. Students noted that evapotranspiration and deciduous forest biomes are associated with plants, and plants need water, so Turkey, which has higher evapotranspiration, must get more rain. Students also correctly deduced that places with less sunshine had more cloudy days and therefore must have had higher rainfall.

We saw only two samples of written work on the salinity exercise – two different draft versions from one team. In one draft, a five-member grouping of the team used the representations to formulate the expected relationship. In the other draft, a two-member grouping of the same team did not. The draft with the expected relationship was the later version. The draft that formulated the expected relationship concluded that irrigation "causes" salinity because (1) the table data showed that Iraq has the most irrigated land and the most salty soil and (2) taken together, the map and bar graph showed that salinity was high in irrigated land but low in rainfed agricultural land. The team that created the draft that did not formulate the expected relationship appeared distracted by table data that showed 19 % of Syria's land has "severe" salinity problems. The team focused on the term "severe" rather than the data from the same table showing that Iraq had 75 % salty soil. Weighing these two different data reports presents a challenge to students' judgment. The students creating this earlier draft also did not notice that they needed to link the bar graph data to the map data, so they concluded only that Syria had more desert than Iraq. Finally, the students appeared to misread the bar graph for sodium and chloride and may have thought that the "blue" bars represented water, not sodium. However, it is clear that this group arrived at the expected answer in the end and that these two students' misconceptions were remediated by their peers.

In the post-unit survey, students reported that the TWD unit increased their curiosity about environmental problems and solutions. Many students also reported that they learned about watersheds, as evidenced by these two examples:

> The single most important piece of information is that I learned about the various watersheds in the U.S. and Middle East and the various problems they faced such as drought or rise in population, which all resulted in lack of water at the end.
>
> Before the whole project I really didn't know what a watershed meant, but as every subject went on I learned more and more about a watershed. Also, before this I didn't know the affect (sic) on it, like new sewage in the Lakes, pollution, and maybe if it gets bad, shutting down places. If everyone did this project, they would be shocked and start changing some things.

14.7 Discussion

In reviewing these results, we see that the students could use selected real-world data – in the form of geospatial representations – as a motivating context for applying emergent scientific reasoning. Both the student work and the teacher's observation that she was "impressed" with the students' reasoning offer encouraging preliminary evidence about the success of our approach. Presenting conceptually important data as geospatial representations can serve as a motivating stimulus to engage students in reasoning about science. Students showed facility in interpreting two different forms of geospatial representation: layered representation, in which different data are superimposed on different maps of the same geographic regions, and parallel representation, in which different data representations, such as tables, charts, and maps, present different data from the same geographic region. With the layered water cycle maps, students reasoned using a blend of everyday logic and implicit applications of some key water cycle ideas, such as condensation and evaporation. When considering the parallel data representations in the salinity activity, some students easily discerned evidence to support an argument associating irrigation with salt pollution. Students developed these conclusions even if they had initial difficulty interrelating the parallel representations and coordinating the data to see conceptual associations.

In the case study, we saw the teacher initially spent significantly more time than planned on inquiry activity setup, thereby running out of time to complete the full range of PFL instruction. Once the students engaged in the invention activities, the teacher appreciated students' capacity to logically reason around geospatial representations. But at that point she had to cut short some of the PFL sharing and telling activities in the interests of classroom time demands. Based on the students' class work and the test results, we think the students had not meaningfully integrated the hydrological concepts in either activity, but they had shown some competence and confidence in reasoning with geospatial data, an important part of building scientific thinking skills. Although the students had learned about the concepts of evaporation, condensation, runoff, or infiltration earlier that year, they rarely explicitly used these ideas in any of their responses. There was occasional evidence of naïve theories, such as a mountain's proximity to the "clouds" leading to more precipitation. In classroom observations, there was little evidence that the teacher was coaching students to link the activity to their existing scientific understandings.

14.8 Recommendations for Practice

Through this project, we identified some clear opportunities and challenges for selecting geospatial data to drive student inquiry. Teacher professional development is the path toward realizing these opportunities and confronting the challenges. As has been noted by others in this volume, geospatial lessons depend on certain forms of teacher knowledge, skill, and attitude. A teacher's confidence in leading inquiry lessons ranks high on this list. In our project, we worked with science teachers who lacked experience in leading inquiry lessons. At the outset, they expressed distinct doubts that their students could analyze the geospatial maps independently. In taking excess time to set up inquiry lessons, the teacher ran out of time to complete the PFL instructional approach and support independent student teamwork. Once students began working with the geospatial maps, however, the case study teacher saw that students could reason effectively. This finding suggests that teachers who are inexperienced in inquiry may be helped by seeing students use geospatial materials, which would reduce the perceived need to devote excessive time to lesson "setup." Like real scientists, students used our geospatial representations to review the arrayed evidence and discern relationships and patterns. Building such classroom opportunities for systematic data review is critical, as past research indicates that middle school students find it difficult to analyze data methodically (Krajcik et al., 1998). Seeing that students have this capacity may go a long way toward preparing the most inexperienced teachers to teach effectively with these materials.

Professional development activities should also provide specific classroom instructional strategies for managing student inquiry. In our work, we noted areas where students experienced problems. These are focused opportunities for teacher guidance. First, teachers will need to troubleshoot the basic problems students have in seeing critical relationships in the data representations, without specifically "telling" them the answers. In many cases, simply asking questions about specific data will point students in the right direction. Second, teachers need to spend much less time "setting up" data-based problems and spend significantly more time on sharing activities, in which students critique each others' answers, before the final "telling." These types of activities are quite alien to most teachers and need to be well explained and perhaps rehearsed. Training will, however, help teachers resist the tendency to assume students "get it" after they find "the answer," because in the sharing activities answers come with explanations. We recommend that teachers carefully assess the quality of student explanations to push for deeper student engagement in scientific concepts. In short, analytic geospatial activities should not be viewed as an end point. Rather, they should be seen as diagnostic starting points for teachers to see how much students have integrated scientific terminology and concepts into their own explanations.

We also learned more about how to set reasonable expectations for student learning. The science teacher understood the impossibility of the PFL goal. Using geospatial representations to "invent" understandings of more advanced hydrological concepts, which in turn requires a molecular understanding of water chemistry, was simply unrealistic. For example, a high school student might be able to use our materials to infer the phenomenon of relief rainfall, which occurs when wind blows air against a mountain, creates updrafts of surface-warmed moist air, which cools leads to condensation and precipitation. But it is sufficient for a seventh grader to appreciate the less sophisticated correlation between topographical elevation and associated variations in both temperature and rainfall. This level of understanding is an appropriate way to build on students' prior knowledge and their grade-level science experience.

Finally, we also saw that our geospatial representations did seem useful in developing an understanding of how human activity relates to specific environmental impacts. Professional development should present such findings to teachers and familiarize them with science learning benchmarks associated with environmental learning. For example, professional development might consistently present the national middle school benchmarks for Use of Earth's Resources and Global Interdependence (American Association for the Advancement of Science, 2001):

> The global environment is affected by national and international policies and practices relating to energy use, waste disposal, ecological management, manufacturing, and population.
>
> Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the Earth's land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life-forms.

14.9 Recommendations for Research

We designed our geospatial materials to be distinct from approaches that engage students directly in geospatial data manipulation. Still, we believe our work can contribute to developing materials that do involve more data manipulation. At various points in the project, both students and teachers reported wanting to work with "hands-on" lab activities more than analyzing geospatial representations. For example, students reported that making presentations in the English class that followed the science class was an engaging and useful activity. They also reported liking to present water scarcity solutions to their peers. Future research might explore how to orchestrate such hands-on data manipulation to fit easily into busy classroom schedules.

Our team initially had wanted to engage students in data exploration using various research-based computational tools. We found ourselves faced with a problem of calibrating the complexity of the real-world data with grade-level appropriate data exploration tools. We ultimately rejected this approach because the local data literacy goals and standards in all four subjects for which we developed our TWD materials (social studies, mathematics, and science) did not call for high levels of GIS data manipulation. Further, to us the steep learning curve required for such tools seemed unlikely to yield a clear benefit in enhanced student conceptual understanding, particularly when considering relatively "short-term" units, such as a 2-week science module. As we saw, even our trimmed down use of geospatial representations seemed to push against the limited time window of the typical classroom. Rather than using research-based computational tools, we chose to focus on engaging students in using data tools more common to the classroom: spreadsheet software in social studies classes and computations in mathematics classes. Future research needs to explore just how much data manipulation can yield useful conceptual learning.

We are encouraged by our findings that selecting core data elements can generate student reasoning, but we would like to see future research explore ways to improve students' ability to discern important relationships among such data elements and explicitly apply scientific concepts. We were struck that the geospatial maps focused on temperature and elevation were more productive toward spurring scientific reasoning than geospatial maps that focused on sunlight, biomes, and evapotranspiration. Given the press of time teachers feel in classrooms, it may make more sense to target data explorations for more narrowly diagnostic purposes in science classrooms. Perhaps more class time should be devoted to helping students learn to apply explicit scientific terminology and principles in constructing their explanations. If so, what classroom processes for repeated scientific concept application engage students most efficiently? Also, is there a way to make these scientific concepts more prominent in the geospatial representations, shifting some of the hard conceptual application work from the classroom discussion to allow students to implicitly engage conceptual information through the instructional materials? What classroom assessments can reveal to teachers how much – or how little – their students have developed an integrated understanding of core scientific concepts? These are all questions raised by our work that could inform productive future research.

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Chapter 15

Lonely Trailblazers: Examining the Early Implementation of Geospatial Technologies in Science Classrooms

Thomas R. Baker and Joseph J. Kerski

Keywords Innovators • Historical • Teacher independence • Success • Early adopters

15.1 Introduction

Teacher's Log. 29 May 1994. Earthview High School, Missouri. "I've just made it through my first semester teaching science using GIS. This morning I led my students through an investigation of global plate tectonics. I wish I had new 486 computers, but I think I'll hang onto these old 386 s running at 33 MHz with 180 MB hard disks and 12-color monitors until these new "Pentium" machines arrive next year. I heard that the State of Missouri has one of those new "home pages." If I can find out what the URL is, perhaps it will list a contact at the state data center there that I can call for some census data that I want to use this fall. I could place the GIS data on my new Iomega Zip drive. Each cartridge holds 100 MB, but I need someone at the university to help me transfer the data from a nine-track tape to a Zip cartridge, and once there, I can uncompress it and chop it. Perhaps the university staff can place it on online and I could Telnet to their server or FTP it using the modem to my school. I will need to transfer it at night when nobody else at school is using the modem. I hope that the data will be in the format that I can use with my GIS. I could try to go to the university to use the DOS zipping program and zip it onto floppy disks, but last time I spanned ten floppies with one zip file, the tenth disk went bad. Before I investigate, I need to go to my appointment with our lab manager to see if my students can get into the lab for more than 2 weeks this fall."

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This fictitious account reflects a day in the life of a teacher using GIS during the mid-1990s. This teacher was a part of a small group of trailblazers who spearheaded the use of GIS in K-12 education. This chapter explores the increase in awareness and adoption of GIS technology between 1992 and 1998 in the USA. The mid-1990s predated most Internet-based mapping tools, as well as digital globes such as *Google Earth*, NASA *World Wind*, and *ArcGIS Explorer*. It even predated or coincided with the release of GIS software designed for the educational community, such as *MyWorld*, *ArcVoyager*, and *ArcExplorer*. During this period of time, several GIS software packages were used in education, including *MFTeach*, *SPANS*, *PC ArcInfo*, *ArcView* (1.0–3.0), and *IDRISI*. These were desktop GIS software packages, good at drawing maps and rapidly improving at supporting geographic analytics. Classroom computers were often few and far between, running DOS, OS/2, Windows 3.1, or, later, Windows 95. They seldom had enough RAM to support GIS. The educational system was struggling with how to get computers in the classroom and then, near the end of this period, how best to use them. Internet access in the classroom did not begin dramatically improving until after this period, with only 27 % of instructional rooms having Internet access by 1997 (Wells & Lewis, 2006). Many science educators were increasingly using inquiry-oriented instructional approaches, as suggested in the 1996 *National Science Education Standards*. It was hoped that computer technology, including GIS, would help extend student inquiries and investigations into the world. Those science educators who used GIS in the mid-1990s will be explored, how they discovered and learned about GIS, and how it was used.

15.2 Literature Review

To better understand the educational and GIS environment these educators and their students worked in, consider some of the following milestones.

1992	Classroom technology snapshot: DOS 5 on a 386 PC or Apple II with 8 MB RAM
1992	ArcView 1.0 released
1992	Tinker publishes article describing GIS, used in middle school as a part of KidNet
1993	ESRI hires first education team members
1993	Beginning of NCGE-ESRI 2-day training events around the country (1993–1995)
1993	Early attempts at a "Secondary Education Project" by NCGIA (Palladino, 1994)
1994	First EdGIS held (Barstow, Gerrard, Kapisovsky, Tinker, & Wojtkiewicz, 1994)
1994	Classroom technology snapshot: Windows 3.x running ArcView 1.0, on a 486 with 16 MB of RAM
1994	TERC launches "Mapping Our City" (McWilliams & Rooney, 1997)
1994	Northwestern University begins "CoVIS – The Collaborative Visualization Project" (Gordin, Edelson, & Gomez, 1996)
1995	NatureMapping launched at the University of Wisconsin
1996	Classroom technology snapshot: Windows 95 running ArcView 2.1, on a 200 MHz Intel Pentium

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1996	The *National Science Education Standards* are published, emphasizing "science as inquiry" (NRC)
1996	First research on GIS in science education emerges (Audet & Abegg)
1996	Second EdGIS conference held
1996	*Geodesy* created by Berkeley Research Group as an ArcView 2.1 extension
1997	The Kansas Collaborative Research Network launched
1998	University of Arizona's SAGUARO Project began
1998	ESRI released the free *ArcVoyager* package, based on *ArcView* 3 technology
1998	First national GIS professional development hosted by ESRI and Texas State University for 2 weeks, summer

While these events do not tell the whole story, they provide a backdrop of the national events unfolding around science educators using GIS. For a more complete chronology of GIS in education from 1988 to 2003, see *Learning to Think Spatially* (2006) (Appendix G).

Everett Rogers' *Diffusion of Innovations* is often used to organize and describe the events surrounding the movement of innovations throughout a social system over time (2003). The primarily characteristics of innovation diffusion include:

1. The innovation
2. Communicated through certain channels
3. Over time
4. Among members of a social system (2003)

Innovations in education and educational technology are often considered within this framework to explain the proliferation of certain techniques and tools. GIS and geospatial technologies are no exception (White 2005, 2008). Much of Rogers' work can provide a theoretical underpinning for the adoption and diffusion of geospatial tools in education. His themes are interwoven into both the design and the articulation of this study, depicting early GIS use by these educators.

In *Diffusion of Innovations*, Rogers identifies the process of innovation adoption, the characteristics, and types. Rogers recognizes adopter and organizational characteristics for change and the consequences of adoption. Rogers' adopter characteristics and process of adoption are of the greatest interest to this chapter. Rogers' work is important because the depiction of the *innovator* (the earliest class of adopter) can shed light on the technical and pedagogical commonalities, implementation patterns, strategies of success, and habits of mind that early GIS-using teachers shared. Moreover, his adoption process can lead us to better understand how and why these technologies resonated with Innovators, but not with others such as Early Adopters or those in the Early Majority. This has particular implications for those conducting professional development today.

Rogers defined five classes of adopters – *Innovators, Early Adopters, Early Majority, Late Majority, and Laggards*. Each class is distinguished by its willingness and ability to adopt a new tool or technique as it is discovered and judged to be worthwhile. Collectively, these five categories represent all members of a social system, cast across a standard distribution. As an innovation is introduced, adoption by Innovators through the continuum to Laggards may occur. Innovators represent 2.5 % of the social system, Early Adopters represent 13.5 %, and the Early Majority is 34 %. The right side of the bell curve represents the slower adopters: Late Majority comprises 34 %, and Laggards represent 16 % of the social system.

In Kerski's national implementation survey of 1999, he suggested *at that time* only about 2 % of public high schools in the USA were implementing *any* level of GIS for instruction (2003). Based on chronology and simple percentages, individuals implementing GIS for instructional purposes between 1992 and 1997 would clearly be "Innovators." This does not suggest schools or educational organizations drove GIS adoption. In fact, subsequent reflection on Innovators interviews will show the opposite. Perhaps more importantly, if the Innovators *were* and *are* already using GIS in classrooms, professional development needs to target the 13.5 % of the social system defined as *Early Adopter.*

Rogers argues that there are common characteristics of Innovators, including tendencies to be venturesome and educated with multiple sources of information at their disposal. They are risk-takers. Innovators appreciate technology for its own sake but are also motivated by acting as a change agent. Perhaps most importantly, Innovators can withstand the "pain of adoption." They are willing to tolerate initial technical problems and are willing to use "makeshift" solutions to complete a task. While not everyone will be an Innovator in every classroom technology, these are the educators who can generally make almost anything work and frequently work well. Rogers notes that it is predominately the Early Adopters who are the social leaders, whose trail must be blazed by the Innovators, before a technology can hope to reach the majority.

Innovators are the smallest segment of the social system and are relatively rare. Yet they are needed to "work the bugs out" for Early Adopters and the rest that may follow. Moreover, Innovators tolerate more trouble and uncertainty than others. Innovators' motives are relatively unique to the category, suggesting Early Adopter motivations should be closely examined. Indeed, many of the people currently training educators or leading professional development are likely to be Innovators. In short, what works for Innovators will likely produce diminishing returns for the rest of the social system. Innovators and Early Adopters are simply different.

In this study, science educators who used GIS in the mid-1990s were surveyed and interviewed to determine how these Innovators became aware of GIS, learned to use GIS and how to use it with students in the classroom. The study and this chapter are guided by the following questions:

1. What did teaching with GIS in science classrooms look like in the mid-1990s?
2. How does Diffusion of Innovations theory inform our view of these early educators?
3. What are the implications for professional development today, when viewed through the lens of experience provided by these Innovators and Diffusion of Innovations theory?

15.3 Study Design, Methodology, and Sample

To adequately capture information from respondents required a survey and interviews, more likely to ensure a high response rate and allow for a depth and breadth of questions. Surveying the primary and secondary educators who used GIS in the mid-1990s was challenging. Because these trailblazers were few and because they were classroom teachers with little time to conduct or publish research (Stenhouse, 1985), the published literature of the period is understandably Spartan and tends to be in conference proceedings and GIS trade magazines. Where it does exist, it is largely comprised of the results of what educators were accomplishing with their students in their own classrooms. While these anecdotal accounts neither were not comprehensive surveys of educators nor were they experimental designs measuring the effectiveness of GIS over traditional instructional media, they nevertheless provide insightful glimpses into the early years of GIS adoption in K-12 education in the USA. Nearly all of the accounts were written by or about science teachers, rather than teachers in other disciplines, and no accounts were written by primary school teachers. Reasons why science teachers led the way over social studies, mathematics, or geography teachers include better access to computer laboratories, more confidence with computer technology, and more experience with inquiry-based instructional methods (Kerski, 2003). These anecdotal accounts were useful as a basis for the names of the population to be surveyed.

The other source for the population to be surveyed came from K-12 teachers who attended two key events in the early development of GIS – the first educational GIS conference held by TERC in 1994 (Barstow et al., 1994) and the first national GIS professional development event for educators held by ESRI in 1998 at Texas State University (Bednarz, 1999). These events were chosen because they attracted the most active educators during that time. The time period was selected because the earliest known accounts of GIS use in secondary school describe the use of GIS at junior and senior high schools from 1987 to 1995 (Friebertshauser, 1997; Ramirez & Althouse, 1995; Robison, 1996).

The literature review and conference attendance list was used to select the sample to be surveyed. An online survey was created and e-mail addresses were obtained. Due to the wide geographic distribution of respondents and the ease of electronic tools, we felt that an online survey would net the highest response rate. Because respondents were given only 7 days to respond to the survey, we limited the number of questions to ten, including the first question that determined whether the respondent was a valid part of the desired population: "Did you teach middle school or high school science for at least 1 year between 1992 and 1998, *and* did you use GIS with students in an instructional setting for at least one multi-day project during this time period?"

If the respondents did not answer yes to the first question, they could skip to the end of the survey and exit. Those who did meet the criteria of the survey were provided with this statement: "The following questions were designed to accomplish our goals in discovering commonalities among these educators, and how they could overcome challenges in the days before widespread professional development opportunities existed."

Questions for those who met the criteria were as follows. We asked for names only to ensure that there was no double counting and to link the survey with the responses from the telephone interviews:

1. What is your name? Where did you teach [city and state]? What subjects did you teach between 1992 and 1998?
2. How many years were you teaching when you started using GIS?
3. Name three things your students did with GIS.
4. What stands out as a barrier or challenge to your use of GIS during that time?
5. What stands out as a success in your use of GIS during that time?
6. How did you learn to use GIS?
7. What GIS software did they use first and eventually use most frequently?
8. What professional communities and organizations were you involved in during 1992–1998?
9. Did you feel like you had a GIS mentor? If so, what organization were they attached to and how did they help you?

A selected set of respondents who were available over a 1-week time frame were chosen for interviews. These interviews were designed to be completed in 25 min. The questions were chosen with the goal of providing deeper insight in what motivated the educators and what changes have they experienced between their trailblazing work and today:

1. Describe the PD GIS experience you had if you had one.
2. How did you first hear about GIS?
3. What administrative support did you have for GIS? How did you obtain the hardware and software?
4. What three things made you stay with GIS?
5. What has changed in the way you think of GIS now versus then?
6. What do you do differently now with GIS versus then?
7. What is your advice on PD for GIS?
8. Name three of your core teaching philosophies.

Once the surveys and interviews were complete, the authors reviewed the data, identifying trends and commonalities in responses. As the data were relatively modest, manual methods for sorting, organizing, and describing data were employed.

15.4 Results and Discussion

Out of the 30 surveys sent, two were returned due to invalid e-mail addresses. Fifteen respondents either did not return the survey or indicated that they did not meet the criteria. Thirteen educators completed the online survey, and eight educators were interviewed.

Chemistry was the number one subject taught by the respondents, mentioned seven times, followed by biology (six times), and environmental science (four times). However, 19 other sciences were also mentioned, as well as six other subjects ranging from reading to languages to social studies. This illustrates how versatile the topics were in which GIS was applied but also how diverse the trailblazers were. Curiously, despite some prior anecdotes at the time about CAD teachers sometimes being the initial GIS teachers on a campus, CAD was taught by only one teacher responding to the survey.

The trailblazers did not come from a single local conference or university, but rather arose from a variety of experiences occurring internally, within the school, or externally, at a national event. The educators taught in schools from Oregon to Maryland, from North Dakota to Colorado, with no two educators teaching in the same state. The trailblazers were geographically lonely on a national level, isolated by hundreds of miles from the nearest GIS-using educator.

To better frame the discussion of results, the five phases of innovation adoption (knowledge, persuasion, decision, implementation, and confirmation) are used (Rogers, 2003). These phases can serve as a model of GIS adoption for current educators. Professional development specialists will note the progression of development in these Innovators. While educators in Early Adopter and Early Motivator will vary, the responses by the Innovators can provide a solid guidepost.

15.4.1 Knowledge: The Individual Is Aware of an Innovation

Five out of eight responding educators found out about GIS through a national event. Most frequently cited was the National Science Teachers Association conference, and secondly, state technology and education conferences. Before geotechnology-based professional development opportunities existed, meeting a GIS in education staff person at an exhibit booth run by private GIS companies was remembered as a "watershed moment" by several educators. In fact, one commented that "three minutes at the exhibit was enough to get me hooked!" One respondent found out about GIS through an early article about computer mapping in education (Tinker, 1992).

15.4.2 Persuasion: The Individual Develops Interest in an Innovation and Gathers Knowledge About It

How did educators in the 1990s learn to use GIS given the lack of professional development? Eight responses indicated that they were self-taught. These educators were Innovators, willing to spend the time to experiment and willing to complicate their lives by working closely with community leaders, GIS professionals, their own IT staff, and administrators because they saw, early on, the value in the inquiry-based methods that GIS could support. Four respondents mentioned ESRI's materials or training for GIS professionals. Three mentioned a teacher workshop sponsored by a regional university. Only one respondent mentioned having attended a professional development opportunity that was specifically geared to the needs of K-12 educators that was offered by the Center for Image Processing in Education (CIPE).

Interestingly, none of the GIS professional societies (such as the Urban and Regional Information Systems Association (URISA), the Geospatial Information Technology Association (GITA), the American Society for Photogrammetry and Remote Sensing (ASPRS), and the American Congress on Surveying and Mapping (ACSM)) nor educational professional societies (such as the National Science Teachers Association (NSTA), the International Society for Technology in Education (ISTE), and the National Association for Research in Science Teaching (NARST)) appeared to be a force hastening the diffusion of GIS into education. The only program that attempted to bring together university and secondary educators during the time was the Secondary Education Project through the National Center for Geographic Information and Analysis at the University of California, Santa Barbara (Palladino & Goodchild, 1993), but it was not targeted to science teachers. The first national conference on GIS in education (1994) was noted by four respondents, but one respondent felt like "we were being lectured to by universities that "knew" how GIS should be taught." While hundreds of universities started GIS programs during the 1980s and 1990s (Goodchild, 2006), their emphasis was to teach *about* GIS (after Sui, 1995). It is our judgment based on analyzing the history of this period that far from being on the sidelines, these secondary education trailblazers actually became the leaders in teaching *with* GIS.

15.4.3 Decision: The Individual Makes a Value Judgment About the Innovation

Educators were asked "what stands out as a success in your use of GIS during that time?" Responses indicated that educators were motivated in part because *students* were motivated, because students were seeing interconnections, because GIS allowed students to present to a public audience, and because of career opportunities with their city government and local nonprofit organizations. Two responses indicated that the teachers grew in their own professional development through its use, one by contributing to research concerning the teaching *with* GIS versus teaching *about* GIS and another through producing the first geologic map for the state of Maryland ("that is still in use today"). Thus, these educators perceived GIS to be educationally valuable for reasons that transcended content knowledge or skills acquisition. Indeed, not one educator mentioned that they were motivated to use GIS for these reasons, and one mentioned that she was thankful to be able to have the freedom to use GIS before the era of national standardized high-stakes testing that would have made it more difficult for her to use inquiry-based methods.

According to Rogers, three types of innovation decisions can be made in the diffusion model. These include optional innovation decisions, collective innovation decisions, and authority innovation decisions. The diffusion of GIS in education is characterized by optional innovation decisions, made by individuals who are in some way distinguished from others in a social system. Collective innovation decisions – made collectively by all individuals of a social system – did not happen. A large body of educators did not embrace GIS use at this time. Authority innovation decisions – made for the social system by powerful, influential individuals – did not apply to GIS in education during this period or in the decade to follow. While national standards created during this time embraced inquiry-based methods and the use of real data to solve real problems, no authoritative body such as the US Department of Education or state or local education authorities mandated the use of GIS in education. One wonders what the impact that GIS would have had during the 1990s if top-down authority innovation decisions rather than optional innovation decisions would have dominated.

15.4.4 Implementation: The Individual Uses the Innovation to Various Degrees

Educators were asked to name three things that their students did with GIS. The projects that the students of the respondents worked on illustrate the applicability of GIS to a wide variety of settings, scales, and topics. These include local projects, such as making a trail map of an area next to the school and mapping fire hydrants for the city. Nearly all of the local projects included fieldwork. The use of GIS to support field studies at the local level was mentioned by 12 out of 12 respondents, with examples ranging from mapping log piles deposited by tidal flow, mapping the local watershed, to creating a living history of the neighborhood of the historically African American high school. Teachers also taught regional topics such as mapping radio telemetry positions, impervious versus permeable surfaces using land use and land cover data, and a study of the Colorado River drainage basin. Interestingly, global topics were grappled with less frequently. Aside from a mention of locating environmental hot spots, global studies were not featured as one of the "three things your students did with GIS." This is curious, as some global data sets were available during the mid-1990s, from CIESIN at Columbia University and the Digital Chart of the World. It is clear that one of the most appealing aspects of GIS to these innovators was its potential to incorporate meaningful field experiences, to understand local processes and phenomena, and to connect students with their own community's decision-making system and potential employers. GIS was used by the innovators to do something new, rather than repeating something that they were *already doing* in the curriculum using traditional means.

Challenges in the use of GIS in education in its early years were many. While some educators found it challenging to use educational software in an environment when computers were still new to classrooms, GIS education trailblazers were attempting to incorporate industry-standard software into education. Not only were classroom computers far different from those in industry, but in addition, these educators had the additional burden of not only learning the software but teaching with the software. Teaching with software is far different from learning software (Schrum & Glassett, 2006). Challenges listed tended to fit into these topics: (1) The lack of computer memory and slow speeds when working with spatial data (seven mentions), (2) the difficulty in learning the software (five mentions), and (3) the cost for equipment and software (three mentions). Interestingly, only two teachers mentioned the lack of a mentor in their area, even though the comment from one respondent that "There was only one person in my community that knew anything about GIS at that time" may have been true of others. Throughout the 1990s, the number of GIS users in community planning, in public works, in assessors, and in other fields greatly expanded, but the number of educators using GIS was largely confined to universities. University professors using GIS by and large were teaching *about* GIS in a GIScience program, rather than *with* GIS in a content area such as geography or environmental studies. One teacher cut to the heart of the matter with this comment: "The overarching challenge has always been and still is getting new things into the curriculum. This one is about "running the race" at all, while the hardware, software, data, training, and lessons are just the individual hurdles within the race. Despite the explosion of GIS use in science, business, & government, it remains difficult to get teachers & administration not only to get over the individual hurdles, but to decide to run this race. The fast pace of technological changes emphasizes the glacial pace of revising education standards, so education falls behind the real world."

What constitutes professional development for educators who seek to use GIS in their curriculum? We would argue that training in GIS software only meets a fraction of the type of professional development needed by Early Adopters. Just as important is discussion about pedagogical strategies for implementing spatial analysis and fostering spatial thinking, how GIS can support fieldwork and inquiry, and much more. GIS training was received by two of the Innovators, but, according to these respondents, was inadequate, not tailored to educators but rather to GIS analysts, focused on running the software but using parcel data and edit tools that would seldom be used in the classroom. Commented one educator, "I was the only HS teacher there [at the professional development experience, a 2-week class run by the university]. The first 2 h was a lecture on topology, which [left] people wondering "what did we sign up for?" The instructor largely left them [the students] on their own, sometimes leaving the room for long periods. One student left in tears at the end of the first week." Indeed, after reading about some of the terrible experiences of some of the respondents, perhaps more of this type of professional development would have stymied, rather than encouraged, the use of GIS in education!

Teachers were asked "what is your advice on professional development for GIS?" Responses focused on using GIS in a hands-on, inquiry-based mode that is tailored for different audiences. One advised to "play to the natural curiosity of learners – don't stifle it. Give them the tools to explore their questions." Most were adamant about using GIS for analysis, rather than "zooming in and changing colors," and several mentioned not using technology as an end in itself, but as a means to an end. One respondent recommended to focus on people who "get it when they see it" because GIS is "not for everyone." One even went so far as to say that professional development is "a waste of time. We keep providing tool use. Two percent will self-teach and use it with kids. The other 98 % will forget it." Several mentioned that the professional development is too focused on geography, and should be focused on environmental studies instead, for example. Several mentioned a project-based approach for professional development, so that learning becomes about the investigation, not the tool.

The initial set of educators using GIS created their own lessons and curricula, which for the most part were not shared. There was little incentive to go to the extra work of sharing these instructional resources, given the lack of places to store them online and given the physical size of the data sets at a time when most computers and networks could not handle them, much less transfer them, particularly in schools. Conversely, a notable subgroup in the survey indicated not making formal lessons or curriculum at all – directing the students to "figure it out," primarily using the software manuals. Each of these cases potentially hindered the spread of GIS in education. The difficulties of sharing lessons and data led to the development of ArcLessons (http://edcommunity.esri.com/arclessons) near the end of the decade, which subsequently had an impact on the education community for several reasons. First, it was built by teachers and for teachers, not by and for GIS professionals. Therefore, the language and goals meshed with what educators wanted to do with GIS, which is in many ways fundamentally different to what GIS professionals want to do with GIS. Second, ArcLessons provided an easy way to upload and store not only the lessons themselves, but also the spatial data sets that accompanied the lessons, and provided server space that was sufficient to handle both components.

15.4.5 Confirmation: Use of an Innovation That Is Fully Integrated with Daily Tasks

One educator's comments were indicative of the importance that educators and students alike sensed that their innovations went beyond the school to the community: "We were able to produce a variety of reports for our city that showed on GIS map layers where a lot of estuarine things were happening that they didn't know about like drainage pipes that dumped water into the estuary and where sampled bird populations were occurring." However, what Rogers refers to as diffusion within organizations did not occur, either within the educator's own school or in his or her own school district. One educator stated that the stiff competition from Advanced Placement (AP) courses tends to take students away from GIS, because GIS is not associated with a specific AP exam. Another shared that after years of conducting GIS workshops for teachers in her district, to her knowledge, nobody in that district was using GIS for instruction by the end of the period of study.

As Rogers explains, both positive and negative outcomes occur when an individual chooses to adopt a particular innovation. Rogers lists three categories for consequences: desirable/undesirable, direct/indirect, and anticipated/unanticipated. Negative outcomes from GIS ranged from trying to obtain free or low-cost spatial data, "doing battle with IT" [the information technology staff] as one respondent described it, to computer crashes due to lack of RAM. Innovators are aware of negative outcomes but persist nonetheless. Despite these and other frustrations of teaching inquiry with computers, not one of the educators responding to the survey or in the telephone interviews said that they wished they had never touched GIS. Although one must take into account the biased positive attitude that is associated with the adoption of a new innovation, that Rogers himself recognized, the best evidence that the respondents viewed GIS as a valuable addition to their teaching careers is that all of them were still using GIS two decades later.

15.5 Conclusions and Recommendations for Research

The innovation of using GIS in education is a complex story but one in which the educators shared a remarkably common vision. The Innovators did not implement GIS in the same manner, but they all used GIS because they believed GIS could help them accomplish projects, investigations, and goals where other tools could not. GIS meshed well with their core teaching philosophies. These included respecting student interests, fostering discovery, keeping the goal in mind, constructivism, experiential and outdoor education, caring, rigor, problem-solving, and encouraging students to think. More research is needed to better identify whether GIS can drive inquiry-oriented approaches or if GIS is best introduced in the context of an instructional model with which the Early Adopter or Early Majority is already familiar.

Innovators used the communication channels available to them at the time, primarily local contacts via the telephone, and through professional conferences, to build loosely coupled relationships. However, these relationships were not established well enough to be termed "networks" and therefore the description "lonely trailblazers" fits. The relationships framing the use of GIS in classrooms began with science educators but often included representatives from GIS companies, higher education, and in local, state, and federal government agencies. Moreover, the educators were geographically lonely, separated from other educators by long distances. They may also be characterized as being disciplinarily lonely – the only educator in their school using GIS. Fortunately, the Innovators were in place at a critical time; their stories became not only the blueprint but the inspiration, used and cited by others who continued the diffusion of GIS in education in the first decade of the twenty-first century. The GIS education community has grown substantially between 1998 and 2009. Research to document the effects of community, niche networks, and online social networks to support GIS in education would be valuable.

Respondents reported that they had been teaching anywhere from 2 to 26 years before they started using GIS in education, with a mean of 13.5 years in the classroom. It may be surprising to some that it was primarily veteran teachers who recognized the utility of GIS for classroom instruction. This group had been around education long enough to know what works and what does not. It is commonly believed that younger teachers are more familiar with and more adept at using technology, yet this idea does not appear to be supported in this study. More research should be considered that identifies characteristics of educators and their environment necessary for successfully using geospatial tools.

Are these educators still trailblazing GIS in education? The employment status of two respondents was unknown, but 10 of the remaining 11 respondents were still using GIS at the secondary or university level in 2009. Two had gone so far as to be full-time GIS education consultants. The overwhelming majority responded to the question, "What has changed in the way you think of GIS now versus then?" that "nothing" had changed. That their original vision had not changed is a testament to enduring value of GIS to education. While several indicated that they are more realistic about how far and how fast GIS can change the face of education, they are still enthusiastic about the power of GIS to integrate disciplines, foster deep inquiry, support fieldwork, and provide career pathways. This was evident in that some respondents sent additional data that would not fit in the online survey form, and many of the telephone interviews that were scheduled to last 20 min lasted over 90 min.

The surveys and interviews made it clear that each respondent had a clear sense that they were trailblazers during the initial decade of GIS in education, matching Rogers' suggestion that Innovators are motivated by the idea of being change agents. These educators were determined that despite frustrations, they would keep the end goals in sight. These end goals included their own personal and professional growth (making a positive difference in the lives of the students) and goals for the students as well (fostering scientific thinking, problem-solving, and spatial thinking; grappling with issues relevant to the twenty-first century). GIS technology and methods meshed well with the inquiry-based focus of these educators. The excitement for GIS and science is apparent in these Innovators (even over several years), but what about their students? More research into the effects on student learning, attitude, and self-efficacy is needed. Longitudinally, does the integration of GIS into science increase student interest in science, grades, choice of academic majors, or even choice of careers?

The individual support given by GIS vendors was cited by 11 out of 13 respondents, and in six cases, respondents identified this as the key ingredient that made them "stick with" GIS despite the challenges. Did this reflect the authors' bias in selecting educators to survey who were using *ArcView* software more often than other GIS software? Clark Labs, makers of IDRISI GIS software, staffed a K-12 education coordinator position until 1997. The literature of the most active GIS-using educators from 1992 to 1998 features users of ESRI software. The responses indicated that the ESRI education team made an impact because the team was comprised of educators, not salespersons, who understood the unique needs of educators, and they were accessible for consultation about far more than the software functionality. Nine respondents indicated that they started with ESRI's *ArcView*, and 13 respondents indicated that this was the software they most frequently used. Of the other software sets indicated (*IDRISI*, *Image Display*, *Alice*, *Jedi*, *Spans*, *PC ArcInfo*, and *ArcCad*), only *IDRISI*, *PC ArcInfo*, and *ArcCad* were listed as being frequently used. The others were used for a finite period to be replaced with *ArcView*. Educational research evaluating the role of vendor support would be valuable to the proliferation of GIS and preparation of published materials. In terms of adoption, what are the implications for open-source GIS or community-supported GIS?

Has GIS in education moved from the Innovators to the Early Adopters? Innovators are the smallest segment of the social system and are relatively rare. Yet, they are needed to "work the bugs out" for Early Adopters and the rest that may follow. Innovators tolerate more "pain" and uncertainty with an innovation than others. Innovators' characteristics are different from Early Adopter and Early Majority characteristics and should be closely examined in the future. As evidenced by this study, many Innovators seem to be highly motivated to use desktop GIS to support original investigations with students. Innovators view the technology as another powerful tool to visualize data. Early Adopters may not readily fit this profile. Innovation complexity and the resulting decrease in relative advantage will, among other variables, stymie innovation diffusion as we move toward the majorities (Rogers, 2003). The complexity of multiple systems (pedagogical, school environment, technical, etc.) might also create a barrier for those in the Early Adopter or Early Majority categories. Identifying the impact of complexities for various adopter categories will help, in part, focus professional development efforts to archive greater effectiveness. Additional research needs to be conducted, evaluating Rogers' categories, innovation complexity, instructional and curricular needs, and interests of those educators.

What are the key factors that need to be embedded into professional development so that GIS will move beyond the Innovators and be used by the Early Adopters? Are Innovators only generating additional Innovators? It seems to the authors based on the interviews that teacher training by Innovators was largely focused on inquiry and problem-based learning. These inquiry-oriented uses of GIS in the classroom seemed to resonate only to a small percentage of educators. The GIS innovations were instructional, rather than technical. Early Adopters will need to clearly view GIS in five ways that Rogers' identifies: They will need to see that it provides relative advantage over their existing instructional methods, that it is compatible with their existing values and practices, that it is easy to use, that it can be "tinkered with" or "has trialability," and that teachers will be able to observe results from its use. One of the advantages of today's GIS is also one of its challenges. Teachers in the 1990s could teach using GIS on a desktop computer. Teachers today can teach desktop GIS, combine desktop with web-based GIS services, or use GIS entirely online. The multiple pathways, tools, and choices today keep the innovators motivated but may be confusing for the Early Adopter. A suitable analogy for diffusion might be

Project Learning Tree and Project Wet. These projects packaged a set of curricula with a standard professional development model, diffusing widely during the 1980s and 1990s, becoming some of the most widely used methods and curricula in environmental education. Similarly, curricular materials such as the *Our World GIS Education* and a standard professional development model might be the best way to impact educators seeking to use GIS. If Early Adopters require these types of grade-specific instructional materials, then one might argue that Early Adopters may perceive GIS to have value if it can help them teach *core content* better than traditional approaches. Can GIS help students learn core content more quickly or in a richer way? These are the studies that must be done to convince Early Adopters and their administrators who support them. Another question that must be answered is, "Are new 3-D tools such as ArcGIS Explorer and Google Earth reaching the Early Adopters?" How do these virtual globes affect the geotechnology adoption rate? Because these are largely visualization tools rather than analysis tools, does that mean that the geographic and scientific inquiry pieces have to be removed in order for the Early Adopters to make them their own?

Rogers notes that it is predominately the Early Adopters who are the social leaders, whose trail must typically be blazed by the Innovators before a technology can hope to reach the majority. Many of the people currently training teachers or leading professional development are likely to be Innovators. It is unclear as to whether, as we train more and more educators, we are working with Innovators and Early Adopters or working across the entire social system. Professional development (particularly with preservice programs) needs to touch all categories of the social system. As long as the educators using desktop GIS are primarily the innovators, they are likely to be looked upon as using "niche" technologies that the majority but won't touch. By 2009, the majority of educators may even be at the point where enough geospatial technology is all around them in their cell phones, vehicles, and on hikes that they may want to make their students aware of it, but they won't spend time using it in the classroom. Early Adopters and Early Majority have thus far considered the costs to outweigh the benefits of using desktop GIS. Does the arrival and use of vetted curriculum series such as the *Our World GIS Education* series mean that Early Adoption of GIS has begun? GIS tools do not equate to teaching core content as Project Learning Tree, Project WET, and Project WILD have been viewed for environmental science. One instructional methodology, curriculum, or tool will not ensure success across all categories of innovation adoption. Yet, could it be desktop GIS' versatility in many content areas that fosters this difficulty?

What works for Innovators will likely produce diminishing returns for the rest of the social system. For professional development specialists to be successful, identifying the nuances of educators in each adopter category must be identified and addressed. Moreover, it is expected that as educators from different adoption categories move through the adoption stages, the activities and results will look different. Innovators in GIS education may be more accurately described as "scouts" or "explorers" whose instructionally innovative pathway is complex and difficult for the majority of educators to follow. Rather, the true trailblazing will be done by the Early Adopters who create the pathway or model that others can follow. Perhaps these Early Adopters should be the focus of future professional development activities, leading to the most widespread diffusion of GIS in education.

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Chapter 16
Understanding the Use of Geospatial Technologies to Teach Science: TPACK as a Lens for Effective Teaching

James MaKinster and Nancy Trautmann

Keywords Framework • Geographic Information Systems (GIS) • Google Earth • Professional Development • Science Concepts • Technological Pedagogical Content Knowledge (TPACK) • Watersheds

16.1 Introduction

Geospatial technology, especially GIS (geographic information systems) and global visualization tools, is rapidly emerging as powerful tools for use in secondary science classrooms. Educational use of these tools began in geography courses but has extended into the science classroom with an ever-growing assortment of online resources, publications, and professional development opportunities for teachers. While there is a fairly active community of researchers in the field of geography who are studying the use of geospatial technology for teaching and learning, the field of science education has been relatively slow to embrace and critically examine the use of these tools (reviewed in Barnett, MaKinster, Trautmann, Vaughn, & Mark, 2013).

Geospatial technology and relevant data can create meaningful contexts for science teaching and learning. These opportunities can provide students with the ability to explore real-world scientific or environmental issues as they analyze existing data and maps or create new maps based on their own data. The ability to use and manipulate various types of geospatial data (e.g., population data, hydrology, environmentally sensitive areas) enables students to investigate the scientific, social,

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economic, and political perspectives underlying environmental problems and issues. Students can then develop potential solutions that reflect real-world complexities.

The goal of this paper is to provide researchers and practitioners with a knowledge framework to research the use of geospatial technology in teaching science and to see their own work in a new light. Technological Pedagogical Content Knowledge (TPACK – pronounced T-pack) provides a clear and useful way to examine how technological, pedagogical, and content knowledge interact (Koehler & Mishra, 2009; Mishra & Koehler, 2006). This chapter reviews relevant literature on Pedagogical Content Knowledge (PCK). It defines our perspective on TPACK. Finally, this chapter presents a research-based teacher case study illustrating the potential of TPACK as a means to understand the representational and pedagogical opportunities created when using geospatial technologies to teach science.

16.2 TPACK as a Model for Teacher Knowledge

16.2.1 Pedagogical Content Knowledge

Shulman defined PCK as "an understanding of how particular topics, problems, or issues are organized, presented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (1987, p. 8). Shulman also argued that:

> The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students. (p. 15)

In other words, PCK is the ability of a teacher to provide his or her students with meaningful activities or representations of specific topics or concepts. Obviously, this construct is at the core of what it means to be a good teacher. Consequently, the National Research Council (1996, 2000) and a variety of other organizations use PCK as their primary framework for defining effective teaching.

Though a variety of scholars have explored this construct in an effort to refine, redefine, and expand what is meant by PCK (e.g., Appleton, 2006; Gess-Newsome, 1999; Loughran, Mulhall, & Berry, 2004; Van Driel, Verloop, & de Vos, 1998; Veal & MaKinster, 1999), the core aspects of PCK (content and pedagogy) remain relatively unchanged from Shulman's original conception. Content knowledge refers to the topics, concepts, and principles within a discipline; how content within a discipline is organized; and the diversity of student alternative conceptions (Shulman, 1986, 1987). It has been argued that the foundation of PCK is *content knowledge* and that the ability to apply pedagogical strategies is dependent upon the extent of a teacher's content knowledge (Van Driel et al., 1998; Veal & MaKinster, 1999). Clearly, strong content knowledge is essential, at least, for designing appropriate learning environments, helping students make conceptual connections, and answering students' questions.

Pedagogical knowledge, on the other hand, refers to a broad category of knowledge that includes how to support student learning, classroom management, the adaptation of curriculum, teaching strategies, and student assessment. There are general principles and concepts for each of these topics, which can serve to guide decisions made by teachers. It is also important to note that pedagogical knowledge can be developed both theoretically and practically. Lectures or discussions in a course can enable preservice teachers to develop an understanding of the theoretical foundation that underpin such strategies as project-based or cooperative learning. While field experiences for in-service teachers serve as practical experience in which they can learn context-specific pedagogical strategies grounded in experience, mentoring, and trial and error.

PCK represents the ability to create learning environments, represent ideas, and provide explanations of specific topics, concepts, and principles within a subject matter domain (Veal & MaKinster, 1999). However, there are relatively few science-specific examples in the literature that document the development of PCK focused within a specific content domain or topic. One exception is the work of van Driel et al. (1998), which explored the development of teachers' PCK to teach chemical equilibrium. Another example is the work of Veal and Kubasko (2003), which examined biology and geology teachers' PCK in teaching evolution. The authors discussed not only the curricular context in which these teachers worked but also illustrated the complex sociocultural nature of their communities. A relatively new line of research in the field of educational technology uses technological knowledge as a specific content domain in order to put forward a framework for understanding what it means to teach effectively within the domain of technology.

16.2.2 Technological Pedagogical Content Knowledge

Technological Pedagogical Content Knowledge (TPACK) refers to the ability of a teacher to integrate technological skills and understandings with pedagogy and subject matter (Koehler & Mishra, 2009; Mishra & Koehler, 2006). In addition to pedagogical knowledge and content knowledge, technological knowledge adds a third dimension, which represents the ways in which teachers integrate the use of technological tools into their teaching (Fig. 16.1). TPACK enables individuals to talk about how these three types of knowledge intersect individually (PCK, TCK, and TPK). Before exploring these constructs within the domain of geospatial technologies, we will discuss the nature and value of TCK and TPK in terms of science teaching and learning.

Technological Content Knowledge (TCK) entails two primary constructs. First is the fundamentally different way that technology enables a learner to see something or explore a representation of content that may have been difficult or impossible in the absence of the technology. One example is how computer-generated 3D chemical models allow one to explore the structure and nature of molecules, which would be difficult or impossible based on two-dimensional drawings. The second construct of TCK refers to the ways in which technological representations can be combined with other technological or non-technological representations in meaningful ways. For

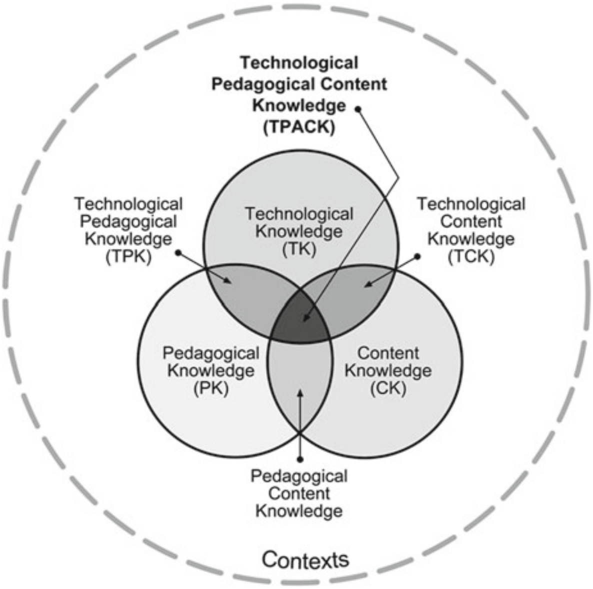


Fig. 16.1 Koehler and Mishra's (2009) representation of TPACK, highlighting the importance of considering and defining the context in which an individual is situated (Reproduced by permission of the publisher, © 2012 by tpack.org)

example, DNA sequences can be used in conjunction with morphological features of a group of organisms to construct a more accurate evolutionary tree.

Technological Pedagogical Knowledge (TPK) refers to the extent to which an individual is aware of the existence of various technologies, understands their capabilities, and recognizes the pedagogical opportunities they create for teachers and the learning opportunities they create for students. For example, science teachers increasingly rely on the use of handheld data collection units such as Vernier's LabQuest system (Vernier, 2009), which can be used as a computer interface or a stand-alone data collection device in the field. This technology, no matter what the topic of focus, creates myriad opportunities for students to collect data, engage in on-the-fly visualizations, and export data to related graphing software. Teachers who effectively use these devices understand the teaching potential of their technological features. Such features include the ability to draw predictions of relationships on the screen before collecting data or seeing data graphed in relation to what they are observing in real time (e.g., during a lab examining the relationship between temperature and fermentation). Teachers who demonstrate high levels of TPK use technology to represent ideas and/or ask students to use technology in ways that contribute to their understanding of content.

Technological Pedagogical Content Knowledge (TPACK) lies at the intersection of technology, pedagogy, and content (Fig. 16.1). This construct represents the ways in which technology enables teachers to represent content differently, while leveraging one or more pedagogical opportunities created by the nature of the technology. Although these two aspects may or may not occur simultaneously, the use of specific technologies usually presents teachers with multiple opportunities. The extent to which a teacher can take advantage of such opportunities is often dependent upon the context in which the teacher and the students are situated.

16.2.3 TPACK as Activity

Knowledge is commonly referred to as if it resides in the head of the learner, and learning is confused with the memorization of information. However, situated cognition theory argues that knowledge is best understood as an *activity* that is distributed among the knower, the content, and the context (Barab et al., 1999; Brown, Collins, & Duguid,1989; Greeno, 1998; Lave & Wenger, 1991). In other words, as argued by Young (1993), knowledge is the active interaction of an individual, within a specific context, grappling with specific content. MaKinster et al. (2006) used the example of a piano player. What it means to be knowledgeable about playing the piano can only be understood when one considers who is playing and in what context. A jazz piano player sitting on the stage at Carnegie Hall being asked to play a Bach piano concerto is viewed very differently than a trained classical pianist in the same context. Knowing is manifest by what an individual can *do* within a particular setting. Knowledge is activity.

Therefore, when using the lens of TPACK to understand teaching and learning, one must consider the context in which the activity of teaching and learning is taking place (Fig. 16.1). Koehler and Mishra (2009) described TPACK in a manner that highlighted the importance of defining the context in which learning occurs and considering the ways in which the various types of knowledge play out differently in different contexts. A central and important conviction of our perspective of TPACK is that such knowledge *is and can only be* represented through activity within a specific context.

16.3 TPACK and Geospatial Technology

TPACK is an analytical lens through which we can examine both the potential of a technology and teacher knowledge as activity, focusing on each constituent element as needed. Each of the dimensions can be used individually to identify various types of knowledge, which can then be used to explore the opportunities created by the interactions between and among them. In other words, each of the intersections in the model, TCK, TPK, PCK, and TPACK, buttresses the conceptual framework to explore the opportunities and challenges created by a specific technology.

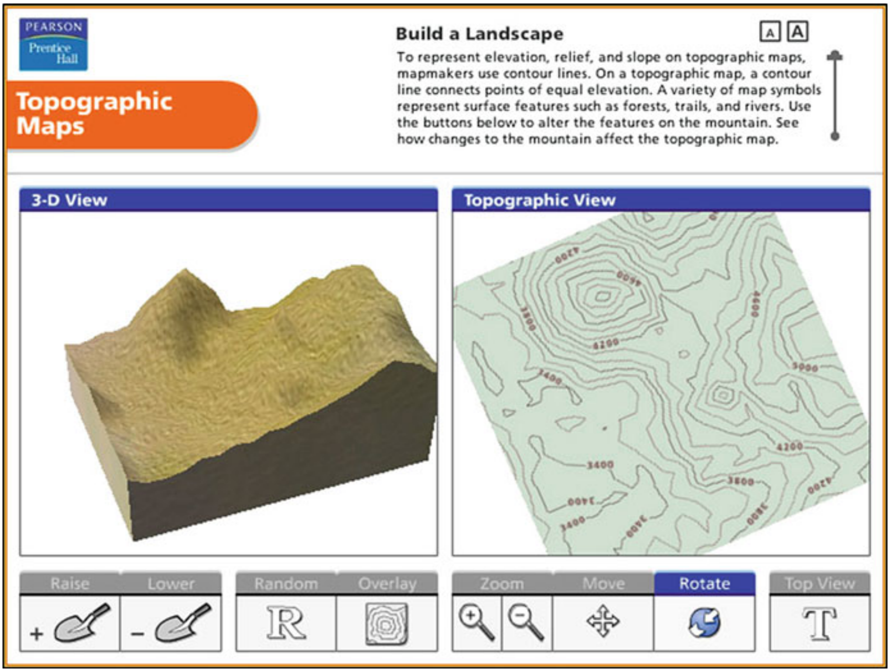
This manuscript is intended to provide a theoretical perspective that can be applied more broadly to research. The opportunities created by geospatial technologies reflect our collective experiences, the research literature, and ideas that emerged during the writing of this manuscript. We will describe the general nature of TCK and TPK as related to geospatial technology, before using the case of an individual teacher to illustrate the potential of using TPACK as a lens to understand what it means to teach science effectively using this technology.

16.3.1 The Nature of TCK When Using Geospatial Technology

One of the primary reasons teachers are attracted to geospatial technology is its ability to represent content in new or compelling ways (Milson & Alibrandi, 2008). For example, global visualization tools, such as Google Earth, are rapidly becoming popular tools for presentations and student explorations. The ability to "fly" to any location on earth can provide students with a sense of the spatial relationships between various locations or geographical features. Using a simulated three-dimensional environment, students can explore locations that they would not be able to visit otherwise, for example, touring around and even within the volcanic crater at Mount St. Helens. Science teachers demonstrating TCK understand the potential of global visualization tools to represent scientific concepts such as topography, mapping, erosion, subduction, and volcanism, plate tectonics, and watersheds.

Geographic information systems (GIS) not only provide the ability to visualize spatial data but also to explore interrelationships among various datasets from the same location or area. For example, a user can overlay land use with water quality to investigate potential relationships between the surrounding land use of a stream or river and the resulting water quality. As a result, students are able to visually explore related science concepts such as topography, nonpoint pollution, and water chemistry. The ability to overlay datasets and examine relationships among datasets creates powerful teaching opportunities. The extent and depth of such opportunities represent a teacher's TCK. For example, students using GIS can visually explore land-use patterns in relation to topography. They can use analytic tools to quantify those relationships or create stream buffers that enable them to visualize the areas of greatest concern. With access to appropriate data, they can compare the differences and similarities of multiple locations facing the same challenges or impacts. Within the current example, such comparisons may lead to a better understanding of quantitative relationships between water quality in specific streams as related to different surrounding land-use patterns. As stated previously, extended and more advanced investigations could involve students developing predictive models, analyzing complex datasets, representing changes over time, and integrating other computer databases or software with their GIS.

There are also a variety of web-based geospatial tools that represent concepts in compelling ways that create teaching and learning opportunities. For example, topographic maps come to life using a web-based tool that enables a user to virtually sculpt mountains and valleys on a 3D model and watch in real time as corresponding changes occur in the adjacent topographic map (Fig. 16.2). Users can zoom, pivot, and rotate both the 3D View and the Topographic View, providing multiple perspectives for understanding topographic contours. The landscape is viewed in shaded relief, with or without contour lines superimposed. The use of such tools can be evidence of TCK



Build a Landscape

To represent elevation, relief, and slope on topographic maps, mapmakers use contour lines. On a topographic map, a contour line connects points of equal elevation. A variety of map symbols represent surface features such as forests, trails, and rivers. Use the buttons below to alter the features on the mountain. See how changes to the mountain affect the topographic map.

Fig. 16.2 Interactive 3D topographic map simulation. Available at http://www.forgefx.com/casestudies/prenticehall/

when teachers understand the conceptual connections that are possible within such a tool. The instantaneous changes that occur on one side of the model due to user-induced changes on the other side of the model result in students being able to make a direct link between the topography of a surface and the contour lines required to represent such a surface. A teacher, who can facilitate the use of this tool effectively and lead a discussion that helps students make and understand the conceptual connections, would be said to have higher levels of TCK in this context.

16.3.2 The Nature of TPK When Using Geospatial Technology

Some of the core pedagogical aspects of teaching include facilitating student learning, creating assessments, using different types of teaching, and the development of lesson plans. Below we will explore each of these in more detail in relation to teaching with geospatial technology, each of which is an example of TPK.

First, global visualization tools and GIS lend themselves not only to having students *explore* geographic data, but also these tools can be used for *creating* maps, tours, and images that serve as various forms of assessment (Audet & Ludwig, 2000; English & Feaster, 2003; Hall-Wallace & McAullife, 2002; Malone et al., 2005). One aspect of a teacher having higher levels of TPK would be the ability to effectively develop and use student assessments that serve as valid and reliable instruments for assessing student learning. The challenge for a teacher is to provide the prompts and scaffolds necessary for students to adequately document or represent what they have learned both in terms of skills and content understandings.

Second, when creating maps, tours, and other geospatial projects, it is common for students to work collaboratively in pairs or groups (e.g., Bodzin, 2008; Morgan, MaKinster, & Trautmann, 2009). This collaborative approach fits the idea that student learning is best supported when students can explore and have conversations around shared artifacts (Barab, Hay, & Duffy, 1998; Blumenfeld et al., 1991; National Research Council [NRC], 1996, 2000). Collaborative learning results in students developing scientifically correct conceptions more often than when working alone (e.g., Lumpe & Staver, 1995; Schroeder, Scott, Tolson, Huang, & Lee, 2007). Effectively facilitating collaborative learning when using technology is another example of a teacher having high TPK.

Third, the potential of geospatial tools creates opportunities for lessons to range from the fairly structured (e.g., many of the lessons in *Mapping Our World*) to guided inquiry, open inquiry, and/or project-based tasks that provide students with opportunities to explore the various dimensions of a given question or problem (e.g., Bodzin, 2008; Doering & Veletsianos, 2007; Trautmann & MaKinster, 2010). For example, facilitating inquiry or project-based lessons requires teachers to understand the roles and behaviors they can use that support this type of learning (NRC, 2000). It also requires teachers to understand how to structure verbal or written questions so they are productive and lead to greater levels of student ownership (Colburn, 2000). A teacher who is able to facilitate an inquiry- or project-based lesson that uses geospatial technology effectively would be said to have high TPK.

Finally, central to pedagogical knowledge is the ability to adapt lesson plans to one's own classroom context (e.g., Barab & Luehmann, 2003; Squire et al., 2003). Good teachers adapt existing lesson plans to fit their classroom norms and expectations as well as their students' conceptual readiness and developmental level. Adapting or creating lesson plans that involve technology add an additional layer of complexity to an already challenging task (Barab & Luehmann, 2003). Teachers who are able to successfully adapt lessons that use geospatial technology in ways that meet the needs of their students and result in student learning are demonstrating TPK.

16.4 Exploring the Potential of Using Geospatial Technology to Teach Science

Building on previous studies of the GIT Ahead project (Trautmann & MaKinster, 2010), we present the case of one GIT Ahead teacher as a means to explore the ways in which different geospatial technologies create specific representational and pedagogical opportunities for science teaching and learning. This case is an example of how GIS and global visualization tools create opportunities to represent scientific content in fundamentally different ways, while creating pedagogical opportunities in terms of collaborative group work, formative assessment, and summative assessment. Although not intended to be exhaustive, this case study should serve as a representative example of the utility and power of geospatial technologies. More importantly, we hope this analysis will inform how professional development researchers and practitioners look at their own work.

16.4.1 Methodology

This case study was developed from multiple sources of data representing the perspectives of the researchers and teacher. These data included classroom lessons, written teacher reflections, informal conversations, a formal presentation by the teacher about this unit, two interviews, and classroom observations. All of these data focused on the implementation of a 2-week watershed unit taught during the spring of 2008. The initial interview and presentation were guided by the following questions:

1. What was the goal of this unit?
2. What did you have the students do?
3. How did you view your role as a teacher?
4. How did you support your students during their investigation?
5. How would you describe what your students were able to accomplish?
6. What were your greatest successes when teaching this lesson?
7. What were your biggest challenges in teaching this lesson?
8. How would you describe the impact of this unit on your students?
9. How would you describe the impact of this unit on yourself as a teacher?

The second interview was designed to explore TPACK explicitly and was guided by the following questions:

1. How do you see Google Earth as being able to represent science concepts or ideas in ways that are not possible or as easy in the absence of this technology? (TCK)
2. How do you see ArcMap as being able to represent science concepts or ideas in ways that are not possible or as easy in the absence of this technology? (TCK)
3. Pedagogy refers to a broad collection of ideas, strategies, approaches, and techniques (e.g., teaching methods, evaluation, group work, questioning, wait time, feedback, individual instruction, lecture, and demonstration). Did using Google Earth for your watershed unit create any specific pedagogical opportunities for you as a teacher? Did it make anything possible or easier? (TPK)

4. Did using ArcMap for your watershed unit create any specific pedagogical opportunities for you as a teacher? Did it make anything possible or easier? (TPK)
5. Measurement plays a central role in this unit. Can you talk about its importance in this unit and within your classroom in general? (TCK)

The interviews were recorded and transcribed in their entirety.

Data were analyzed using the constant comparative method (Glasser & Strauss, 1967) across all data sources. Specifically, we used the pattern of open coding, axial coding, and selective coding advocated by Strauss and Corbin (1990). This type of grounded analysis was essential to understand the complexities of this case and to ensure that our interpretations accurately represented what happened in the classroom. Data collection and analysis occurred sequentially because we viewed the theories and explanations as dynamic constructs that changed and were clarified over time, especially in light of further investigation. We took several deliberate steps to promote the reliability of the analyses, including triangulation of data collection methods (Lincoln & Guba, 1985) (e.g., classroom observations, interviews, written reflections, lessons), triangulation of types of data (documents, email, interviews, field notes), and member checking (Stake, 1995) with the teacher.

16.4.2 Exploring the Impact of Land Use on Water Quality Within the Stone Creek Watershed

This case was chosen because (a) it is a well-defined unit that incorporates two of the most commonly used geospatial tools, (b) the geospatial extension of this unit was a natural and integrated part of the curriculum, and (c) the teacher came into the project with average-level technology skills. Consequently, this case reflects the possibilities for teachers with typical rather than particularly tech-savvy backgrounds. While what is presented below may seem somewhat complex for a teacher with average technology skills, one must keep in mind that this unit occurred after two summer institute experiences and several follow-up Saturday workshops.

16.4.2.1 School Context

Mr. Braddock (pseudonym) is a veteran teacher with 30 years of experience. He teaches General Science at Stone Creek Middle School (pseudonym), located in a small village in the Finger Lakes Region of New York State. The primary sources of employment in this rural county are dairy farming and tourism. The largest village, Stone Creek has a population of 3,000. Twenty-one to thirty percent of students come from families receiving public assistance, and 32 % of students are eligible for free and reduced lunch (New York State Report Card, 2008).

16.4.2.2 Unit Context

Over the past 2 years, Mr. Braddock and his students investigated the stream that runs by their school. Students collected and identified macroinvertebrates, then compared the types of organisms in their sample with those identified in water quality biotic indices that were based on the pollution tolerance of different macroinvertebrates. Using this approach, his students determined that their stream had comparably high water quality. Mr. Braddock decided that the next step should be to determine why this was the case. He saw water quality as a core environmental issue and wanted to help his students understand the broader geographic context in which their stream was situated. This desire led him to participate in the yearlong GIT Ahead professional development project focused on geospatial technology.

16.4.2.3 Professional Development Context

GIT Ahead was a National Science Foundation funded program (2006–2010) designed to help teachers teach science using geospatial technology and to help middle and high school science students to see geospatial technology as tools for exploring scientific questions and high-demand careers. Each year a cohort of up to 20 teachers participated in a yearlong professional development experience that included an 8-day summer institute, 6 Saturday workshops during the school year, and web-conferencing opportunities and other forms of ongoing support (Chap. 4; Trautmann & MaKinster, 2010). Mr. Braddock was an active participant in this project during the 2007 summer institute and the 2007–2008 academic year, consistently attending the professional development workshops and designing curricula for his classroom.

16.4.2.4 Watershed Unit

As part of his GIT Ahead experience, Mr. Braddock decided to build on his stream macroinvertebrate unit by using geospatial technologies to explore watersheds, streams, and rivers. His ultimate goals were to help students understand what a watershed is and how land use in a watershed could affect the quality of water in streams and rivers.

To help students visualize the watershed, Mr. Braddock used Google Earth imagery that was enhanced by vertically exaggerating the terrain. On this virtual surface, he overlaid a GIS layer that highlighted the streams within this area and a USGS topographic map that included the contour lines and other symbols from the map's legend. The students each worked at their own computers and virtually explored the Stone Creek watershed. They started at their school and followed the stream through the town, up a steep-sided and geologically diverse ravine, and into the headwaters. The task was to determine the highest and lowest points in the watershed, by using the elevation information provided by Google Earth, and to figure out how to interpret the symbols on the topographic map. This independent student exploration lasted about 30 min. It served as the context for meaningful classroom discussions about watersheds, contour lines, topography, stream direction, and headwaters. Next, students were asked to follow the stream in the opposite direction as it joined with other surface water bodies, eventually reaching the Atlantic Ocean.

Mr. Braddock described the ability to fly through a topographic map as a "powerful experience" for his students. They discovered the source and ultimate destination of the stream running by their school and measured its elevation at various points as they learned the meaning of topographic contours. Because the students were able to make the topographic overlay transparent to varying degrees, they were able to explore how the symbols on the map related to the landscape features they represented underneath (e.g., close contour lines represented a steep rock slope in the ravine and more widely dispersed lines represented flatter valley lands at the mouth of the stream). While much of this investigation could be done with paper maps, it was the ability to virtually explore the landscape that engaged the students and led to them making stronger connections between the representations they were exploring and the real world.

Mr. Braddock's students used ArcMap as the tool for measuring attributes of the Stone Creek watershed in greater detail. First, the students used the measure tool and GIS layers representing streams, ponds, lakes, and watershed boundaries to determine the area of the watershed in square miles and the total length of the stream and its tributaries. Mr. Braddock described the students' surprise when they realized that the total length of streams in their watershed equaled the 40-mile length of the large lake on which their town is located. Because Mr. Braddock was unsure how to calculate land cover percentages within the bounds of the watershed, he developed a fairly elegant way of simplifying his students' analysis of the land cover along Stone Creek. Instead of measuring or calculating total areas, he had them take linear measurements of the stream, categorized according to adjacent land cover type. Mr. Braddock introduced this task by saying:

> We are to the third piece of analyzing the watershed, and I'm going to argue it's the most important. Scientists and geographers have identified what's farmland and what's forested land. If it's green, it's forest. So what you want to do is to determine the total length of the stream within each type of land cover. With the measure tool, you are going to determine how much is in forest, as compared to agriculture, which would be shrubs, grassland, and cultivated crops. (Classroom Observation)

Mr. Braddock had the students use the linear measure tool in ArcMap to measure the length of stream running through each type of land cover (forest, agricultural, residential, and commercial). Using these measurements, they calculated the percentage of the stream's overall length running through each land cover category. While this approach is less exact than measuring land areas, and could result in considerable over- or underestimation of land cover types within a watershed, it enabled the students to conduct this portion of the investigation within two class periods and with minimal support and guidance from the teacher. The measure tool was straightforward, easily used by the students, and provided the possibility for analyses that otherwise would have been difficult or required more structure. Mr. Braddock used the students' results to talk about concepts such as surface runoff, precipitation, land use, land cover, riparian habitat, riparian buffers, and nonpoint source pollution. When his students had finished analyzing the Stone Creek watershed, they chose another nearby watershed, ideally the one in which they lived, and conducted the same measurements and analysis for that watershed. Mr. Braddock wanted to help the students appreciate his opinion that "if you understand one watershed, you understand *all* watersheds" (classroom observation).

16.4.2.5 Technological Content Knowledge

Mr. Braddock chose to have his students use Google Earth to learn how to interpret topographic maps, because he knew how difficult it is to understand contour lines without viewing the topography that they represent. This is an example of Mr. Braddock's application of Technological Content Knowledge regarding how he chose to teach this particular topic. Mr. Braddock knew that an ideal experience might be to have his students hike up the Stone Creek Glen, using a topographic map to navigate, but that this approach would not be feasible. Google Earth gave students the virtual experience of traveling through the watershed and may even have been more advantageous than a real field trip, because it enabled Mr. Braddock to have conversations about contour lines, topography, stream direction, and map legends with his students *during* their exploration. He was able to address issues and direct student learning as it occurred. While similar investigations are possible using foam board and the creation of 3D watershed or contour models, Google Earth enables students to explore a representation of the landscape itself.

Considered from the perspective of TCK, global visualization tools allow a teacher to teach specific concepts in fundamentally different ways. First, students are able to explore a 3D representation of a specific feature, change their view or perspective, and access supplementary information that helps them to interpret the landscape. Doering and Veletsianos (2007) describe Google Earth as enabling "students to modify their view of the world and their concept of space." It facilitates students' exploration of familiar places in a very unfamiliar manner (overhead in simulated 3D). Bodzin (2008) describes this opportunity as providing students with unique perspectives of their geographic area, which often translates into increased motivation and enhanced opportunities for student learning. Second, this experience can create opportunities for students to construct their own knowledge. Mr. Braddock described the power of using Google Earth as:

> …making the abstract concrete. Unless I show images of watersheds, how do students know what a watershed looks like? I can use words and describe a watershed; however, [understanding the concept of a watershed] on their own requires the students to want to listen to me. In a public school I have a continuum of students in terms of willingness and ability. By using Google Earth, I don't need to explain a watershed; they see and experience it for themselves. My perspective reflects that of Kahlil Gibran from *The Prophet*, I can't give you my understanding; you have to arrive at it for yourself. I'm merely there to help [students] along the way. (Teacher Interview)

Mr. Braddock's knowledge of watersheds, nonpoint source pollution, and water quality were demonstrated by his strategy of using ArcGIS for the students to examine the potential impact of surrounding land cover on Stone Creek. His goal was to provide students with the opportunity to explore "what a watershed is, why a watershed is, and what determines the quality of the water." He recognized the need for students to appreciate the diversity of the landscape through which the stream flowed and to think about the potential impacts on a stream of different land cover or land use. The exercise of measuring the length of stream flowing through various types of land helped the students to visualize how land cover might impact water quality. For example, Mr. Braddock talked about pesticide and herbicide runoff from agricultural lands and the role of riparian buffer areas in mitigating such effects. Such discussions are possible in the abstract, but they are far more vivid when conducted within the context of technology-enhanced explorations and analyses of the students' local watershed. In other words, while Mr. Braddock could talk about these concepts theoretically, the geospatial tools permitted the students to explore and relate these concepts within a local context. Concepts such as runoff became more tangible when students saw the amount of farmland that surrounded a stream. They were then able to think about the consequences of farmers spraying pesticides and/or herbicides on those fields.

16.4.2.6 Technological Pedagogical Knowledge

While there were numerous pedagogical opportunities created by the use of geospatial technologies, Mr. Braddock described the creation of an authentic context, the role of measuring as a method for inquiry, and the ability to differentiate instruction as three aspects that were central to the success of this unit. Authenticity depends on the perspective of the learner (Barab, Squire, & Dueber, 2000). If a student perceives an activity or project to be personally meaningful, relevant, and engaging, then it is authentic. Mr. Braddock described the Google Earth lesson as "clearly the next best thing" to hiking along the stream and mapping its watershed.

Another way in which Mr. Braddock leveraged local investigations to create authentic contexts was by asking his students to apply what they had learned about the potential impact of land use and land cover in the Stone Creek watershed to a similar analysis of the watershed in which they lived. Students had to make the same measurements on the watershed in which they lived. While the original investigation was grounded within their school community, the application of this new knowledge was focused even closer to home. Mr. Braddock described one student wanting to determine which way the stream near his house flowed. Using the topographic map in Google Earth, he was able to interpret the contour lines and check his conclusion by examining the elevation change between two points in the stream.

When describing the pedagogical opportunities afforded through the use of Google Earth and ArcMap, Mr. Braddock focused on the central role of measurement as a primary means for supporting guided student inquiry. A key consideration was the ease of measuring in ArcMap versus Google Earth. (The measurement tool in ArcMap keeps track of the total distance when following a stream or measuring the area of an irregular polygon, whereas students using Google Earth have to record each measurement and perform the calculations themselves.) Mr. Braddock acknowledged that most students could probably do this, but he opted for a method that would permit his students to focus on the concepts underlying their work rather than the mechanics:

> ArcMap is simple. It allows my students to calculate the area of a watershed and compare it to a marsh. At the moment you think your lesson plan or an approach is not simple, then you're wrong. [The guiding question for me as a teacher is] how easily can I get my kids who don't like math to quantify the percentage of a stream flowing through a forest? (Interview)

Mr. Braddock's focus on measurement required students to understand individual concepts and the interrelatedness of those concepts. Through a progression of tasks, they learned how to use a topographic map, discovered the nature and structure of a watershed, considered the different types of land use and land cover in a watershed, assessed the relative amounts of each land cover type along the stream, and then synthesized all of these ideas to explain why the water in Stone Creek near their school was of high quality. Students were able to see how much of the stream was protected by forest:

> It's concrete. When we say that 70 % of the land cover along Stone Creek is forest, they can interpret that. They also measure that less than 2 % is commercial. They can see that. When they can see that the marsh at the end of the stream is many times smaller than the watershed, they can put that all together. (Interview)

Finally, Mr. Braddock applied TPK in his reflection that Google Earth had provided a number of opportunities to differentiate instruction to meet the needs of individual students. In this context, he saw differentiated instruction as:

> …easy to do with geospatial technologies. Jordan is a top-notch student, had these great answers, and consistently insightful statements. Whereas Kyle is extremely limited, had had limited answers, of course, but both of them analyzed their watershed with the technology correctly. (Interview)

Each student or pair of students could work at their own pace and reach their own conceptual limits. The fact that some students were comfortable with the technology allowed Mr. Braddock to focus his attention on those who needed assistance. He concluded, “Students have figured out for themselves, with my guidance, that the water we drink is determined by the land we take care of.”

16.5 Conclusion

TPACK serves as a powerful framework to analyze the ways teacher knowledge manifests itself in the classroom. Mr. Braddock's case illustrates the opportunities and challenges created by using geospatial technologies to teach science. Our hope is that this work will help science education researchers and practitioners, who are conducting teacher professional development efforts, to look at their own work in a new light. There has been relatively little discussion in the science education literature about the utility of teaching science with geospatial technologies, especially in terms of teaching specific science and environmental concepts. Professional development providers need to understand and think carefully about how their work with teachers translates into classroom practice and student learning.

There are several related areas in which future research is needed. First, future research should explore the opportunities created by using geospatial technologies to teach science within each of the various content areas. In other words, in what ways do these technologies create enhanced opportunities for learning concepts in earth science, biology, or environmental science? Second, researchers should examine the ways in which TCK, TPK, and TPACK vary among teachers using similar technologies or teaching similar concepts. As discussed above, Trautmann and MaKinster (2010) began to explore this using a single teacher. It would be interesting to know how consistent this phenomenon is and how teachers perceive domain-specific knowledge differently. Finally, since this paper and Koehler and Mishler (2009) highlight the importance of context, there is a significant need to understand the ways in which different contexts affect or interact with teachers' TPACK. The context for teaching can be defined, at the very least, in terms of (a) the curriculum, (b) the physical setting and resources, and (c) the school and school community. It would be interesting to know how the actions of teachers with similar TPACK are influenced by the contexts in which they work.

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Chapter 17
Moving Out of Flatland: Toward Effective Practice in Geospatial Inquiry

Bob Coulter

Keywords Implementation • Geospatial inquiry • Interest • Model-based reasoning

17.1 Introduction

For more than a decade, teachers have sought to leverage the power of geospatial tools to promote higher levels of student learning. Ranging from relatively modest projects such as using global positioning system (GPS) units for geocaching to comprehensive, analytical neighborhood studies informed by a geographic information system (GIS), the common hope has been that these cutting-edge tools will provide the motivation and resources needed to go beyond the limits of a more traditional curriculum.

A number of strategic drivers underlie this movement, with some or all being present in a given effort. For example, many science teachers seeking to leverage the power of models use geospatial analysis with their students to investigate climate patterns, seismic activity, and other phenomena. Other teachers employ geospatial tools to promote career awareness, noting the current projections that geospatial careers are among those expected to be "high growth" fields of the near future (U.S. Department of Labor, 2008). Others are simply looking to make their projects more meaningful to students, many of whom seem to simply prefer technology-rich learning experiences compared to more traditional ones.

Running in tandem with this growing interest in the use of geospatial technologies, a cottage industry of consultants, workshops, conferences, and curriculum materials has sprung up to support and advocate for geospatial technology in the classroom. While reliable and comparable data are not available, these efforts appear to be strongest in the United States. However, notable efforts also are

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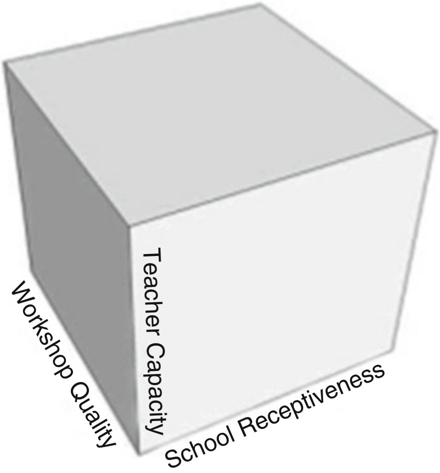

Fig. 17.1 A three-dimensional model of elements supporting successful implementation of geospatial technologies in the classroom

underway in other countries including Canada, the United Kingdom, and Australia. Despite these efforts, the goals and aspirations held by many advocates of geospatial technology have greatly exceeded the reality of how the tools are used in the typical classroom. Thus, vignettes of successful implementation abound, but most leaders in the field would agree that use of geospatial technology becoming the norm in schools remains a largely unrealized goal.

Attempts to understand this gap between vision and reality have led to a number of thoughtful research efforts, including those undertaken by Kerski (2003) to understand implementation patterns and by McClurg and Buss (2007) to understand the elements of a successful teacher professional development experience. The findings of these and other efforts will be summarized and folded into the analysis that follows. Despite the insights emerging from this research and the good-faith efforts of professional development providers to implement their recommendations, fostering effective use of geospatial technology with a typical teacher remains an elusive goal. Even if we could arrange for every teacher to experience high-quality professional development possessing the characteristics McClurg and Buss identified as being essential, and even if these teachers return to a receptive school setting (possessing many of the variables identified by Kerski), something more – a third dimension relating to individual teachers' professional capacity – is required (Fig. 17.1).

Even in a supportive environment, the author's experience over the past decade of work with teachers has shown that the key to successful implementation of geospatial technology is a teacher ready and willing to undertake an intellectual endeavor of sufficient magnitude. More specifically, teachers' ability to lead rich geospatial inquiry is predicated on several specific attributes, including:

- Understanding of the topics at hand
- Curiosity and passion to learn more

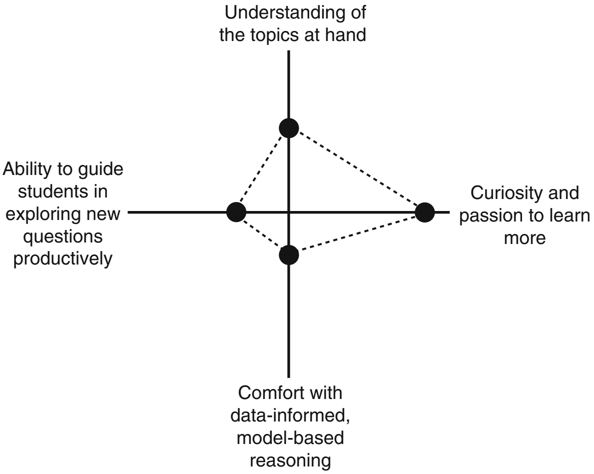

Fig. 17.2 Representation of one hypothetical teacher's capacity factors

- Comfort with data-informed, model-based reasoning
- Ability to guide students in exploring new questions productively (Fig. 17.2)

Each of these "capacity factors" is critical to realizing the promise of geospatial education. To the extent that any are missing or inadequately developed, the quality of the work is diminished. When a few of these factors are underdeveloped, the project rapidly loses value. With each limiting factor, it becomes less likely that a teacher will pursue technology-enriched geospatial inquiry, reverting instead to more pedestrian curriculum materials. For a project looking for relatively quick implementation of geospatial technologies, these factors may be useful teacher selection criteria. Districts looking at more comprehensive reform efforts might consider these dimensions as essential elements of teacher competence to build over time, as prerequisites or perhaps in parallel with geospatial professional development efforts.

It is important at this juncture to identify what effective and meaningful use of geospatial technology looks like. Successful use is defined here as more than mere use of a prefabricated mapping exercise or going to the local park to find a geocache. For example, one teacher with whom the author has worked for 8 years now in two different schools considers herself to be "using GIS" when she has the students symbolize a map that groups the states into regions that mirror their social studies textbook. Thus, West Virginia and Florida are in the same "southeast" region of the United States. Other uses include making a map to show where their assigned state is on a map of the United States. By printing the map and including it in the requisite fifth grade state report, GIS is nominally integrated into the curriculum. The net result of projects like these is the geospatial equivalent of a bulletin board full of identical worksheets. Even closer to the worksheet mentality, Kerski (2003) cites an example of a teacher participating in a workshop whose primary goal appears to have been printing out blank maps for his students.

While such low-level use may be an important first step for a teacher looking to gain confidence using GIS, it shouldn't be the desired end point. A much more ambitious growth trajectory is required before a class is engaging in meaningful geospatial inquiry. In the author's experience, the most successful classrooms are led by teachers exhibiting what Rosenholtz (1991) described as "certain" and "nonroutine" practice: Teachers are certain of their pedagogic beliefs (not simply following the latest fads or district mandates), and the classroom environment is nonroutine (the work flow and project scope are organic and varied to maintain interest and meet the goals of the projects currently underway). It would be something of an educational oxymoron to have a teacher who is certain in her pedagogy and grounded in modern understandings of learning, leading a rich and organic classroom in pursuit of rote outcomes. Quite simply, teachers who meet Rosenholtz's framing of effective teaching are much more likely to create richer learning environments. They will also be more likely to possess all or most of the four capacity factors listed previously.

This aligns well with what we know about effective use of geospatial technology in the classroom. In vignettes showing exemplary projects (e.g., Audet & Ludwig, 2000; English & Feaster, 2003), there is an underlying but generally unstated assumption of students' thought levels. Rather than the rote, mechanical use characteristic of the regional coloring and state-labeling projects described above, students engaged in exemplary practice are functioning with higher-level, integrative thinking. While there are a number of schema that capture this way of thinking, Gardner's *5 Minds for the Future* (2008) captures the scope and breadth of effective high-level thinking concisely:

- *The Disciplined Mind*: By working toward mastery in a particular way of thinking, a student comes to appreciate academic disciplines and potential career fields. For example, looking at a community issue from a scientific perspective gives a different perspective than looking at it from a historic perspective. Over time students come to appreciate these complementary perspectives and the underlying structures and rigor of each discipline.
- *The Synthesizing Mind*: Complementing the strengths of seeing the world through disciplines, students who can synthesize different perspectives and representations to arrive at a deeper understanding are well equipped to handle the barrage of data and information available in our networked society. In particular, the capacity of modern geospatial tools to integrate multiple layers of spatial and quantitative data enables this synthesis. With the guidance of an expert teacher, students' capacity in this regard can grow over time.
- *The Creating Mind*: By engaging in an academically rigorous study that synthesizes various forms of data, students can create new products that have value in the community. Whether that involves a report on the value of urban forests or maps of local crime data, being able to create geospatial representations that

have value in the community gives students a sense of purpose and self-efficacy that is all too often lacking in traditional school work.
- *The Respectful Mind*: As students encounter diverse perspectives and alternative ways of seeing an issue, they can come to respect both the depth and complexity of real-world issues and the fact that well-meaning people will have disagreements over these issues. By developing the capacity to differ respectfully and ground discussions in data, students will be able to have constructive dialogues while building important skills for the future.
- *The Ethical Mind*: At a larger, meta-level framing, students engaged in rich geospatial inquiry can see how human purposes work together – sometimes in harmony, other times in conflict. As they study change over time, political contests, or human-environmental trade-offs, students are grounded in issues that require ethical consideration. What makes the best society now and in the future?

Within a rich project, several of these minds come into play. For example, in a study of a local watershed I led with fifth graders, students synthesized the data they collected on the chemical and biological health of the stream (thus gaining early exposure to two major scientific disciplines). They were also introduced to the discipline of urban planning as they explored land use maps showing how the water flowed from high-value residential zones to lower-value areas surrounded by industrial and commercial zones. Through their effective synthesis of these disciplinary perspectives, they created maps that still have value in presenting the ecological and socioeconomic challenges in the watershed. As residents of the upper middle-class regions in the watershed, they came to be more respectful of the range of communities in the watershed and were quite thoughtful in their analysis of the social and ecological implications of their findings. While there is a limit to how far 11-year-olds can go in terms of moral development, these opportunities to think about the community from different perspectives help to build an ethical framework that will mature over time.

17.2 Professional Development and School Culture Influences on Geospatial Education

In a national survey of GIS-using educators, Kerski (2003) found that 88 % of those responding either “agreed” or “strongly agreed” that GIS contributed to students’ learning. Perceived benefits cited include (1) the potential for increased curricular relevance, (2) support for interdisciplinary investigations, (3) opportunities to develop students’ exploratory data skills, and (4) a more general feeling of enhanced student motivation. Granted, this was a survey of people who already owned GIS software at their school, so they were at least a somewhat biased sample. What is more interesting than the expression of support is the comparatively low level of implementation with students. Despite the strong perception that GIS offers many educational benefits, actual implementation lagged considerably behind software acquisition.

In most cases, it took a year or more for actual classroom use to occur, and in some cases an astounding 5 years or more had passed. Practically speaking, trying to resume use of complex tools after such a long period of inactivity leaves considerable gaps in understanding of basic software operations.

This gap between how teachers perceive benefits of using GIS and low levels of acting to realize these benefits warrants serious consideration. What is it about using GIS in the classroom that proves to be so daunting? Specific concerns cited in the Kerski study included a lack of time for curriculum development, lack of support for training and implementation, and the perceived complexity of the software.

At the time of Kerski's study (2003), geospatial curriculum modules were just becoming available. Teachers interested in using GIS with their students were usually given software, a few key data sets, and a lot of encouragement. Clearly, more is required for successful implementation. With the publication of the first *Mapping Our World* book (Malone, Palmer, & Voigt, 2002) and the online publication of an assortment of modules such as the Missouri Botanical Garden's *Mapping the Environment* series (Coulter, 2002), teachers were less likely to be left to their own devices for curriculum. In addition, for the past several years, ESRI has made many lessons and tutorials available through their ArcLessons web site and published additional curriculum resources.

While these developments are quite positive, they are likely not sufficient on their own to promote meaningful and effective implementation of GIS in the classroom. At the very least, the potential richness of geospatial inquiry is limited if students are led through step-by-step exercises. A "one-size-fits-all" curriculum that is ready to print out and be used right away can be a good first step in supporting teachers, but such a use belies the real power of GIS. As one teacher in Kerski's study noted (p. 133):

> 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.

Going through the motions of a printed, prestructured curriculum can teach students how to use the tools, but if all they are doing is following directions of where to click and what to choose, the curriculum doesn't do enough to support inquiry. To realize the power of the tools, students need to be supported with guidance toward using open-ended, exploratory data analysis. They need to be encouraged to raise questions, pose hypotheses, and draw conclusions that are informed by the data. Since the development of these capacities requires significant mentorship and coaching, students need a strong and well-prepared teacher. A packaged curriculum can – at best – point the way and show the possibilities. The teacher is the one providing the guidance when the class takes the very necessary steps away from the prescripted lesson path. Thus, it is essential that teachers be certain of their practice and comfortable leading nonroutine classroom environments as Rosenholtz argues. Specific to geospatial inquiry, the four capacity factors illustrated in Fig. 17.2 described previously are embedded within that more general certainty of practice.

Given the centrality of the mentorship role in enabling higher-level geospatial inquiry to happen, teachers need to have (or develop) a range of pedagogic and content skills in addition to procedural software training. A strong understanding is required both of data analysis techniques and of the specific content area being investigated. For example, teachers who are not familiar with the logarithmic Richter scale are ill equipped to help students interpret patterns in earthquake data effectively. In addition to the mathematical dimension of the study, an effective teacher also understands the earth science concepts the data illustrates. When a student notes a pattern of increasing depth of earthquakes moving away from a plate boundary, what does this mean? In this case, the data suggests that the boundary is a subduction zone. Part of the mentoring task is to help students go beyond simple identification of the boundary type by linking the spatial data with the relevant tectonic model. This helps to build in students a disposition toward science as a model-based endeavor and not simply a process of learning and repeating specialized terminology on demand. Productive geospatial teaching requires strong and integrated technology, mathematics, and science teaching skills. Emerging work in Technological Pedagogical Content Knowledge (TPACK, pronounced T-Pack) described later in this chapter is providing promising developments in this regard.

On top of these requirements, exploratory geospatial inquiry requires a shift in pedagogy away from focused whole-class instruction toward students working individually or in small groups on similar but somewhat different projects. A teacher leading this decentralized class needs considerably more sophisticated group management skills. Central to this is the flexibility to check in with each group and respond quickly and constructively to their needs, which inevitably will be quite different from the needs of the previous group or the next one. Within a short period he or she will likely be helping a student symbolize data more effectively to discern a spatial pattern, helping the next refocus after some off-task behavior and then guiding a third one in locating data needed to answer a new question that emerged from the investigation.

This ability to maintain multiple simultaneous strands of focus requires a much higher professional capacity than a GIS training workshop could reasonably be expected to develop in a participant who didn't already possess to some extent the four capacity factors cited earlier in Fig. 17.2. In Kerski's study (2003), teacher professional development and the availability of subsequent support back at school factored highly in whether or not a teacher implemented GIS-enhanced inquiry in the classroom. On the surface, this seems self-evident for any user: New users need effective training in the use of complex tools, and inevitably issues will emerge that either weren't covered in the workshop or that are idiosyncratic to a local software installation. Unlike other professionals who may simply need to add updated technology to their practice, teachers moving toward rich geospatial inquiry often face the larger challenge of initiating simultaneous change in several dimensions of their professional practice. As described above, they need strong technology fluency, skills in data analysis, content knowledge, and group leadership skills that are different from standard classroom management practices. Managing this multidimensional change with even less complex tools such as web-based projects has proven to be overwhelming (Feldman, Konold, & Coulter, 2000). Teachers just learning a complex tool like GIS without complementary strengths in data analysis, content understanding, and group leadership will likely feel inundated, which may explain the delays Kerski found in implementation.

To better understand the professional development needs associated with effective use of GIS, McClurg and Buss (2007) summarize 5 years of experience leading workshops for teachers. As they note, "Ample evidence exists to suggest that, in order to learn new teaching strategies, teachers need information, theory, modeling, coaching, support, and feedback through sustained, intensive, experiential learning opportunities (p. 80)." Clearly, enacting this multifaceted change requires sustained support in a professional community, not simply a training exercise. The study by McClurg and Buss delineates a number of key features that support successful use of geospatial tools in the classroom.

First, pacing within the workshop environment was shown to be a strong predictor of success. Initial research found that intensive week-long training sessions often left teachers overwhelmed with techniques and unsure of what to do back in the classroom in regard to software installation and use. As a result, McClurg and Buss changed to a model of shorter sessions, each of which introduced a more narrowly defined set of skills. Between sessions, teachers were expected to implement what they learned and report back at the next workshop session.

Similarly, the GIS workshops offered by the Missouri Botanical Garden have morphed over time to reflect this need. By scaling back the number of software features taught, providing opportunities for guided practice throughout the workshop, and providing ongoing support as teachers move toward implementation, implementation rates grew to be much higher than when teachers were taught simply how to use GIS with their students (Coulter & Polman, 2004). Pacing needs to reflect how people learn, and allowing our enthusiasm for the tools to accelerate the pacing does a disservice to those we ultimately hope to serve. A slower pace, focused on key features of the tools with ample opportunities for practice, will produce greater and more meaningful levels of implementation in the long run.

A second dimension of effective professional development articulated by McClurg and Buss was relevancy in terms of curriculum and location. Teachers need to see the curricular relevance, particularly in light of the constraints that current standards and accountability movements have imposed on most schools' curriculum. If it's not in the standards, it's much harder for a teacher to justify a project in a crowded school day. This is an area where prepackaged, district-adopted curriculum has an unfair advantage. Since these units come pre-correlated with the relevant standards, it's easy to say "It's standards based!" In fact, local organically grown projects can address these standards as well as (and arguably even better than) prepackaged curriculum, but few teachers have the time to document correlation with specific standards. A good teacher knows instinctively when a project can lead to productive learning, but may not be able to cite chapter and verse whether Science Standard 3.B.i has been addressed. The default answer for many is to go with the official, preapproved curriculum.

This "tyranny of the curriculum" as David Sobel (Personal communication, 2009) calls it allows a thin version of relevance to take hold. Too often teachers think it has to "meet my curriculum," meaning that it has to have a documented correlation with state and local standards. If that documentation happens to come from an outside "expert," so much the better. Just as the slow food movement seeks to restore the value of having a quality meal over prepackaged "quick service" eating, effective geospatial inquiry depends on a "slow curriculum" movement that values teachers' ability to create and lead rich learning opportunities. Whether the activity is at the right level of challenge for a student, or if it is likely to be generative of the skills and dispositions needed to succeed in future endeavors, is all too often a secondary consideration if it is given any attention at all. It takes a teacher with particularly strong pedagogy, certain in their practice (to use Rosenholtz's term), to overcome this tyranny. Political savvy in this area goes a long way, as well.

In addition to curricular relevance, teachers and students are also looking for local relevance. As just noted, many prepackaged curriculum units usually address the curriculum relevance issue by citing the standards being addressed, but they rarely have data or a content focus that is closer to home. Teachers we have worked with in the St. Louis region appreciate the capacity of GIS to map global patterns in seismic activity, but they also want to be able to map the more locally relevant issue of seismic activity along the New Madrid fault running just south of metro St. Louis. This local data brings home the notion of seismic activity and provides a link to what students learn from the news. The "ring of fire" in the Pacific is interesting, but a student will understand it better and have more interest if there is a more immediate reference point to build from.

At minimum, this search for local relevance requires technological savvy to focus on a subset of the larger data set. It may also require additional skills if teachers need to locate and prepare new data for student use. Pedagogically, teachers need the capacity and comfort to go "off script" with the lesson as they diverge from a prepared curriculum module to an investigation of local issues. More generally, teachers need the intellectual curiosity and depth of content understanding to be able to identify what locally relevant events can be used to engage students with broader concepts. Curriculum planning that amounts to doing Chap. 7 after Chap. 6 has been completed is simply inadequate, even if the unit is spiced up with a mapping exercise.

A third dimension of a successful workshop identified was the issue of ongoing support for teachers. This was provided in the workshops led by McClurg and Buss using a variety of tools, including:

- A web site for posting ideas and concerns
- E-mail and phone access
- On-site school visits by project staff
- Support manuals and handouts
- Equipment checkout (for GPS units)

Even moderately complex use of geospatial tools is an ambitious undertaking for a teacher, so this comprehensive suite of support is essential. Web, e-mail, and phone support can help solve basic issues, but more complex work, such as curriculum planning or neighborhood explorations, requires greater interactivity. Sitting down at a table or at a white board to diagram the flow of an investigation usually works much better than exchanging text-based e-mails or having a phone conversation. For community-based projects, actually getting out into the study area and helping teachers to see the pedagogic possibilities that surround them provides the space for essential mentoring to occur.

In each of these cases, much better results emerge when professional development providers go to the school and work directly with the teacher. More distant communication is always limited by the medium used. A curriculum diagram constructed together with the teacher can capture a visual representation of how the different program strands complement and reinforce each other, and mentored community explorations help teachers to see their community with new eyes, alert to the possibilities that are sometimes literally or metaphorically in their backyard. For example, teachers at one middle school in St. Louis knew of their adjacent urban park as a walking place, but they were unaware of the birding "hot spots" and the possibilities for building and maintaining geocaches in the park. Having gone out and done that exploration, the project staff and teachers jointly have those elements as real and tangible parts of the community, ready to be employed in their ongoing curriculum conversations. Similarly, work with another middle school in southern Missouri helped the teachers to see how landforms and land use throughout the entire watershed could be brought into a water quality investigation, instead of just testing water at the point closest to the school.

Thus, on-site support is an important tool for promoting teacher growth. When the workshop leaders can provide that it is ideal, but this isn't always a practical option, owing to the distance between the school and the workshop leader and the competing demands on the workshop leader's time. This is where local, school-based support is essential. Technical support for installation and data access issues is needed, as well as support for curriculum planning. Ideally, the workshop leader can contribute targeted expertise while working to build local capacity for ongoing support. This becomes easier if the larger school culture is receptive and multiple teachers and administrators from a school or community are collaborating.

Looking to the future, as social networking becomes more popular, we need to find ways to leverage the capacity of these tools to build and maintain communities of practice. In the example cited above of teachers' interest in local seismic activity, an ideal project web site would have links to local data, background information, and suggested inquiry paths. As the available tools become more powerful and social networking becomes more ingrained in popular culture, there are likely to be promising advances in how online teacher support can be provided. The open question here, of course, is how much time teachers are going to spend using these social networking tools for professional purposes. The Missouri Botanical Garden and the Massachusetts Institute of Technology are just beginning to explore this issue by working with teachers to create and use tools such as wikis for collaborative curriculum planning and blogs to record ongoing reflections. Our experience to date suggests that teachers may be willing to do this during a summer institute but that during the press of time during the school year, postings become a casualty of limited time availability.

17.3 Going 3D: Critical Teacher Capacities That Enable Geospatial Education

The dimensions just discussed concerning an effective workshop design and a supportive school culture are necessary conditions for success, but ultimately not sufficient. The teacher quality variable is generally unspoken in the geospatial education literature, but as the preceding discussion shows, it is an essential component of higher-level inquiries. To recap, the argument so far has been that effective geospatial teachers need to possess certain capacities (summarized in Fig. 17.2) relating to their knowledge, disposition toward learning, comfort with model-based inquiry, and ability to support and extend students' inquiries. This enables them to create a certain, nonroutine practice that promotes a higher level of thinking such as that captured in Gardner's "Five Minds" framework.

This framing of the issue implies both pedagogic and academic capacities that are – unfortunately – not universally held in the current teacher population. Based on more than a decade of experience leading geospatial teacher workshops and providing follow-up support, the author has found that teachers who fit the capacity profile advocated here are much more likely to thrive in a geospatial workshop and in turn achieve higher-quality implementation back in the classroom. Those who don't fit the profile won't magically grow to higher-level practice through exposure to GIS. Instead, a fundamental reorientation to pedagogy appears to be a prerequisite. At best, exposure to rich geospatial inquiry may be the catalyst that provokes a willingness to undergo this reorientation. Given how durable professional identities tend to be, such a change is more likely to be the exception than the norm.

Evaluation data from Local Investigations of Natural Science (LIONS), a program based at the Missouri Botanical Garden and funded by the National Science Foundation, shows this split clearly. In LIONS, classroom teachers were hired to run geospatially rich after-school programs investigating local environmental and cultural features. The intention was that this would allow teachers to teach from their passions and in a project-focused environment, countering a school climate that has become all too standardized and segmented. In addition to looking for high-quality after-school programs, the evaluation protocols were looking for impact back in the classroom. That is to say, does experience leading a project-based after-school program free of external curricular constraints lead to changes in a teacher's regular classroom teaching?

Initial teacher recruitment for the project was the responsibility of the partner district. With no particular selection filters put in place by the district, the teachers were offered a position if they applied. Since not enough teachers of any capacity applied to fulfill the grant targets, the project director recruited additional teachers both within and outside the partner district. These were targeted recruitments, going after specific individuals whose practice broadly exhibited the four capacity factors discussed previously.

The initial cadre of teachers exemplified the gap identified by Carol Dweck (2000) between those who saw their capacities as fixed (with several district-recruited teachers identifying themselves as “not being science people”) and those who saw themselves as learners capable of mastering new skills and content. As the project got underway, this split became quite evident in practice. Observation, survey, and interview data all indicated that teachers with richer, more academically challenging practice and who saw themselves as learners had higher levels of student engagement and higher-quality projects underway throughout the year. Teachers whose general practice was more of a passive rote-exercise, “follow the script” approach brought that into the after-school environment even though it was freed of the usual curricular and resource constraints. At these sites, projects would be started, but without passion. If time ran out on a project, it simply wasn’t completed. Virtually no detours were made from published stepwise curriculum projects. The geospatial angle to projects was limited to maps created as part of the published curriculum materials. Throughout, the teachers exhibited little passion to be learners themselves and equally little confidence in their pedagogic judgment, deferring to printed curriculum or suggestions from the project staff as to how to proceed. As is typical in an environment based on scripted curriculum, the learning environment was very routine: Each week tended to be very much like the previous one.

Conversely, teachers more actively committed to developing their own professional practice through LIONS grew over the course of the program to lead multiple, synergistic projects with a shared sense of urgency and commitment among the teachers and students. In a couple of cases, extra program sessions were scheduled to enable completion. Far from being scripted, teachers leading these groups generally integrated multiple published curriculum units with community resources to foster positive learning environments. In a sense, their practice embodied elements of Gardner’s Five Minds in that they pulled resources from specific disciplines, integrated them effectively, and created new experiences customized to the needs and interests of the participating students. Unlike their more passive colleagues, these more successful teachers drew on (and further developed) their capacity factors as they deftly stitched together resources to create a positive learning space. Their classroom environment was anything but routine, with each day’s work defined by what came next in the project flow. Geospatial applications included map readings, field explorations, creation and maintenance of their own geocaches, and formal GIS-enhanced investigations of trees in the schoolyard using ArcView and the CITYgreen extension from American Forests.

One example from the teacher workshops held in the second summer of the program makes this split in teacher practice particularly clear. A 3-day workshop was offered to all teachers, but there was no common set of dates that worked for more than about half the teachers. Their availability, coincidentally, fell into two clusters that also mirrored the split just described. Expecting that each group had different professional development needs, the LIONS staff ran the workshop as two separate sessions, anticipating that they would cover the same general terrain but at different levels of pedagogy. (While there is certainly some benefit to having participants in a group with mixed abilities, very few teachers were available for the "other" session, so whether they should have been mixed was a moot point.)

In the workshops, the teachers in the two groups confirmed what was observed of their practice to date. The less certain, passive teachers focused on preparing to use a new scripted curriculum that they enacted over the course of the school year at a skeletal level. As in the previous year, intellectual passion shown by the teachers was minimal, and virtually no quantitative or spatial data passed near the students. The higher-capacity teachers, on the other hand, shared insights with each other throughout the workshop on supporting multiple simultaneous inquiries and giving students ownership of projects. The most obvious manifestation of the differences between the groups came in their reaction to a new program option that became available when MIT became a project partner. In the spring of 2008 LIONS began partnering with the Scheller Teacher Education Program at MIT to develop augmented reality games on handheld computers. These games leverage the GPS technology built into some handheld computers to guide students in local investigations by displaying the student's current position on an aerial photograph of the game site. Imagine, for instance, being put in the role of an environmental detective looking for the source of water pollution in a local creek. When teachers in the summer PD workshops gained hands-on experience with the tools, the gap in practice couldn't have been more striking. Teachers in the first group asked if the project staff could "come and do these games with their kids." In practice, not one actually did arrange for project staff to do this, despite several follow-up reminders that it was a program option. The more certain, high-capacity teachers, having spent a good part of the first day of the workshop sharing experiences and techniques, didn't get to the augmented reality tools until quite late in the day. After a quite brief overview, they broke for the day. Upon returning in the morning, more than half of the teachers – without having had any first-hand experience with the tools – had already downloaded and installed the game builder software on their own and started exploring the possibilities.

Throughout the author's work on this project and in more than a decade of leading other geospatial workshops for teachers, there has been very little in the way of a middle ground. Teachers exhibiting more of the four capacity factors are certain of their pedagogy and lead intellectually rich classroom environments. The projects they undertake with their students promote many if not all of the dispositions Gardner describes as being essential skills for students to develop. Teachers who exhibit lower levels of these essential capacities are unlikely to move toward meaningful geospatial inquiry. Virtually no teacher has gaps waiting to be filled in their curriculum, and without the passion needed to move out of scripted, pro forma efforts, more substantive investigations aren't going to occur. At best, students will be given an opportunity to complete a printed tutorial. This is likely better than a textbook description of the phenomenon being investigated, but it is inherently limited. As these experiences represent a first effort with geospatial tools, much of the effort is focused on learning the software interface and working through the “newness” of the tool. For students in these routine environments, a day in the computer lab is almost certainly much better than a day in the textbook-driven classroom. However, as a short-term, scripted endeavor that is unlikely to be repeated in a student’s career, the net impact on students’ skill development will be modest at best. Not all instances of “doing GIS” in the classroom are equal.

17.4 Revisiting Professional Development and School Culture Influences

The ambitious agenda described in this chapter for fulfilling the promise of geospatial education won’t be realized easily. In fact, achieving it in the current structure of schooling or with the current teacher workforce is unlikely. The problem is systemic, and thus not amenable to a technical fix growing out of a new version of software or a better training workshop. With that somewhat pessimistic premise, this chapter closes with a few reflections on the tensions this model introduces and suggestions about how schools can be made more hospitable to rich student inquiry such as what is envisioned here.

First, great learning environments begin and end with the teacher as the primary architect. The past decade of efforts to standardize education has all too often eliminated the teacher from the equation in favor of an approach to education that can best be characterized as “transmission of knowledge.” Like a business model, certain predetermined packages of learning are delivered on a preestablished, system-wide timetable. The entire system is graded based on how well the ultimate recipient (the student) can reproduce on demand the contents from the metaphorical “packages” of knowledge he or she received from his teacher. Like concentric rings, the student, teacher, school, and district each receive grades based on students’ ability to recall and reproduce packaged knowledge. One curriculum management tool emerging from this approach is so specific that if a student does poorly on a tested concept, the database can be checked to see if he was absent on the day the concept was introduced. While most aren’t that obsessive in their tracking of students’ learning, the general thrust of controlled learning environments is clearly the dominant paradigm.

It is ironic that teachers are increasingly held accountable for outcomes they control less and less. Support for the nuanced judgment of the teacher is, in practice, devalued in mainstream education. It is a rare school district that actively supports a teacher in her efforts to know what her students need to understand and to act on this in designing the best way to frame learning experiences. Instead of excessive control and regulation, teachers need support in developing this wisdom – commonly framed as “pedagogic content knowledge,” or PCK for short (Shulman, 1987). A teacher armed with a strong base of PCK can make the judgments implicit in the model of education argued for here. This gives her the certainty of understanding that allows nonroutine but productive environments to flourish.

Specific to applications of geospatial tools in education, the emerging work in Technological Pedagogical Content Knowledge (TPACK) is particularly promising and valuable (Koehler & Mishra, 2008), as it works to extend traditional PCK to encompass the affordances and constraints of technology use in education. As noted by Makinster and Trautmann (Chap. 16), TPACK "creates an opportunity to explore the ways in which technology enables teachers to represent content differently while leveraging one or more pedagogical opportunities created by the nature of the technology." We need to continue building models of how best to integrate technology into the learning environment, extending the underlying insights through PCK work over the past 20 years.

More generally, we need to attract and retain in the profession teachers possessing the essential capacities described here, who are capable of leading productive geospatial investigations. The sterile and surface-level understanding commonly found in textbooks is insufficient. Instead, intellectual passion and depth of understanding are required to help students "get into" a field. This is where pedagogic content knowledge is critical. What hooks in a field grab a student's interest and invite more investigation? Which aspects are foundational building blocks that scaffold further understanding? The nuances of graduate-level work in meteorology may not be the most important things for a seventh grader to understand in his first experience studying weather patterns. At a more fundamental level, teachers (and in turn students) need to embrace the more active view of learning that Dweck articulates. "I can learn this" needs to replace the "I'm not a science person" or "I'm not good with computers" mind-set.

Along with helping students to *know* the most useful concepts in a field, teachers need the capacity to promote deep inquiry within the class so that students can see how these concepts *integrate*. Curriculum design needs to focus on how to structure students' investigations so that they build robust conceptual networks over time. These conceptual networks give students strong understandings within the discipline at hand and the ability to creatively synthesize among disciplines. Within geospatial education, these conceptual networks rely heavily on model-based reasoning as students build and interpret spatial and quantitative displays.

Finally, in guiding students toward exploring questions, we arrive at the heart of education. Drawing from its Latin root *educare*, to lead out, teachers guide students into new paths of investigation, promoting the development within each student the seeds of being a lifelong learner. Done well, geospatial education has this potential, enabling students to bring a spatial perspective to whatever fields they pursue in their future. As a first step toward building geospatial education past the vignettes of exemplary practice and into the mainstream, we need to work toward building, empowering, and nurturing a more powerful corps of teachers. Regulation, control, and standardization aren't the answer. Until a larger portion of the teaching profession is empowered to promote high-level geospatial inquiry, we need to work optimistically and incrementally, making change where we can and working to reform the system so that more teachers and students can flourish.

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Chapter 18
What Happens After the Professional Development: Case Studies on Implementing GIS in the Classroom

Robert Kolvoord, Michael Charles, and Steve Purcell

Keywords Case studies • GPS • Project-based learning • Apple's Classrooms of Tomorrow (ACOT)

18.1 Introduction

Trying to master technology is like shooting at a moving target; Moore's Law suggests that the information processing capacity of modern computers doubles about every 18 months (Moore, 1965). It is no longer possible for one to know all there is about technology given technology's propensity to change so quickly. A set of skills learned 1 year may serve teachers well for 1 or 2 years, but those skills can quickly become outdated in as little as 3 or 4 years. As cellular phones, digital cameras and camcorders, computers, GPS navigation units, and other electronic devices become more commonplace in consumers' lives, today's students have mounting expectations that these devices (and more) will debut in tomorrow's classrooms. The implication is that teachers will not only recognize these devices but also have a plan to effectively utilize them to promote inquiry, learner engagement, collaboration, and problem solving in their classrooms.

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In our roles as both teachers and technophiles, we are engaged in ongoing conversations about technology's role in learning and teaching, and we understand it takes time for technology's impact to be realized in the classroom. Of this, Cuban (1996) writes:

> This persistent dream of technology driving school and classroom changes has continually foundered in transforming teaching practices. Although teachers have slowly added a few technologies to their repertoires, techno-reformers have seldom been pleased with either the pace of classroom change or the ways that teachers have used new machines. (p. 3)

Time alone, however, is insufficient cause for cultivating and sustaining change; reform efforts must be accompanied by intentional activities that scaffold teachers' design, development, implementation, and assessment of technology-based tools that hold significant potential and appeal for enhancing student learning. Our contribution to that effort is represented through our teacher professional development initiatives: VISM (Visualization in Science and Mathematics, 1999–2004), GODI (Great Outdoors, Digital Indoors, 2001–2004), GRASP (GIS/GPS Related Activities for Student Progress, 2005–2007), and Rural STEM (Science, Technology, Engineering, and Mathematics, 2005–2009), along with a unique dual-enrollment effort with high schools focused on GIS called the Geospatial Semester (2005–present). Each of these projects focused on national or regional audiences and featured geospatial technology as the centerpiece (VISM included other tools with a broader focus on scientific visualization).

In each project, teachers came to James Madison University (JMU) for face-to-face workshops, and we provided additional follow-up support in the succeeding academic years. While each project had a slightly different focus, the teachers all had an opportunity to learn about geospatial technologies and their classroom applications. In each project we have done long-term follow-up to learn more about how teachers integrate geospatial technology into their classroom. As we describe below, we are beginning to see deeper pedagogical implications that speak to active, engaged learners who are involved in authentic, inquiry-based problem solving. Such methodologies promote informed decision making, collaborative problem solving, and multisensory/multimodal learning opportunities. Selected teachers who participated in these projects are the subjects of the case studies in this chapter.

18.2 Theoretical Framework

According to the National Staff Development Council (NSDC), teacher professional development may be an important factor that can impact student achievement (NSDC, 2006). Much of what is held up as technology training for teachers distills to one-shot interventions that focus more on mouse clicks, keystrokes, and menus than on substantive considerations of how to teach with technology. Before- and after-school training models represent reasonable responses to the rigid structure of school days, yet they often lack a context that sets technology utilization within considerations of student learning. Software and hardware training are important first steps, but their value is best realized when they are coupled with sustained opportunities for teachers to create products, to collaborate with peers, and to reflect upon their successes and challenges within the parameters of their classroom, content, and learners.

The design and implementation of our teacher professional development efforts were influenced by the historical research on Apple's Classrooms of Tomorrow (ACOT) program. The ACOT model is a widely recognized taxonomy of the stages through which teachers progress as they integrate technology in the classroom. We viewed the ACOT model as a reasonable framework on which to examine and advance the evolution and progression of teachers' utilization of geospatial tools that might lead to a more contemporary climate of change – one that is commensurate with the potential these tools bring to bear on authentic, inquiry-based learning.

The ACOT program was a "research-and development-collaboration among public schools, universities, research agencies, and Apple Computer" … that "set out to investigate how routine use of technology by teachers and students would affect teaching and learning" (Sandholtz, Ringstaff, & Dwyer, 1997, p. 3). While much of the early ACOT research focused on student and classroom changes, the Stages of Concern (Sandholtz et al.) was an attempt to examine the transformation in teachers who utilized technology in their classrooms along a continuum of five stages. Teachers, they note, progress through various stages as they become more familiar with technology and move towards more learner-centered, constructivist approaches to instruction.

In applying this model to the question of teacher success in incorporating geospatial tools, we posited that teachers would go through a similar set of stages in adopting these new and relatively advanced technological tools into their own practice. Our interpretation of the ACOT framework for geospatial technologies in the classroom identified four stages of tool use by teachers: *Entry, Adopt, Adapt,* and *Innovate* (Charles & Kolvoord, 2003). A model was developed called the VISM matrix which applied the four stages to four different kinds of scientific visualization tools resulting in a table of activities that were representative of the four stages. It was proposed based on conversations with the instructors over the duration of the VISM project and updated in successive years of teaching the workshop as the instructors gained additional experience teaching the tools to practicing teachers.

Entry describes a level of competence with the tool and ability to apply it at the workshop and during any follow-up sessions. *Adopt* means that the teacher has taken a lesson/activity prepared by someone else and implemented it with little or no substantive change with students to teach a content-based lesson. *Adapt* implies that the teacher has taken a lesson/activity prepared by someone else and made substantive changes to it to meet their particular classroom needs. *Innovate* means that the teacher has created original activities/lessons to meet a classroom objective. In the case of geospatial technology, we consistently found that Innovate meant that teachers created their own project using an original data set/source. We further describe some of these projects in the cases below.

The above categories were employed to describe and consider how teachers used scientific visualization tools in the years subsequent to their initial workshop experience and to track the stages of teacher development in using that technology. The focus was not necessarily that all teachers should move to the Innovate stage; effective adaptations of the tools in such a way that student learning was enhanced were equally valued. We proposed this as a path that teachers might follow based on the ACOT model and then compared that to our actual experience over the years.

18.3 Prior Assessment Work

Post-workshop assessment data from the various projects indicated that all of our teacher professional development efforts were well-organized learning experiences that were highly valued by the participants. The programs' leadership, instructors, instruction, and tools all earned average ratings of 4.5–5.0 on a 5-point scale. We surveyed Project VISM teachers' use of the tools using the VISM matrix mentioned above. We collected surveys from about half of the 118 VISM participants responding 2 to 5 years after the workshop, and we conducted interviews and/or 1-day classroom visits with 25 % of the teachers. Because some of the participants had retired from teaching by the time of the follow-up surveys and interviews, the response rate from teachers still active in the project was higher: over 55 % for the surveys and nearly 30 % for the interview/visits. Surveys were also conducted for GODI, GRASP, and Rural STEM – both pre- and post-workshop as well as one or more years out from participants' initial training. From these assessments we know that use of the tools was widespread. More than half of the VISM respondents used at least one of the tools at the *Adapt* or *Innovate* level. Those who only *Adopted* the tools can be divided into those who *Adopted* one activity and those who *Adopted* several activities – the latter being a wider application of the tool.

Of the four tools taught to the participants in the VISM project, geospatial technology was the one most used. Data suggested that this was because of the power of geospatial thinking to be applied across the curriculum. At the workshop, teachers informally noted the wide applicability of geospatial technology as compared to the other tools. We also noted the availability of training resources for geospatial technology beyond the project for continued professional development. Rural STEM participants were to implement four to six activities during the subsequent school year. No stipulations were placed on the level of sophistication of the activities, recognizing that participants had varying levels of knowledge and experience with both technology and teaching. Eighteen months after they completed their initial training, all Rural STEM participants had implemented at least one geospatial activity, and six (30 %) had achieved the target 4–6 activities.

In the surveys, teachers consistently noted developing further skills in geospatial technology without project-related follow-up. Two to five years after the workshop, more than four times as many VISM teachers (42 % of the active teachers) said that they were more or equally competent with geospatial technology than those (9 % of the active teachers) who said they were less competent with the technology compared to the end of the workshop. Those who had improved their skills had purchased classroom-ready curriculum support materials that make use of geospatial technology, attended additional workshops focused on geospatial technology, or revisited workshop notes. GODI, GRASP, and Rural STEM teachers all reported making changes in their classroom teaching as a direct result of their participation in the program, with three-quarters reporting that their participation had improved their teaching methods.

Across all programs, teachers consistently noted obstacles to their use of the tools. First and foremost was the lack of time to develop classroom-ready activities and sufficient space in the curriculum to teach these new activities. The demands of the federal No Child Left Behind legislation and high-stakes testing were obstacles to implementing geospatial technology projects. Other significant obstacles were changes in teaching assignments and personal life and changes in hardware and software access at their school.

Teachers also noted indirect effects of their professional development experience. Ninety-seven percent reported being better equipped to learn and use other technology tools or resources besides geospatial technology in their teaching as a result of participating in the VISM workshop. Seventy-one percent reported that it raised their status in school and/or district as a technology leader. Seventy percent of GODI participants indicated they either revised or restructured their existing content, 75 % introduced new technologies into their classes, and 63 % increased their use of existing technologies.

The results from these surveys and follow-up interviews have clear limitations. They rely on teacher self-report data, there was no use of a random sample group design, and there is no direct student learning data. However, they start to outline the impact of our professional development initiatives. In the next section, we highlight the work of seven teachers to explore in detail how the tools introduced in the workshops play out in the classroom.

18.4 Teacher Case Studies

In this section, we feature in-depth looks at teachers from the different professional development projects and explore the evolution of their classroom use of geospatial technologies over time. The teachers were selected to represent a range of grade levels and geographic regions as well as interesting cases of implementation of geospatial technologies (Table 18.1).

Teacher #1 (GODI and GRASP) – Teacher #1 teaches at a rural high school near a small city in Virginia. He has taught Ecology for 7 years. He graduated from a major research university with degrees in Psychology and Biology and then moved on to a Master of Teaching in Science Education. While Teacher #1’s training was focused on Biology, he was assigned to teach Ecology and decided he wanted to “break out of the worksheet world” that was the primary pedagogy for that class.

Table 18.1 Summary of case study teachers

Case	Gender	Years of experience	Discipline	Grade level	Location	Level of use[a]
1	M	7	Ecology	High school	Rural – VA	I: geospatial projects
2	F	10	Social studies	High school	Rural – VA	I:geospatial projects
3	F	8	Biology and earth science	High school	Rural – VA	I: geospatial projects
4	M	28	Technology education	Middle school	Rural – NY	A: geospatial activities
5	F	16	Science	Middle school	Rural/urban – PA and VA	A: geospatial activities
6	M	30	Science and technology education	Middle school	Suburban – IN	A: geospatial activities
7	M	30	Geoscience	High school	Urban/suburban – AZ	I: geospatial projects

[a] "A" refers to *Adapt* and "I" to *Innovate*

A year after he began teaching, a colleague suggested that Teacher #1 participate in the GODI project to learn about geospatial technology. Teacher #1 saw the workshop as a hands-on opportunity to learn new technologies. He particularly liked the focus on GPS and curricular lessons applied to Shenandoah National Park. He perceived the professional development as focused on case studies and with components that would easily fit into his classes. The lab-related focus gave him possibilities for things that his students could do rather than "read and watch." His reflection was that the tools he learned offered "a blank canvas and more paint."

Teacher #1 employs strong project-based focus in his classroom. In frequent classroom observations, his students are engaged and able to work independently using the technology tools. Teacher #1 has created an innovative series of projects for the teachers and is clearly in the *Innovate* stage of use of geospatial technology. In the subsequent year, Teacher #1 received some district funds to purchase GPS units and he began to implement the tools in his classes. During this year, monthly follow-up sessions with the GODI project helped Teacher #1 retain his enthusiasm and allowed him "to venture out of the shallow end" in using the tools.

Teacher #1 was later involved in two other projects (one in American Studies and another at the University of Kansas) through which he continued to build his skills. He also transitioned to ArcGIS 8 during this time period, making him feel like he was staying up to date with the tools. At this point, Teacher #1's skills were significant enough that he was asked to contribute as an instructor to a statewide professional development effort in geospatial technology, conducted in parallel with the adoption of a statewide site license for ArcGIS. He also participated in Project GRASP. At this point, he felt that his technical skills were strong and his classroom applications solid, but helping to teach others allowed him to continue to hone his teaching skills.

His classroom application evolved to participation in the Geospatial Semester, a dual-enrollment effort between high schools and James Madison University. Students learn about GIS and conduct locally based projects using GIS and earn college credit as they finish their high school degrees. This new effort at his school allowed him to create and teach a year-long class that focused solely on geospatial technology and enabled students to pursue extended geospatial projects. He has participated in this project over the past 3 years. His students have done high-quality work, including a project for the Nature Conservancy exploring the permeability of land in sub-watersheds in Albemarle County.

In thinking back on his geospatial technology professional development (PD) experiences, Teacher #1 had the following thoughts:

- Follow-ups are critical to combat atrophy, to try new things, to keep technical skills sharp, and to avoid the "appetizer only, no dinner" syndrome. That is, you don't get enough in a workshop to fully implement a new tool/technique.
- In PD workshops, the balance between instruction and time to experiment is critical to avoid the "cookbook mentality." This dichotomy is needed and important.
- Overarching projects showing connections and offering a continuum of ideas are critical.
- The opportunity to keep learning in follow-up sessions is of utmost importance.

Teacher #1's burgeoning geospatial technology skills have led him to leave full-time teaching to take a GIS position in an environmental engineering company. His company has integrated part-time teaching (the Geospatial Semester) as a part of his position, in part to support continuing professional development. This highlights an interesting difference between the software training typically found in industry and the broader emphasis on professional development in K-12 schools.

Teachers #2 and #3 (GRASP) – Teacher #2 teaches at a rural high school in an isolated valley in Virginia. She has taught for 10 years at the same school, primarily in Social Studies (World History, US History, Sociology, Economics, Geography, and now GIS). She majored in History and Political Science and minored in Education at a small liberal arts college.

Teacher #3 teaches at a rural high school (different school, but the same district as Teacher #2) in an isolated valley in Virginia. She has taught for 8 years at the same school, primarily Ecology, as well as Biology and Earth Science. She majored in Biology and minored in Philosophy and Religion at a small liberal arts college. She also completed all of the education minor except for student teaching. She worked for a couple of years in the banking industry prior to taking a teaching job.

Teacher #2 and Teacher #3 have known each other for most of their lives and are long-time friends. Teacher #2's first geospatial technology professional development was in a community college class that she took for personal interest and for professional recertification credit. There were other teachers in the class and she enjoyed the experience but did not implement the technology in her teaching because the software was not available at her school at the time.

Teacher #3 had no prior geospatial technology experience. Parent and administrative interest led to a desire to adopt the Geospatial Semester. Due to their experience and project-based focus (see below), Teachers #2 and #3 were solicited to offer the course and despite concerns about not having enough knowledge/background, they agreed. Teachers #2 and #3 agreed to participate in professional development (GRASP) to prepare for offering the Geospatial Semester.

Both Teachers #2 and #3 have a focus on project-based learning. They emphasize hands-on learning and both wanted to offer a course that would offer an alternative to the highly constrained Virginia standards-based courses predominant in their schools. Teacher #3 reported that her classroom style is based on the philosophy that "kids learn more by doing."

Teachers #2 and #3 joined the GRASP PD workshop midway through the year. In this particular set of workshops, teachers completed an initial 2-day introduction during the late summer, attended monthly follow-up sessions, and finished with an extended, in-depth 3 days of classes during the following summer. While these teachers missed the introductory portion of the workshop, they were highly motivated to catch up as they were preparing to offer the Geospatial Semester classes in the following year.

Regular biweekly classroom observations and student work products have shown that both teachers have been extremely successful in the Geospatial Semester. In observations of their classes, they have created a powerful project-based learning environment and their students have both built solid technical skills and applied them in community-based projects. In fact, Teacher #3's students won the statewide mapping contest in 2008 sponsored by the Virginia Association for Mapping and Land Information Systems (VAMLIS).

Teacher #2 reports that the process has been exciting and that she has developed a comfort level with instilling in her students a willingness to experiment. She's found that students don't lose respect when she can't provide answers, but rather appreciate her honesty and are excited for the opportunity to work together.

Teacher #3 reports that she appreciated the follow-up support that was available via e-mail and visits. She also noted that her comfort level was increased by her perception that the workshop instructor was someone with whom she could work. She reports that the GIS class is the one class in which she felt like she knew the least but was comfortable admitting ignorance. She also felt like the students saw her modeling lifelong learning and the fast-changing world of technology.

At the end of the professional development workshop, participants had to develop lesson plans to integrate geospatial technology in their classes. Teachers #2 and #3 asked if they could develop a plan and pacing guide for their Geospatial Semester class. Both report that developing this plan was a huge support in going through their first and second years of teaching the class.

The two teachers remained in regular contact, conducted joint projects, and offered each other support with technical snags. Teacher #2 reported that ongoing support from JMU was important, as was the technical and administrative support in her school. She feels that her efforts are valued and the school is willing to support the effort (even in situations with slightly lower enrollment).

Teachers #2 and #3 both started in the *Adopt* stage but moved within the first 6 months to the *Adapt* stage and were beginning to *Innovate* at the end of their first year. In their second year, they continue to work at all three stages (*Adapt, Adopt, Innovate*) in different parts of the class and as needed. Their student projects are clearly in the *Innovate* stage.

Teacher #4 (Rural STEM) teaches in a rural middle school in central New York. He has taught for 28 years. He initially earned an Associates Degree and worked in the business world for 6 years before returning to a regional state university in New York for a degree in Industrial Arts and then later a Master in Technology Education. He has worked in the same district for his entire career, except for 1 year serving as a professional developer for a regional consortium and another year as a curriculum developer for a local nuclear plant. His entrée into geospatial technologies was when his wife bought him a GPS. He was very interested, but never quite figured out the GPS. He saw an e-mail solicitation regarding the Rural STEM workshop and it piqued his interest. He had lots of prior experience with professional and curriculum development, but no real sense of geospatial tools.

Teacher #4 found the Rural STEM summer workshop experience to be valuable and challenging, reporting that at times his “head was spinning.” He was particularly engaged with the social interaction with teachers from across the country. Teacher #4 did not immediately implement the technology upon returning home, but rather took a very different tack. He began a series of activities to be an advocate for the technology in his home district. He began by writing a grant for additional GPS units and by meeting with his superintendent who supported a regional conference visit. He also made a cold call to the GIS instructor at a local community college that led to the development and offering of a 2-day workshop by the community college for teachers from his district.

This all happened prior to Teacher #4 having used the technology with his students. In fact, challenges getting the software installed meant that his GPS-based activities were postponed until the spring of the first year. However, these activities were at the *Adapt* level with novel elements. Teacher #4 saw the first year as an introduction, and he finished it by attending additional professional conferences.

Teacher #4 participated in a summer follow-up workshop at JMU and then returned home to do presentations at a professional conference, return to the local community college for additional training, and organize and lead a curriculum development workshop for his district in his second year of implementation. While the quality of the output from the workshop was quite variable, he felt that it was an important experience for teachers in his district.

Teacher #4’s main focus in the fall of the second year was in organizing and executing a “GIS Day,” a day-long event at the school involving all the students and 17 staff members, along with GIS professionals, community members, and representatives from local government. This activity was part of the work that Teacher #4 did to “plant the seed” and build awareness. In the spring, he worked with 6th grade gifted students to do a Geospatial Enrichment class and along with the GPS activities, started to implement geospatial technology. The activities were both at the *Adopt* and *Adapt* stage. During this time, he also worked with the local community college and a high school teacher to set up an articulation agreement so that a GIS class taught at the high school could earn college credit.

At the end of the second year, he again returned to JMU for a follow-up session. He also continued his conference attendance with a visit to the ESRI International User Conference and work with a local institute. He again organized professional development for teachers in partnership with the local community college. The largest effort was devoted to leading a professional development group that planned, organized, and executed a staff development day devoted entirely to geospatial technologies. Each teacher in the district was introduced to geospatial technology in a staff development day in October.

As the new school year began (year 3 after the workshop), Teacher #4 again organized GIS Day, though a smaller version than the previous year, executed the professional development day listed above, and expanded his geospatial technology teaching to 5th and 8th graders as well as to more of the 6th grade class. The GIS activities continue to be at an *Adopt/Adapt* level and the GPS activities are at an *Innovate* level. He continues to mentor fellow teachers and act as an advocate for geospatial technologies in his district. He is also helping to develop some GIS-based alternative energy curricula but has yet to use them in his classroom.

Teacher #5 (Rural STEM) has taught for 16 years in both Pennsylvania and Virginia at all grade levels, though most of her experience has been at the middle school/junior high level. She has primarily taught science, though much of her work has been in special education classrooms. She holds a B.S. in Elementary and Special Education from a land grant university, as well as a certification in high school Earth Science in Virginia. She is currently pursuing a Master's degree in Geosciences. Her previous teaching job was in a middle school in a rural county in Virginia where she taught science for 5 years in a regular classroom. She moved and changed positions this year and is currently teaching high school science in an inclusion classroom in an urban high school on the other side of Virginia.

Teacher #5 came to geospatial technologies accidentally. She attended an NSTA conference and chose to go to a keynote session being given by a faculty member in the department at JMU where her son had just matriculated. The technologies demonstrated in the session captured her attention and got her extremely excited. At the same conference, she attended another session about geospatial technologies from a group that offered to bring training sessions to districts. She returned to her district determined to get this training offered locally. She worked very hard to convince administrators to sponsor this free workshop and a year later, the initial workshop was offered.

Although the district workshop was of high quality, Teacher #5 reported that it was too short and lacked any sort of follow-up, leaving her too confused to even ask questions. She described the initial exposure to geospatial technology as being comparable to learning a foreign language. Three days offered too little time to "digest and apply" what she had learned. This also was the case for her fellow teachers, most of whom donated their workshop materials to Teacher #5 in a clear expression of their unwillingness to incorporate this technology in their teaching.

Teacher #5 was able to make a few simple interactive maps to illustrate a concept about aquifers. This was an *Adopt* level activity and she had some success using these with her students. She recognized that the technologies offered much more, but she felt that she didn't understand enough to move forward.

She heard about the Rural STEM workshop in a visit to JMU to see her son and got very excited about participating. She found the summer workshop experience to be intense, reporting that at times it "hurt her brain." However, the experience gave her the confidence that she could in fact become facile with the technology. She found the level of detail both challenging and very good as it gave her a sense that she understood what was going on instead of the technology being a black box. Teacher #5 enjoyed learning about the use of GPS units and made their use a priority for classroom implementation. She invested significant time practicing with GPS between the midsummer workshop and the start of the school year.

Upon returning to school, Teacher #5 wrote and won a local grant to obtain more GPS units to use with her students. In the succeeding school year, she used those GPS units (typically in *Adopt* or simple *Adapt* activities) as well as Google Earth. She recognized that it was "not quite" GIS, but it served her classroom needs and allowed her to promote the technology with fellow teachers. She implemented a couple of GIS activities focusing on tornados and energy use, with the help of a visit from the Rural STEM instructor. Positive reaction by the superintendent who visited her class that day led to some additional support for the teacher. These activities fall in the *Adopt* mode.

Teacher #5 returned to JMU for a summer follow-up workshop. She came with greater confidence than in the earlier session, along with determination to increase her skill level because she realized that she was not yet skilled enough to do her own lesson design. She felt that the follow-up offered her the time and support to solidify her knowledge.

In the succeeding school year, she dramatically increased her use of geospatial technology, bringing in lessons that had been developed for the Rural STEM project, as well as activities from the Mapping Our World book (Malone et al., 2005). She was firmly in the *Adopt* stage for GIS and moved on to the *Adapt* stage by harvesting pieces of lessons and combining them into new activities. She also organized a GIS Day for her school.

In thinking about her students' work with GIS, Teacher #5 reports that she found that her sixth graders had moved to a much deeper level of thinking about the content that she was teaching. The visualization tools brought them beyond a surface understanding of the concepts to consider the application (she described the example of thinking about the elevation around her school and how it impacted water flow). The students' questions and thinking had changed to such an extent that Teacher #5 felt that her content knowledge in Earth Science was perhaps inadequate to the task, and she enrolled in a Master's program in Geosciences to help build her content knowledge (and apply geospatial technology).

Teacher #5 again returned to JMU for a follow-up session in the summer, but distractions in her personal life prevented her from getting as much out of that session. She changed jobs and districts the following year, which severely impacted her use of geospatial technologies. In her new high school job, there was much less support for taking students outside to do GPS-based activities and there were no Windows-based computers on which to do the GIS activities. She returned to the use of Google Earth on the Macintosh computers that were available, and she has joined another professional development project (CoastLines) which offers a Mac-based GIS package.

Teacher #6 (VISM) teaches at a relatively affluent suburban middle school of about 900 students near a medium-sized city in Indiana. He earned a Bachelor of Science from a regional university, a Master of Science from a major research university, and is currently completing a graduate certificate program in administration and technology from Johns Hopkins University. He has taught for 30 years, and for the past 8 years, he has taught a course that he was pivotal in creating called the Integrated Solutions Block (ISB). In 8 periods a day, he team teaches a total of 950 6th, 7th, and 8th grade students each week. His classroom is a unique computer lab with over 100 computers in a school that emphasizes twenty-first-century workplace skills. Throughout the school, students work collaboratively on projects and tasks with the guidance and assistance of the teacher. Project-based learning has been implemented across the staff and across the curriculum. As part of his job he facilitates multi-teacher interdisciplinary projects with all three grade levels.

Teacher #6 began his use of scientific visualization tools by taking an image processing workshop in the 1990s. He *Adopted* and *Adapted* activities from that experience into his classroom such as determining velocities of model roller coasters using digital images. He also attended a prior training for geospatial technology but gained little competency with using ArcView. Prior to the Project VISM workshop, his students completed an interdisciplinary project in which they presented a business plan to their peers for a start-up company in a Southeast Asian country.

Teacher #6 began the VISM summer workshop with a rationale for using the tools based on technology's potential both to motivate students and to help them connect with real-world problems. By the end of the workshop, he added to his rationale the idea that these tools allow students to see abstract ideas at a concrete level and to engage in higher-level thinking. Five years later his rationale was even more developed, including adding the idea that technology can enable students to do inquiry-based investigations. He described his workshop experience very positively and began to *Adopt* and *Adapt* geospatial technology activities into his ISB class (required of all students at his middle school). Sixth grade students completed a study of the Earth using the Internet, Excel, and geospatial technology to learn about the earth, its demographics, and geography. Seventh grade students downloaded recent earthquake and volcano data from the USGS website, displayed it, and drew conclusions about plate tectonics from the map. Eighth grade students used geospatial technology to research through a US government database to learn more about states and their capitals using census data.

Teacher #6 also *Adapted* work from other technology projects into his classroom. For example, his 6th grade students worked in cooperative groups to design a Rube Goldberg machine that applied their knowledge of simple machines. In one observation, about ten engineers from General Motors joined the students for a

90-min session to assist the students' work, and ten homeroom teachers worked together on this with Teacher #6 coming in to their class to support the project.

When asked prior to the workshop about what obstacles he faced in implementing geospatial technology, Teacher #6 cited a lack of teacher knowledge of the tools and a lack of well-designed curriculum materials that use the tools. Following the workshop he added a concern about a lack of space in a crowded curriculum. Five years after the workshop, he restated that time is the key obstacle, both to learn the tools and to prepare activities. He stated that there is little time to really prepare technology-enhanced lessons except through various professional development workshops he has attended. He stated that the other obstacles were gone: "The computers are here, curriculum integration is here, connections to Standards are here without being a constraint."

Five years after the workshop, his skills with geospatial technology had improved. Most participants reported a similar gain in skill even though the project had offered only one 3-day follow-up workshop a couple of summers after the original 3-week workshop. Teacher #6 learned more about geospatial technology using books, and he explored the ESRI website and its related tutorials to better understand ArcView. He applied for and received several grants from a leading global technology services provider delivering business solutions to its clients and a major electronics retailer to connect ideas with GPS and geospatial technology. He purchased GPS devices and began to integrate data from those into geospatial technology projects. Working at the *Innovate* level, he demonstrated relationships and developed activities relating data on the GPS device with geospatial software.

Teacher #7 (VISM) teaches at a small suburban high school in a large city in Arizona. He earned his B.S. in geosciences at a technical institute and then added his secondary teaching credentials from a major research university where he later earned his Master's degree. He has taught for 30 years, for the past 8 years on the faculty of a small comprehensive high school of about 160 students located in an industrial park that allows the school to capitalize on business relationships and connects students to possible future careers. Class sizes average 20 students, and the school website states that the "school and staff provide a challenging academic curriculum that emphasizes science, technology, engineering, mathematics, and business with opportunities to apply knowledge in real-world settings." He currently teaches chemistry, forensic science, and conceptual physics, and he leads a robotics club. He began his use of scientific visualization tools by taking a month-long image processing workshop early in the 1990s. He helped develop activities that used image processing in teaching mathematics and science and eventually left the classroom for 5 years to be the project director for a nonprofit organization that promoted computer-aided visualization as a tool for inquiry-based learning.

He participated in Project VISM as he was returning to the classroom. Prior to the workshop, he was already using geospatial technology at the *Innovate* level and had helped develop geospatial technology activities for other teachers as a project director. A year following the workshop, he reported that he had further developed his skills at innovating with those tools. He described his use of ArcView in his environmental science class as "from the first week of school to the last week."

One major project they completed addressed a question that had been in the local news. During the summer a number of illegal immigrants had died not far from his school while attempting to cross into the United States from Mexico. A policy proposal resulting from this event was to place watering stations out in the desert to prevent future tragedies. He and his students created a map in ArcView and examined the potential effect of these watering stations on the safety and health of the immigrants. They then used a teacher-created simulation that modeled the flow of immigrants with and without watering stations. Their conclusion was that establishing watering stations would most likely not help the plight of the immigrants based on the proposed locations. This activity took 5 weeks to develop and 2 weeks to complete. A second ArcView project was researching and mapping the flow of goods and people at six border crossings between Arizona and Sonora. They eventually published their work as part of an online electronic atlas (eAtlas). His class was invited to participate in this project by one of the sponsoring agencies. Students researched specific economic indicators and created ArcView maps based on their research. The data included things such as the flow of goods and people at six border crossings between Arizona and Sonora. The class's contribution was part of a larger economic database. Using ArcView they created a map with themes that displayed this information.

Teacher #7's use of geospatial technology tools has continued over subsequent years, and he has shared his geospatial technology expertise with his colleagues in his small school. Elementary teachers were trained in basic mapmaking and use it with their students. He is using geospatial technology in his Forensics class, *Adopting* an activity about crime in Houston. Next year he plans to have students do a forensic study on the immigrant deaths – from finding a body, measuring the bones to decipher gender and height, and plotting real and fictional data on a map to find where they came from. He has become involved in doing Partners in Science projects in the past, and in the next year he plans to work with students to determine the best places to start a prescribed burn in a nearby mountain range. Results will be used to make another forensic case study of a fire, using maps to trace it back to the origin and determine if it was caused by human activity or by lightning.

A number of factors have supported Teacher #7's exemplary use of visualization tools. His prior expertise in using these tools on a regular basis in his teaching was critical. The eAtlas project happened in his classroom because of his prior contacts with the local university's office for K-12 partnerships. As a teacher he talked about how he sees the relevance of geospatial technology mapping activities in everyday news items and has a strong interest in drawing that into the classroom to help connect scientific learning with current events. The immigrant studies and forest fire forensics are examples of this. When asked to describe how he was able to keep his skills sharp in using these tools, he stated, "To learn the tool, I teach students with the tool." His "use it with my students or I'll lose it" attitude tolerates a fair amount of uncertainty in the first use of the tool, which is ultimately critical to its successful use.

The lack of teacher time to prepare quality lessons and the increasingly crowded curriculum were seen as the major obstacles that teachers face in using the tools. For this experienced and successful user of scientific visualization tools, professional development opportunities like Project VISM were a place to develop his teaching craft knowledge as well as learn new tools. Even as an accomplished computer user, Teacher #7 found himself gaining increased confidence with the computers and the tools, and encouragement from the other teachers to use it in the classroom. Participating in Project VISM made him think "Yes, I can do this with my students." When asked his rationale for using the tools with students, he was very clear in his response: they are engaging for students. It involves them and puts them into the problem. These tools allow for activities that can be adapted to current events so easily – in some cases right from this week's headlines.

18.5 Recommendations for Practice

A key predictor of successful implementation of geospatial technology projects is that prior to the workshop teachers can describe other projects (with or without technology) that they had implemented with their students that accomplish district curriculum goals. Thus, the innovation involved in using geospatial technology was as much facilitating project-based learning as it was the employment of advanced scientific visualization tools. We see this both in earlier survey and interview data and in the cases described above. Teacher #1 had a strong project-based focus in his classroom prior to the workshop. Teachers #2, #3, and #5 describe a project-based approach in contrast to typical science and social studies offerings in their state. Teachers #4, #6, and #7 showed clear evidence of project-based learning skills prior to workshop. Because geospatial technology lends itself best to scientific projects more than isolated activities or exercises, prior experience in doing projects that accomplish district curriculum goals is critical to whether teachers can successfully use geospatial technology.

Others have recognized that "Investing in long-term professional development goals…means relying on the professionalism and expertise of each teacher, not only in the areas of content and pedagogy, but also in the appropriate use of technology" (Bowe & Pierson, 2008, p. 11). We would state further that effective teacher professional development initiatives should be informed by the idea that teachers construct their own unique program for professional development (Charles & Kolvoord, 2003) while acknowledging that this development takes place in a system which is "superficial and fragmented" (Ball & Cohen, 1999, p. 5). This program is initiated by the teacher and is based on his or her goals and intrinsic motivation to create a better classroom. This is in contrast to the extrinsic motivation common in staff training mandated by districts or schools and driven by organizational mission and goals. All seven of the case study teachers described above have used geospatial technology over an extended period of time to support the goals of their curriculum. Over time we have evolved more effective follow-up support, but all seven teachers also showed an ability to construct their own programs.

Teacher #1 experienced sustained follow-up support in the GODI project, but he also developed his skills on his own initiative through two other projects

(American Studies and the University of Kansas project). He became an instructor for statewide professional development in geospatial technology and eventually was involved in the Geospatial Semester. Teachers #2 and #3 also adopted the Geospatial Semester, but they also joined the GRASP PD experience, making up for missed sessions. They were intrinsically motivated to improve their classroom. Teacher #4 resolved some of his confusion about geospatial technology following the first workshop identifying a local community college instructor for support in using the tool and then attended more follow-up sessions. Teacher #5 first attended a couple of geospatial technology sessions that were not highly effective, but eventually found the right PD sessions (Rural STEM with follow-ups) to apply the ideas of geospatial technology to a tool she finds easier to use and more appropriate for her students: Google Earth. Teacher #6 was involved in a workshop that provided limited direct follow-up, but he has purchased books, used website tutorials, and been awarded grants from local businesses to better connect GPS and geospatial technology ideas. Teacher #7 also was involved in the same project with limited direct follow-up, but his prior work developing geospatial technology curriculum, his involvement with other projects that use geospatial technology such as the immigrant studies and forest fire forensics, and even his use of the tools with his students have all further developed his skills.

It is possible that only teachers in categories Rogers (2003) refers to as *Innovators* and *Early Adopters* are likely to construct their own intrinsically motivated program for professional development, whereas teachers in Rogers' *Early* and/or *Late Majority* category need more of a staff training approach. The survey and interview data we have received are more likely to have captured the work of *Innovators* and *Early Adopters* of geospatial technology. But that is not true of all of the cases described. Three of our seven cases (Teachers #2, #3, and #5) are from teachers whose technology skills are not as advanced as the others. However, their students effectively use the tools due to the teachers' familiarity with project-based learning tied to district standards. They may be more typical of teachers in the *Early Majority* of teachers using geospatial technology, and they too have constructed their own unique program for professional development.

Employing geospatial technology often involves curricular innovation, even for those who do project-based or inquiry-based science. Such innovation can be severely constrained by the current system, for example, lack of access to computers. This question of access is a bit of a moving target. One year a teacher has access to the computers, programs, and lab time needed; the next year those same computers might be used exclusively for state-mandated assessments of remedial programs. There are some cases where the curricular innovation is adopted more smoothly. Teachers #4 and #6 both reported that geospatial technology "fit like a glove" for themselves and their colleagues. Teacher #7 reported that his use of geospatial technology has varied according to which subjects he is asked to teach each year. Designers of professional development should take advantage of the growing array of published curricular materials and also design new materials that help scaffold teachers as they move from *Adopt* to *Adapt/Innovate* stages in their use of the tools.

18.6 Recommendations for Research

We have compiled sufficient evidence that some teachers are able to use geospatial technology and that they employ such technology routinely in their practice because, in their professional judgment, these tools help their students learn. Teachers' professional judgment is one acceptable form of evidence, but there also is a clear need for research that shows evidence of improved student learning based on the thoughtful use of these tools. An ongoing challenge is to develop assessment activities that incorporate the affordances of geospatial technologies in evaluating students' conceptual and process understanding. Students' spatial thinking skills are also critical underpinnings to assessing the impact of the technology on their learning.

Strong administrative support is essential for any technology to be successfully adopted and integrated into K-12 settings. Under the pressure of academic accountability born of No Child Left Behind, there is little incentive for teachers to utilize technology if they receive neither the support nor the credit for their technology integration efforts. The recently refreshed National Educational Technology Standards for Administrators (NETS-A) call for educational leaders to "promote an environment of professional learning and innovation that empowers educators to enhance student learning through the infusion of contemporary technologies and digital resources" (International Society for Technology in Education [ISTE], 2009, ¶ 3). Future research should examine strategies for garnering and sustaining strong administrative support both in the school building and at the district level to deploy geospatial technologies in ways that lead to meaningful student learning.

Additional research is needed to find out what geospatial technology adoption looks like for the larger group of *Early* and *Late Majority* teachers as well as *Innovators* and *Early Adopters*. Our participants reported that they believed their attendance and involvement in our teacher professional development efforts improved their knowledge and skills and helped them become better teachers. But what does this look like as teachers' competence and confidence advance over time? What kinds of questions do teachers ask? What kinds of learning activities do they devise? How do they make good instruction even better? It is important to observe longitudinal change over several years of teaching to fully understand the impact of professional development.

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Project Websites

The projects described in paper have websites that feature more detail about each project and offer access to curricular materials developed for each project.

Geospatial Semester. http://www.isat.jmu.edu/geospatialsemester
Great Outdoors, Digital Indoors (GODI). http://www.isat.jmu.edu/common/projects/godi/
Rural STEM. http://www.isat.jmu.edu/stem
Visualization in Science and Mathematics (VISM). http://www.isat.jmu.edu/common/projects/vism/

Part III
Final Chapters

Chapter 19
The Nature and Design of Professional Development for Using Geospatial Technologies to Teach Science

James MaKinster and Nancy Trautmann

Keywords Design Experiments • Evaluation • Framework • Geographic Information Systems (GIS) • Google Earth • Geographic Information Systems (GIS) • Inquiry • ITEST • Professional Development • Summer Institute

19.1 Using a Design Experiment Approach

Many projects described in this book evolved through explicit use of a design experiment approach (Brown, 1992) or design-based implementation research (Penuel & Fishman, 2012). On a macro scale, design experiments involve multiple cycles of design, test, and revision. In design research, ongoing research and evaluation findings frame strategic decisions about how to improve projects over time and how to generate evidence-based claims about science teacher professional development (Barab & Squire, 2004).

The 3- or 4-year structures of most federally funded professional development programs are well suited for a design experiment approach. Within this context, principal investigators (PIs) are motivated by at least two primary factors. First, the PI and project team strive to provide the best possible outcomes by challenging teachers while providing curriculum, personal, and other supports necessary for success (as in Vygotsky's "zone of proximal development" concept, 1978). Second, PIs additionally strive to satisfy participants and ensure widespread dissemination in order to demonstrate viability of the project for continued funding.

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The design experiment research approach in support of geospatial learning requires PIs to do at least two things. First, they must proactively collect targeted formative and summative evaluation data. The most productive survey items, in terms of project design, ask participants to rate usefulness of each session or aspect of an institute or workshop. The surveys can also include open-response items in which participants describe what aspects were most useful or valuable and where they saw opportunities for improvement. During summer institutes, surveys can be conducted daily or every 2 days. During the academic year, surveys should be conducted at the end of each workshop, webinar, or other professional development experience in order to gather timely feedback.

Applying a design experiment perspective encourages PIs and project collaborators to continually improve their work using evaluation results. The project team reflects on experiences and uses participant suggestions and critiques, along with research data, to make improvements from day to day and from year to year. Ultimately, project leaders need to be willing to modify the nature and structure of the professional development experience on an ongoing basis (Moore et al., Chap. 7; Stylinski and Doty, Chap. 8) and to question and modify the practical and theoretical assumptions upon which their work is based (Hagevik et al., Chap. 11; Trautmann and MaKinster, Chap. 4).

For a design experiment to succeed, ample opportunities must be provided for reflective conversations among project team members. These conversations could occur over lunch during a summer institute or workshop, during planning meetings throughout the year, or during annual advisory board meetings. McAuliffe and colleagues (Chap. 7) discuss the importance of having a project team with diverse skills and backgrounds, with curriculum designers, technology specialists, and classroom teachers bringing disparate perspectives to discussions. Ultimately it is the responsibility of the PIs to create a culture in which such reflection occurs on a regular basis and to provide all team members with opportunities to participate and enact recommendations.

Finally, the field needs to move beyond defining optimal professional development strategies according to a prescribed list of characteristics (Penuel et al., 2009; McClurg & Buss, 2007; Parker et al., 2010), aiming instead toward grounding professional development in specific and testable theoretical models. For example, theoretical models underlying projects in this volume include:

- The Next Practice Innovation Model (Blank, Crews, and Knuth, Chap. 5)
- Teachers as Researchers (McAuliffe and Lockwood, Chap. 6)
- Diffusion of Innovations (Moore et al., Chap. 7)

Each creates a specific theoretical context within which results of a particular set of professional development practices can be examined. Ideas or strategies can be tested from a design experiment perspective to determine the extent to which they fit or fulfill the goals of the model. For example, lessons learned through years of research on engaging teachers as researchers (e.g., Calvin & Gilmer, 2008) served to frame the goals and outcomes of the Eyes in the Sky project (McAuliffe and Lockwood, Chap. 6).

19.2 Core Tensions in Project Design

A number of core tensions are evident within and across projects described in Section I of this book. Each tension exists along a continuum. Rather than “either/or” propositions, tensions represent overlapping, yet conflicting, activities that drive the dynamics of a specific system (Engeström, 1987). Barab et al. (2004) built on Wenger’s (1998) approach of using tensions or “dualities” to understand community dynamics and design within the context of an online professional development network. This approach offers the opportunity to examine tension existence, the value of both dimensions of each tension, and potential actions to foster or resolve each within any particular professional development project.

Below, we discuss the tensions as core issues raised in the chapters in Section I. Tensions include:

- Lesson enactment versus design
- Including students in teacher professional development
- Online versus face-to-face interactions
- Teaching about technology versus teaching with technology

Although not an exhaustive list, these issues reflect some of the most salient issues that appeared across projects. Each is discussed below, beginning with a defining question.

19.2.1 Lesson Enactment Versus Design

To what extent does professional development focus on implementing a specific set of lessons, as opposed to choosing from a wider variety of lessons and units or even having teachers design their own lessons based on what they have learned?

Considerable variability exists across projects in addressing this question. Barnett et al. (Chap. 2) provided teachers in the Boston public schools with lessons that made compelling use of specific technologies such as GIS and interactive sound analysis software. With a focus on urban ecology, students were provided with protocols to estimate the ecological value of trees throughout the city and to investigate the effects of urban noise on bird songs. All teachers and students had a shared context – the city of Boston. When explored using engaging and compelling lessons and technologies, this created a meaningful context for learning.

This is an example of lesson enactment, with specific lessons and targeted professional development designed to create a consistent experience enabling all teachers to implement the provided curriculum with fidelity. The project team modeled lessons and engaged teachers as learners. Reflective discussions addressed opportunities and challenges that teachers saw in implementing the lessons in their classrooms. Issues raised within these conversations provide invaluable information for teams to consider in refining curricular materials and accompanying teacher support strategies.

Projects such as GIT Ahead (Trautmann and MaKinster, Chap. 4) and Spatial Sci (Blank, Crews, and Knuth, Chap. 5) focused more broadly on helping teachers learn new technological skills through model lessons that employ a variety of geospatial technologies (GeoPDFs, Google Earth, GIS). Rather than expected to implement provided lessons with fidelity, teachers in these projects were supported in developing their own lessons that make use of technological skills they had learned. Teachers in both projects were able to create their own lessons reflecting their own curricular needs, local context, and personal interests.

Many projects in this book support teachers in the adaptation of curricular materials, creating a culture that explicitly encourages teachers to adapt lessons to fit with their own curriculum, students, and context. A common approach is to provide electronic files for use by teachers in modifying the lessons (see Stylinski and Doty's iGIS project, Chap. 8 and the five-step model proposed by Hagevik et al., Chap. 11). Teachers were given time to plan for implementation within the context of ongoing technological and pedagogical support, surrounded by the project team and other teachers who answered questions and provided resources on demand (Trautmann & MaKinster, 2010; Conover, Chap. 9; Hagevik et al., Chap. 11), a component that is critical for promoting teacher change (National Research Council [NRC], 2007; Penuel et al., 2007).

Supporting teacher lesson development can empower teachers and foster ownership as they integrate new tools and activities into their existing curricula (Blank, Crews, and Knuth, Chap. 5; Trautmann and MaKinster, Chap. 4; Hagevik et al., Chap. 11). For example, the Paleo Exploration Project (Almquist et al., Chap. 3) used a model lesson to provide teachers with the experience of using paleontological data and research to engage students in inquiry. The project focused on helping teachers develop a greater understanding of the science process, learn fundamental earth science concepts, and apply geospatial technologies in data analysis. The teachers were encouraged to use what they had learned to develop their own lessons and activities during the academic year.

Despite the benefits of supporting development and adaptation of lessons, helping teachers to develop their own lessons requires considerable time and effort from the project team. If the project operates within a broad geographic region, classroom visits may not be feasible. The challenge of supporting teachers is also compounded when they teach different subjects within science (e.g., biology, earth science, environmental science) or different disciplines such as science, English, and social studies (e.g., Moore et al., Chap. 7). If support systems are weak, there is an increased risk that teachers might adapt or develop lessons in ways that fail to provide opportunities for scientific inquiry, critical thinking, and authentic assessment.

19.2.2 Including Students in Teacher Professional Development

To what extent do projects include working with students as part of the professional development offered in a summer institute versus leaving that step up to the teachers once they return to their classrooms?

Most of the projects in Section I included students in their summer professional development institutes, reflective of the fact that NSF's ITEST program for several years required a mix of student and teacher involvement. For example, many projects worked solely with teachers during the first week of a summer institute and then included students in the second week. Incorporating students in this way provided teachers with a low-risk, well-scaffolded context in which to practice new lessons and technological tools before taking them back to their own classrooms (McAuliffe and Lockwood, Chap. 6). Stylinski and Doty (Chap. 8) found that working with students on watershed investigations during the second week enhanced teachers' confidence and furthered their understanding of new science content and skills. Some projects took a different approach by working, for example, with students each morning followed by team reflection and planning each afternoon. Ideally, teachers were given time each day to reflect, revise, and learn from these experiences working with students (Barnett et al., Chap. 2).

Parker et al. (2010) described benefits of including students in teacher professional development. However, this approach does have drawbacks. One is the time taken away from other aspects of the program. Most of the projects described in this volume provided between 100 and 160 professional development contact hours each year, with up to 40 of these spent working with students in an informal setting. One consequence is less time for teachers to practice using the technologies themselves in order to process what they had just learned and to prepare or adapt lessons for use in their own classrooms. It is unclear whether working with students during the second week of a project is more beneficial to a teacher than simply implementing a lesson during the school year. Although teachers have a variety of technological and pedagogical supports when working with students in summer institutes, similar support could be provided in helping them to use the technology with each other in a peer teaching model rather than in practicing with students.

GIT Ahead is an example project that did not involve students directly as part of the professional development experience (Trautmann and MaKinster, Chap. 4). This project split its summer institute into two sections, one held early in the summer and the other just before the beginning of the new academic year. This format provided teachers two different experiences: the first focused on learning new ideas and technologies and the second on reviewing what they had learned and developing or adapting lessons to implement immediately in their teaching. Research and evaluation data revealed that teachers felt much better prepared to integrate technology into their teaching after the second week in which they had had time to develop their own lessons and implementation plans. Research is needed into the costs and benefits of devoting a significant portion of professional development to teaching students as opposed to working exclusively with teachers.

19.2.3 Online Versus Face-to-Face

To what extent are professional development workshops conducted online versus face-to-face?

Emergence of interactive web-conferencing software and courseware has created enormous potential for online courses, webinars, and other enrichment experiences (Greenhow, Robelia, & Hughes, 2009). Professional development projects increasingly rely on web-conferencing and other web-based technologies to save time, include teachers across broader geographic regions, and serve larger numbers of teachers. McAuliffe and Lockwood (Chap. 6) used a 12-week online course to familiarize teachers with GIS before face-to-face professional development. Moore and colleagues (Chap. 7) used a series of 25 webinars to work with teachers across Texas, Tennessee, North Carolina, Mississippi, and Florida.

Online interactions provide a number of benefits. First, they offer opportunities to learn new technologies or concepts over a longer period of time, rather than condensing so much into a summer institute. Research has shown greater retention rates when time is taken to process what one has learned (Craik & Lockhart, 1972). Second, web-based communications make it possible to work with teachers over larger geographic areas than would otherwise be feasible. Third, online professional development requires teachers to use their own computers and technology, which enables providers to work with larger numbers of teachers than possible in a typical computer lab (and ensures that the technologies will indeed run on the computers available to the teachers). Finally, online participants learn in different and potentially better ways compared with participants in face-to-face settings. Online discussions, both synchronous and asynchronous, typically create an environment in which participants engage with one another in more equitable ways by giving equal voice to those who tend to be more reserved in face-to-face settings (Bonk et al., 1998).

On the other hand, interacting with teachers in person affords project staff the opportunity to monitor nonverbal cues and to check in continually with individual teachers during instruction, projects, and lesson development time. When teachers reflect on potential uses of what they are learning, face-to-face interaction makes it possible for them to pick up on each other's enthusiasm and discover new implementation strategies. Finally, face-to-face settings foster rich opportunities for informal and highly productive interactions through conversations over meals, between presentations, during project times, and after hours (within residential programs). These conversations create strong ties and contribute substantially to building a sense of community, especially for teachers who are stretching themselves to learn challenging new skills.

Teachers place high value on interacting in person with trusted colleagues because teaching is a personal endeavor and closely tied to personal and socially constructed identities. High-quality, face-to-face interactions therefore contribute significantly to trust development between teachers and professional development providers. This trust inspires teachers to leave their comfort zones and take risks. It fosters ongoing participation because investments of time and effort lead to positive interactions within a trusted learning community.

Perhaps the best solution is a hybrid mix of face-to-face and online interaction. In one such model, experienced teacher leaders facilitate regional cohorts that collectively participate in hybrid face-to-face and online learning facilitated by core project staff. Research is needed to establish the extent to which various such models contribute to the efficacy of professional development in support of teaching with technology.

19.2.4 Teaching About Technology Versus Teaching with Technology

To what extent are projects teaching "about" geospatial technologies versus teaching "with" geospatial technologies?

Many of the projects described in this book began when relatively few geospatial technology options were available to teachers. Google Earth had not yet been released. Web-based GIS was simplistic, lacked most analytic tools, and required a level of bandwidth unavailable in most schools. The only real options at that time were desktop ArcGIS software or a simplified version called ArcExplorer Java Edition for Educators. As a result, many teacher professional development projects focused on learning in detail how to use the complicated ArcGIS software. Projects typically were led by university-level geography or science faculty who worked with teachers in the same way as with their students, emphasizing mastery of the software rather than its use as a tool for investigation. Teachers' developed competencies in using GIS, for example, in projects in which students conducted fieldwork, collected GPS data points, and created a GIS map to display them. There was considerable diversity in the nature and quality of these projects, but many were of great value to students, teachers, and their communities (e.g., ESRI, 2003). The primary challenge to this approach was that few teachers had time to build sufficient GIS skills to become adept enough to feel comfortable teaching the technology to students.

The projects highlighted in this book illustrate a shift from focus on teaching "about" geospatial technologies to teaching "with" them. This newer approach assumes that teachers need to master only the aspects needed to use the software to accomplish their pedagogical and curricular goals. Geospatial analysis becomes less daunting when teachers are provided with classroom-ready datasets and easy access to web-based tools that are intuitive, fast, and reliable. In spite of these improvements, limited Internet bandwidth and lack of technical support continue to be significant barriers for many teachers (Baker & Bednarz, 2003; Kerski, 2003). However, web-based geospatial software has begun meeting or coming close to meeting this vision of what is needed. My World GIS was a good first step in this direction (Kubitskey et al., Chap. 10; Barnett et al., Chap. 2; Moore et al., Chap. 7) and ArcGIS Online and ArcGIS.com (Kerski, 2008; ESRI, 2011) are moving quickly to address these issues and needs. New advances in online mapping have simplified and made more intuitive the steps of visualizing and analyzing field data (e.g., see ArcGIS Online and storytelling with maps).

Teachers need opportunities to learn to use new technologies and to apply them in model lessons. Additionally, they should be given time and support in creating or modifying existing investigations, lessons, and units to meet their specific teaching interests and needs.

19.3 Going to Scale

To go to scale over time, professional development projects need to find balance between working in depth with individual teachers and developing a growing community of teachers with varying levels of technological competence. Many of the projects in this volume seem to be striking this balance. Continued efforts regarding these issues will enable professional development projects to move beyond working with relatively small cohorts of early adopters to serving a broader spectrum of teachers with a wider variety of technological skills and abilities.

An overarching issue across projects is how to effectively expand professional development to work with increasing numbers of teachers without losing the personal touch that is possible in smaller groups. Effectively going to scale requires reaching a balance among these trade-offs, and the most effective models likely will include reliance on teacher leaders to extend the reach of the core project staff.

The five dimensions of scale serve as a useful framework for identifying needed elements: *depth, shift, evolution, sustainability, and spread* (Coburn, 2003; Dede, Honan, & Peters, 2005; Dede, Rockman, & Knox, 2007). All of the projects highlighted in this book demonstrate *depth* by asking teachers to use geospatial technologies as part of transformative learning experiences. The dimension of *shift* refers to fostering ownership over the project and demonstrating a desire to further its impact. This is accomplished in projects that work to meet both immediate and long-term needs of participants and help teachers recognize that the project is responsive to their needs. *Evolution* refers to the ways in which teachers contribute to and influence the design and direction of their professional development experiences and project outcomes. This is inherent in enabling teachers and teacher leaders to have significant input into shaping the nature and direction of the project. Teachers should have ample opportunity to provide feedback about the effectiveness of each aspect of the project and discuss ongoing needs and issues. For projects to evolve in a positive direction, leaders and teams must be willing to hear, process, and respond to feedback. Evolution also occurs when teachers work with the project team to adapt resources, develop complementary ones, and share lessons and teaching experiences with one another using Web-based courseware tools, face-to-face discussions, teacher leader workshops, and focus groups.

The remaining two dimensions of scale – *spread* and *sustainability* – are the most challenging considerations in scaling up projects such as those described in this volume. *Spread* refers to expanding an initiative to a large number of participants. Considering that there are two million science teachers in the United States, few of whom know how to integrate geospatial technologies into their teaching, significant opportunities remain for science teacher professional development. When presenting on scalable innovations for urban science education, Barry Fishman pointed out that a reasonable goal for science educators is to ask ourselves whether a specific professional development or curricular effort influences even 5 % of our target audience (Fishman, Soloway, Krajcik, Marx, & Blumenfeld, 2001). Reaching even that small percentage presents a daunting challenge considering the large number of science teachers and the in-depth professional development needed to support effective integration of geospatial technology into their science teaching.

Intensive summer institutes provide this support, but scaling up to larger numbers of teachers presents substantial challenges in finding sources of funds to compensate teachers and to ensure that every teacher's needs are met even as the project grows. Use of online classes, meetings, and workshops will help, but many of the projects in this book demonstrate the value and importance of also including intensive face-to-face collaboration.

Until school curricula require students to conduct geospatial investigations, spread of these innovations will remain a significant challenge. GIS is used in a variety of professional fields (science, economics, social sciences, political science, geography, etc.), and college curricula are beginning to reflect this reality. However, K-12 curricula do not yet recognize the importance of GIS and other geospatial tools as essential for many disciplines, topics, and content areas.

Finally, the dimension of *sustainability* refers to how the innovation can be adapted to function under a variety of conditions such as teachers with varying levels of technological skill, teaching experience, and responsibilities. The extent to which a project is based on federal grants or other external funding raises issues related to economic sustainability. Few projects have identified sustainable business models in the absence of large-scale funding from state or federal sources. The Urban Ecology project (Barnett et al., Chap. 2) has adopted the strategy of focusing on corporate support as a means to sustain professional development opportunities. The extent to which that is possible for other projects will vary widely.

Going to scale presents formidable but not impossible challenges. Scale-up grants offered within NSF programs such as ITEST provide one option, but only for a small number of projects. As Moore and colleagues point out (Chap. 7), innovative professional development needs to become an integral component of state and national educational systems rather than an external, add-on option. Schools must prioritize professional development so that teachers can participate in valuable experiences that help them challenge their students in ways that align well with district and state mandates.

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Chapter 20
The Nature of Teacher Knowledge Necessary for the Effective Use of Geospatial Technologies to Teach Science

James MaKinster and Nancy Trautmann

Keywords Design Experiments • Environmental • Framework • Geographic Information Systems (GIS) • Google Earth • Professional Development • Technological Pedagogical Content Knowledge (TPACK)

20.1 Introduction

> Great learning environments begin and end with the teacher as the primary architect. (Coulter, Chap. 17)

Much attention has focused on what *students* using geospatial tools for science learning need to know but far less focused on what teachers need to know to lead effective lessons that use geospatial technology (Reviewed in Barnett, MaKinster, Trautmann, Vaughn, & Mark, 2013). Section II addresses this gap by presenting case studies illustrating use of geospatial technologies in classrooms (Coulter, Chap. 17; MaKinster and Trautmann, Chap. 16), outlining the professional development trajectories of participating teachers (Baker and Kerski, Chap. 15; Kolvoord, Charles, and Purcell, Chap. 18), and describing design frameworks for curriculum and professional development (Bodzin, Anastasio, and Kulo, Chap. 13; Hagevik et al., Chap. 11; Yarnall, Vahey, and Swan, Chap. 14; Zalles and Pallant, Chap. 12). Collectively these chapters provide insights into a range of successful strategies and experiences while also identifying the types of background needed for teachers to

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lead science lessons and units in which students make productive use of geospatial technologies in their teaching.

Bob Coulter argues (Chap. 17) that successful geospatial inquiry requires teachers to have a strong understanding of relevant science content, hardware and software applications, data analysis techniques, and pedagogical strategies that meet the needs of their students. Building on this argument and looking across the chapters in this volume, we broadly define a teacher who is successful at *teaching science with geospatial technology* as able to:

(a) Identify, adapt, or create challenging and effective lessons or units involving the interpretation of geospatial data that meet the needs of their students and curriculum
(b) Effectively lead geospatial lessons by managing students and student groups and by providing the necessary technical and conceptual scaffolding

A variety of pedagogical, content, and technological knowledge contribute to these two outcomes. Below we use the lessons gleaned from Section II to identify the types of knowledge teachers need in order to be successful at geospatial inquiry and thus provide professional development designers and researchers with useful models around which to design specific workshops, resources, and opportunities.

20.2 Technological Pedagogical Content Knowledge (TPACK)

To frame our analysis of the types of knowledge needed for teachers to be successful at geospatial inquiry, we rely on the theoretical construct of Technological Pedagogical Content Knowledge (TPACK – pronounced “t-pack”). TPACK is a relatively new theoretical framework that is still being defined and refined (reviewed in Voogt et al., 2013), but it provides a useful framework for consideration of the various aspects of teachers’ expertise. TPACK builds on Pedagogical Content Knowledge (PCK), a construct of central concern and interest in science education (e.g., van Driel, Verloop, & de Vos, 1998; Veal, van Driel, & Hulshof, 2001; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001). Shulman (1986, 1987) originally described PCK as “an understanding of how particular topics, problems, or issues are organized, presented, and adapted to the diverse interests and abilities of learners, and presented for instruction” (1987, p. 8). Since that time, a number of authors have sought to expand and clarify the various dimensions and aspects of PCK (e.g., Gess-Newsome & Lederman, 2001; van Driel et al., 1998; Veal et al., 2001; Loughran et al., 2001; Veal & MaKinster, 1999).

The TPACK framework expands on PCK by adding the dimension of *technological knowledge* to the content and pedagogy knowledge constructs. Originally described by Mishra and Koehler (2006), TPACK describes how teachers’ knowledge of educational technology interacts with their PCK in ways that produce effective teaching and opportunities for student learning. After reviewing

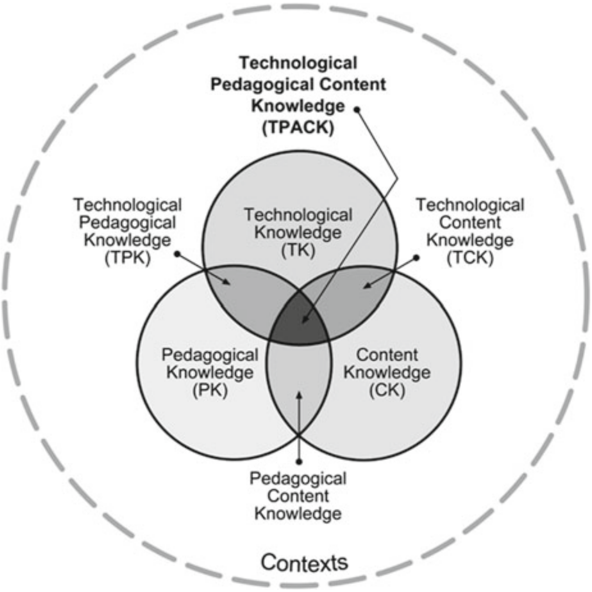

Fig. 20.1 Technological pedagogical content knowledge diagram from Koehler and Mishra (2009) (Reproduced by permission of the publisher, © 2012 by tpack.org)

89 different definitions of TPACK, Cox (2008) consolidated the findings to forge a definition that captures the active interaction among the three fundamental knowledge domains:

> …knowledge of the dynamic, transactional negotiation among technology, pedagogy, and content and how that negotiation impacts student learning in a classroom context. The essential features are (a) the use of appropriate technology (b) in a particular content area (c) as part of a pedagogical strategy (d) within a given educational context (e) to develop students' knowledge of a particular topic or meet an educational objective or student need. (p. 40)

Framing TPACK as the interaction among the three fundamental knowledge domains creates two additional domains – Technological Pedagogical Knowledge (TPK) and Technological Content Knowledge (TCK). These are represented as areas of overlap in Fig. 20.1, and the central triangle formed where all three circles overlap is TPACK.

Technological Pedagogical Knowledge refers to the extent to which a teacher understands the capabilities of various educational technologies and recognizes the pedagogical opportunities they create. *Technological Content Knowledge* refers to how various educational technologies enable teachers to represent science concepts and topics in ways that are meaningful, productive, and often different from traditional classroom representations. Each of these new domains has significant utility. They enable designers and researchers to identify, discuss, and study the types of knowledge necessary for effective teaching using educational technologies.

Unfortunately, much of the research using TPACK has not been domain or topic specific and has focused on educational technologies in general (reviewed in Voogt et al., 2013). This has contributed to lack of clarity regarding TPACK as a theoretical construct. Another weakness is that many authors have failed to recognize or acknowledge the importance of the theoretical assumptions behind the work of Mishra and Kohler (2006) and others (Cox 2008). Recognizing PCK or TPACK as both content specific and context dependent is essential (Cox, 2008; Loughran et al., 2007; Veal & MaKinster, 1999; Mishra & Koehler, 2006). Voogt et al. (2013) concluded that only by identifying the knowledge base "necessary to teach specific subjects" can we develop better research instruments and conduct more meaningful research.

Because this book focuses on a specific discipline (science) and the use of a specific suite of educational technologies (geospatial), we are well situated to ground the definition and nature of each TPACK domain with specific examples from multiple projects. This gives us the opportunity to apply TPACK as a framework within which we can identify the types of knowledge needed by teachers to be successful at geospatial inquiry. Moving from the individual technology, pedagogy, and content dimensions of this model to the constructs involving an interaction between two (PCK, TPK, and TCK) or ultimately three (TPACK) dimensions, one is able to see how each dimension can serve as a lens through which to understand teacher knowledge. While PCK represents the ability of a teacher to create meaningful representations and activities in order to teach specific concepts and topics (Schulman, 1986, 1987), TPACK expands this to include the ability to do so through use of educational technology. Applying the TPACK framework makes it possible to dissect the ways in which these various types of knowledge complement one another, leading to conclusions about optimal design of professional development opportunities and instructional materials. This work builds on earlier efforts within which TPACK was applied to teacher practitioners in science education as well (Borthwick et al., 2008).

In the following section, each knowledge domain is defined and explained using examples from experiences described in earlier chapters. Vignettes illustrate how technological, pedagogical, and content knowledge come together in TCK, TPK, and TPACK in ways that are potentially useful to designers and researchers of projects that support teaching with geospatial technology.

20.3 Defining TPACK in the Context of Using Geospatial Technologies to Teach Science

20.3.1 Technological Knowledge (TK)

Technological knowledge reaches beyond learning how to use a specific piece of hardware or software (Table 20.1). Teachers also need to be able to explore technology and be comfortable learning how to use it on their own for their own purposes. This is likely to be more intuitive for those who have grown up using digital technologies (Palfrey & Gasser, 2010). Most important is for teachers to understand the affordances and challenges created by various technological options. For example, Garage Band (Apple Inc.) makes it possible to create and edit music, but an assortment of other programs is much simpler to use if your

Table 20.1 Knowledge and abilities needed by teachers using geospatial technology to teach science

Pedagogical knowledge (PK)	Technological knowledge (TK)	Content knowledge (CK)
Understanding of	*Understanding of*	*Understanding of*
District and state curriculum requirements	Projections and spatial representation of data	Scientific concepts in the discipline
Students as learners	Differences among various geospatial technologies	How specific science concepts relate to broader events and issues
		Data analysis techniques (qualitative and quantitative)
Ability to	*Ability to*	*Ability to*
Present ideas effectively to students	Interpret maps	Facilitate data-informed, model-based reasoning
Use a variety of teaching strategies	Comfortably learn how to use technology	Describe common misconceptions in science
Implement project-based learning	Identify geospatial technologies that meet a specific need	Visualize and analyze scientific data
Facilitate inquiry-based learning	Effectively use specific pieces of hardware and software	Interpret scientific data
Support students working individually or collaboratively	Identify the affordances and challenges created by various technologies	Use scientific reasoning to critically evaluate ideas
Manage multiple students or student groups working on conceptually related but different projects	Adapt and use existing technologies to create new representations	Interpret scientific data
Create many different types of assessments	Solve problems with hardware or software not functioning properly	Guide students in productively generating and exploring testable questions
Teach based on what students do not understand	Identify and use support when needed in solving technological problems	
Develop specific strategies for motivating students		

(continued)

Table 20.1 (continued)

Pedagogical content knowledge (PCK)
Ability to
Use technology to represent science and environmental concepts in ways that are compelling and engaging within the context of project-based or inquiry-based lessons
Facilitate students making connections among different science concepts
Provide students with opportunities to apply science concepts to real-world contexts
Use assessment outcomes to improve one's teaching
Help students develop the ability to critically evaluate ideas using scientific reasoning
Use teaching strategies that address common student misconceptions in science
Manage students effectively when learning science
Develop strategies that challenge advanced learners
Develop strategies to help students who are struggling academically
Engage students in authentic science investigations that mirror how scientists work

Technological pedagogical knowledge (TPK)	**Technological content knowledge (TCK)**
Understanding of	*Understanding of*
Ways in which geospatial technologies create opportunities to use specific pedagogical approaches such as project-based learning and inquiry-based learning	Ways in which geospatial technologies can represent science concepts, topics, and processes in ways that are engaging and meaningful to students
Ways in which geospatial technologies create opportunities for individual and social knowledge construction	Ways in which geospatial representations can be combined with other representations in meaningful ways
Ways in which geospatial technologies can be used to create authentic contexts for learning	

Ability to	*Ability to*
Identify geospatial technologies that can represent specific science concepts more effectively	Identify geospatial technologies that can represent specific science concepts more effectively
Identify geospatial technologies that enable students to learn effectively	Use geospatial technologies to relate specific science concepts to broader events and issues
Identify geospatial technologies that complement specific teaching strategies	Use geospatial technologies to analyze and visualize data
Use geospatial technologies to motivate students	Combine geospatial and traditional representations of science concepts effectively
Use geospatial technologies to create authentic forms of student assessment	Ability to use geospatial technologies to conduct scientific or environmental research
Creatively adapt geospatial technologies to meet the needs of diverse learners	Adapt and use existing technologies to create new representations of science concepts
Technological pedagogical content knowledge (TPACK)	
Ability to	
Use technology to represent science and environmental concepts in ways that are compelling and engaging within the context of project-based or inquiry-based lessons	
Adapt existing geospatial technology and data to improve its effectiveness in representing science concepts for specific learners	
Design lessons that effectively use geospatial technology to both teach specific science concepts and implement appropriate teaching strategies	
Design and implement instructional sequences using geospatial technology that enable students to make connections to larger and more complex environmental problems and/or scientific issues	
Support students in generating explanations or conclusions as they interpret geospatial scientific data and evidence	
Design authentic geospatial technology-based assessments that provide students with opportunities to apply what they've learned and mirror practices and products of real-world science	

goal is to record and process basic student podcasts (e.g., Audacity, SoundForge). As teachers learn to use a piece of software, they need to be able to imagine how their students would use it, what opportunities it would create, and what challenges they might face.

Meaningful use of geospatial software requires understanding of maps and two- or three-dimensional spatial display of information. For example, teachers using Google Earth need to understand the basic elements of an aerial photograph, such as tone, texture, pattern, and shadow (Bodzin, Anastasio, and Kulo, Chap. 13). Those using two-dimensional maps should have some familiarity with the ways in which map projections distort visualization of spatial data. Most importantly, teachers need to be able to select from among an array of geospatial technologies such as Google Maps, Google Earth, Global Positioning Systems, ArcGIS desktop, and ArcGIS Online, to name a few, in order to determine which option might best meet their needs.

Once a teacher selects a specific piece of software or hardware, they need the ability to solve any technology problems that arise. This may require simply applying something learned during a workshop or seminar or "playing" with the software to learn something new or troubleshoot a specific issue. Often the majority of issues are simple things such as refreshing a browser, clearing the cache, or restarting the application. For more significant problems, teachers also need to be able to identify and use support from sources such as school personnel, online help, and assistance provided through professional development projects in which they are involved.

20.3.2 Pedagogical Knowledge (PK)

Pedagogical knowledge broadly covers what teachers know related to teaching, curriculum, and assessment (Table 20.1). Here we focus on the types of knowledge that are most relevant to facilitating effective inquiry-based or project-based learning using geospatial technologies. An essential piece of the puzzle is a solid understanding of curricular requirements, including within the school, the district, and any relevant state or national mandates. Each of these informs teachers' choices regarding what and how to teach. Yarnall, Vahey, and Swan (Chap. 14), for example, describes how teachers made "…choices about how far to go with the hydrological concepts, based on their understandings of their students' needs and on state standards."

Another essential component of pedagogical knowledge is the ability to determine how best to present ideas and concepts. Students need a certain amount of direct instruction in getting started with geospatial technologies, and teachers need to be able to present and explain how to use software in a manner that students can follow, taking into account what students they already know regarding other types of software. With complex processes such as creating topographic lines in ArcMap, the teacher needs to be able to identify how much detail is appropriate to teach desired concepts without getting bogged down in technicalities of using the software. A knowledgeable teacher can guide students in geospatial projects that mirror those conducted by professionals. For example, in the iGIS project (Stylinski, Chap. 8), for example, teachers were exposed to a variety of geospatial tools, conducted their own watershed investigation as part of the professional development experience, and then returned to their classrooms to design a local watershed-focused investigation using some or all of the geospatial tools available.

The projects in this book emphasize project-based learning or inquiry-based learning rather than focusing on students learning about the technology itself. As Kolvoord, Charles, and Purcell point out (Chap. 18), “using geospatial technology (was) as much about facilitating project-based learning as it was about the employment of advanced scientific visualization tools.” Other authors refer to the need for teachers to possess or develop a certain facility with inquiry-based teaching and learning, which requires comfort with relinquishing some level of direction and ownership to students (National Research Council, 2000). Ability of teachers to facilitate open-ended discussion is a key aspect of applying pedagogical knowledge related to inquiry- and project-based learning. For example, when students use GIS to analyze habitat and biodiversity data with the goal of selecting the site for a new wildlife preserve, they are likely to have to weigh trade-offs and alternatives. Class discussions could foster critical thinking and help students wrestle with criteria for the new conservation area and make well-reasoned decisions about the best possible location. The ability to orchestrate “discourse among students about scientific ideas” is an essential ability for teachers who are facilitating scientific inquiry (NRC, 2000, p. 22).

Facilitating project- or inquiry-based learning requires teachers to be able to support students working both individually and collaboratively. The Frameworks for K-12 Science Education (2012) recognize that students should “actively engage in science and engineering practices and apply crosscutting concepts to deepen their understanding of each field’s disciplinary core ideas.” In the context of geospatial projects, teachers need to help individual students develop certain software skills or process a particular idea. Students need to be able to pose productive questions that enable the entire class to think through specific decisions or actions (Yarnall, Vahey, and Swan, Chap. 14; Coulter, Chap. 17; Kolvoord, Charles, and Purcell, Chap. 18). As Coulter (Chap. 17) points out, teachers also must be able to manage multiple students or student groups working on projects that are conceptually related but different. For example, a teacher might have students mapping and studying pervious versus impervious surfaces and water runoff from their school property. Each group might choose a different area to study, a different way to represent their data, and perhaps even different analytical techniques.

20.3.3 Content Knowledge (CK)

Geospatial technologies lend themselves most readily to explorations in biology, earth science, and environmental science or environmental studies. To be comfortable teaching any of these subjects beyond the textbook, teachers need to have a solid understanding of their discipline. They need to understand scientific concepts and topics at the level of their students and to be able to represent these ideas and concepts in ways that are developmentally appropriate (Table 20.1). Greater depth of understanding is needed to effectively answer content-specific questions and facilitate inquiry-based learning. This can create significant challenges for middle school teachers, who are responsible for teaching all four science disciplines.

Because geospatial technologies lend themselves so well to project-based learning, it is helpful for teachers to know about relevant local, national, or global events or issues that can be used to engage students with broader concepts (Coulter, Chap. 17; Stylinski, Chap. 8). Such issues can be used as the basis for student projects or to contextualize presentation of scientific concepts or environmental issues. For example, earth science students who live in glacier-affected regions are surrounded by topographic features such as moraines, drumlins, and erratics that can serve as tangible examples of the effects of glaciers on landscapes. Tools such as Google Earth and ArcGIS Online enable students to visit such locations virtually. Seeing an aerial view of a topographic feature gives new meaning to what is seen on the ground.

Focusing on a local environmental issue such as development or expansion of a landfill gives students the chance to join their community in weighing competing land uses and environmental values. Geospatial representations are particularly useful for visualizing how “human activity relates to specific environmental impacts” (Yarnall, Vahey, and Swan, Chap. 14; Zalles and Pallant, Chap. 12), balancing trade-offs among social, political, scientific, economic, and ethical values in decision-making. Tying such local issues to broader ones enables students to recognize the relevance of what they are learning in their community to similar issues at state, national, or global scales.

When using geospatial technologies to teach science, teachers must be able to facilitate data-informed, model-based reasoning (Coulter, Chap. 17). Like many authors in this volume, Yarnall, Vahey, and Swan (Chap. 14) assert that using real-world data in the form of geospatial representations created a “motivating context for applying emergent scientific reasoning.” To take advantage of the motivation and engagement so often displayed by students using geospatial tools, teachers need to be able to identify one or more datasets that can serve as the basis for productive questions. A significant challenge is presented by the limitations often inherent in publically available datasets, in which data may be formatted in a nonintuitive manner, limited in geographic reach, or more complex than is needed for the investigation at hand (Zalles and Pallant, Chap. 12).

With data in hand and appropriate technology in use, then the teacher must be able to guide students in productively pursuing testable questions (NRC, 2000). Using a qualitative approach, students using geospatial visualization tools make visual estimates of relevant spatial parameters. For quantitative analysis, they use data-driven queries or selections. In a manner similar to curriculum decisions, a teacher must know what level of data analysis is developmentally appropriate for his or her students. Given the potential limitations of real-world data, it can be challenging for teachers to facilitate evidence-based reasoning about complex phenomena. As Zalles and Pallant (Chap. 12) explain, “the differences between the relative certainties and uncertainties in the data influence the learning goals of a data-centered, inquiry and problem-based curriculum." For example, "there is more certainty about the causes of earthquake patterns along different plate boundaries than there is about what amount of weather variability constitutes climate change" (Zalles and Pallant, Chap. 12, p. 287).

20.3.4 Technological Content Knowledge (TCK)

Technological Content Knowledge represents the integration between what a teacher knows about relevant technological applications and about the science topic of interest. More specifically, TCK refers to the extent to which an individual understands the ways in which educational technologies can represent science concepts, topics, and processes in ways that are engaging and meaningful to students (Table 20.1). Educational technologies increasingly create the potential for new and more varied representations, but each technology has its own particular strengths and constraints (Koehler & Mishra, 2008). Defining TCK for a particular subject or domain must therefore be based on an understanding of the ways in which content and technology provide affordances and also constrain the types and nature of representations available to a user (Koehler & Mishra, 2008). Below are examples from this volume of how various geospatial technologies can be used to represent specific scientific and environmental concepts.

TCK and Google Earth. Google Earth is one of the most intuitive geospatial tools available. Students can easily explore its map functions. Teachers find it a powerful tool with which to present or explore a variety of science and environmental concepts. Users can tie information such as explanatory text, photos, or videos to specific locations identified on satellite imagery for most of the globe. Some versions of the program can incorporate GIS data layers and other file types as well. Bodzin, Anastasio, and Kulo (Chap. 13) point out that one of the greatest utilities of Google Earth is in enabling the user to "examine landscape changes over time through analysis and interpretation of satellite data images and aerial photographs."

MaKinster and Trautmann (Chap. 16) describe a teacher using Google Earth to have students explore and measure a local stream system in order to determine elevation changes and size. This is then used in the context of relating land use to water quality within the watershed. The teacher used

> …Google Earth imagery that was enhanced by vertically exaggerating the terrain. On this virtual surface, he overlaid a GIS layer that highlighted the streams within this area and a USGS topographic map that included the contour lines and other symbols from the map's legend. The students each worked at their own computers and virtually explored the Stone Creek watershed. They started at their school and followed the stream through the town, up a steep-sided and geologically diverse ravine, and into the headwaters. (pp. 291–292)

Using Google Earth in this manner, students visualized and explored the science concepts of *watersheds, topography, stream flow*, and the idea of a water system's *headwaters*. These concepts were embodied by representations in the landscape and became intuitively clear to students through their geospatial explorations.

Bodzin, Anastasio, and Kulo (Chap. 13) describe another classroom use of Google Earth:

> To understand concepts involved in the formation of urban heat islands, students use Google Earth to investigate how shopping malls change natural environments. The module begins with a student investigation of the spatial and environmental aspects of a shopping mall in Huntsville, Alabama. Students learn to use basic elements of aerial photo interpretation (including tone, size, texture, pattern, shadow, site, and association) to aid in identifying objects in aerial photographs, enhancing their three dimensional visualization skills. Next, students use Google Earth to complete a geographical case study of Atlanta's urban heat island effects and the consequences of urban deforestation in the greater Atlanta area. (p. 308)

Through this experience, students visualized and explored the concepts of *heat islands, natural environments,* and *human impact* using the imagery in Google Earth and remote sensing imagery added by the project team. Bodzin and colleagues (Chap. 13) explain their approach when designing Google Earth exploration:

> We use Google Earth to take advantage of a scientist's craft by designing Google Earth images that clearly display aspects of scientific understanding. For example, when one uses the Google Earth search feature to observe Mt. Fuji, the resulting image display does not prominently illustrate key features that identify Mt. Fuji as a volcanic mountain. When we design our placemark images, we take advantage of the ability to resize, rotate, and adjust the angle of the image to provide learners with an initial image display that highlights prominent physical features. This helps novice learners to better understand the connection between Earth and environmental processes and the landscape. (p. 317)

These are just two examples of how Google Earth imagery makes it possible to represent scientific concepts and processes in ways that go beyond what can be done with textbooks or static two-dimensional representations.

TCK and Desktop Geographic Information Systems. While desktop GIS software is more complex technically than Google Earth and you are typically limited to a 2D view of the landscape, the ability to overlay, manipulate, and analyze "layers" of data affords science teachers with a number of opportunities to represent science concepts and topics in a variety of ways. The teacher described by MaKinster and Trautmann (Chap. 16) built on the students' initial use of Google Earth by having them use ArcMap to measure the watershed and the land cover within that watershed as a means of exploring how land cover and land use might influence water quality within that watershed. The watershed included both forested and agricultural areas. This exploration and the nature of the data provided students with an opportunity to construct their own understanding of *nonpoint source pollutio*n, a scientific and environmental concept that requires, like others mentioned above, students to visualize a process occurring across a landscape.

Conover (Chap. 9) provided an example of a high school in which teachers partnered with a local marine nonprofit organization focused on the lobster-fishing industry:

> Students used GIS to analyze bottom type, bathymetry, and water-temperature data to locate these important lobster settlement areas and inform the hatchery manager as to where to best release their larval lobster stock…The hatchery raises and releases larval lobsters

> into the local embayment to promote a healthy lobster population. Students worked with the lobster-hatchery manager and local lobstermen to identify habitat areas that were particularly favorable for larval lobster settlement. (p. 201)

These students were able to develop an understanding of science concepts such as *dispersal, population dynamics, niches, and bathymetry* through the use of geospatial data. The problem they worked to address, like many others presented in this volume, is inherently spatial in nature. Students were able to use both qualitative and quantitative approaches to assess habitat suitability for larval lobsters with GIS.

TCK and My World GIS. We are in a time of rapid change in the world of web-based mapping applications. One of the first such applications, designed specifically for use by teachers and students, was My World GIS. Developed through the GEODE initiative at Northwestern University, My World GIS is designed to support inquiry-based learning in middle school through college classrooms (http://www.myworldGIS.org/). Kubitsky and colleagues (Chap. 10) describe its functions:

> Students are able to investigate geographic data with easy-to-use tools to explore the environment and much more with a carefully selected subset of features of a professional geospatial technology environment. These include multiple geographic projections, table and map views of data, distance-measurement tools, buffering and query operations, and a customizable map display. (p. 226)

The CASES curriculum (Edelson et al., 2005) includes a project in which students use My World GIS to determine suitable sites for a power plant, which must be located along a large body of water for cooling purposes (Kubitsky et al., Chap. 10). Students use the web-based GIS to explore the land and identify potential environmental impacts of building a power plant in specific locations:

> In order to do this, students learn how to create a Buffer that extends the area of an object on a map. Finally, students examine the proximity of the lakes to roads and railroads. In the process, students learn to use the measurement tool to determine the distance from the location. This makes it easy for students to visualize the area surrounding the selection. (p. 228)

Through this sort of application of GIS, students learn about the environmental impacts of power plants such as *thermal pollution, diminished air quality, protected species, property values, and waste management.*

These examples illustrate how geospatial technologies can support the teaching and learning of specific science and environmental concepts. Prior to this volume, the research literature has included few examples of what TCK actually looks like (Voogt et al., 2013). Many of the chapters in this volume describe the motivating and compelling context for learning of specific scientific or environmental issues that can be created through exploration of geospatial questions with relevance to the real world.

Different technologies lend themselves to different types of investigations, based on the representational and analytic capacities of each tool. The types of questions science teachers want to ask often require multiple data layers, measurement tools, and the analytic capacities of either virtual or desktop GIS. The simpler-to-use geospatial technologies such as Google Earth do not have as powerful analytic options, so that is a trade-off that teachers must weigh. However, if teachers dedicate the effort to learning how to use the more complex tools, they generally find that these can be used to teach a broad range of science and environmental topics in new and engaging ways. Fortunately, web-based GIS software is increasingly providing students and teachers with a greater number of analytical tools and capabilities.

20.3.5 Technological Pedagogical Knowledge (TPK)

Technological Pedagogical Knowledge refers to the extent to which a teacher recognizes the pedagogical opportunities offered by various technologies (Table 20.1). Geospatial technologies lend themselves to certain types of learning experiences. For example, the types of scientific or environmental questions one can ask when using geospatial technologies lend themselves to project- or inquiry-based learning. Through such investigations, students can construct their own understandings, both as individuals and socially among their peers and the teacher (Cobb, 1994). Students can work in parallel, or they can work on different aspects of a common problem – for example, taking a pro or con stance or addressing scientific, economic, political, and social perspectives on a given environmental issue.

Many projects presented in this volume provide students with the opportunity to construct their own understandings of scientific and environmental concepts. Fundamental to any investigation or project is the need for a teacher to create an *authentic context for learning*. Barab, Squire, and Dueber (2000) define an authentic context as one in which students perceive their learning and experience as personally meaningful and relevant. Creating such a context requires a teacher to have knowledge of local resources, his or her students, and to frame the investigation in a manner that ties student interests and backgrounds to the local resource or issue in a compelling manner. Coulter (Chap. 17) describes how simply tying a lesson to standards fails to make tangible connections to students' lives, and he argues that connections need to be made relevant to local resources:

> …many pre-packaged curriculum units usually address the curriculum relevance issue by citing the standards being addressed, but they rarely have data or a content focus that is closer to home. Teachers we have worked with in the St. Louis region appreciate the capacity of GIS to map global patterns in seismic activity, but they also want to be able to map the more locally relevant issue of seismic activity along the New Madrid fault running just south of metro St. Louis. This local data brings home the notion of seismic activity and provides a link to what students learn from the news. The "ring of fire" in the Pacific is interesting, but a student will understand it better and have more interest if there is a more immediate reference point to build from. (p. 416)

Similarly, MaKinster and Trautmann (Chap. 16) describe how a teacher asked students to apply what they had learned by comparing their schools' watershed to the ones in which each of them lived. Mr. Braddock asked his students to

> …apply what they had learned about the potential impact of land use and land cover in the Stone Creek watershed to a similar analysis of the watershed in which they lived. Students had to make the same measurements on the watershed in which they lived. While the original investigation was grounded within their school community, the application of this new

> knowledge was focused even closer to home. Mr. Braddock described one student wanting to determine which way the stream near his house flowed. Using the topographic map in Google Earth, he was able to interpret the contour lines and check his conclusion by examining the elevation change between two points in the stream. (p. 396)

Once a motivating context is identified, and in order to take full advantage of geospatial technology, a teacher must understand how to engage students in *project-based learning*. This requires the ability to identify and facilitate student groups, support groups working in parallel or on different aspects of a common problem, and potentially facilitating fieldwork while providing students with data, information, or resources as needs arise. Baker and Kerski (Chap. 15) described the diversity of the projects pursued by the teachers they surveyed:

> The projects that the students of the respondents worked on illustrate the applicability of GIS to a wide variety of settings, scales, and topics. These include local projects, such as making a trail map of an area next to the school and mapping fire hydrants for the city. Nearly all of the local projects included fieldwork. The use of GIS to support field studies at the local level was mentioned by 12 out of 12 respondents, with examples ranging from mapping log piles deposited by tidal flow, mapping the local watershed, to creating a living history of the neighborhood of the historically African American high school. Teachers also taught regional topics such as mapping radio telemetry positions, impervious versus permeable surfaces using land use and land cover data, and a study of the Colorado River drainage basin. (p. 364)

In the context of such projects, teachers need to understand how to guide students in productively exploring their own questions. Coulter (Chap. 17) bases his chapter on the argument that "geospatial inquiry requires a shift in pedagogy away from focused whole-class instruction towards students working individually or in small groups…." This can be done both implicitly and explicitly. It is important for teachers to model the type of inquiry and questioning they hope their students will engage in as well. At the same time, teachers need to support creative problem solving as students attempt to carry out an investigation, design methods of data collection or analysis, and synthesize what they've learned into something meaningful. Kolvoord, Charles, and Purcell (Chap. 18) describe a teacher who was excited because she had

> …developed a comfort level with instilling in her students a willingness to experiment. She's found that students don't lose respect when she can't provide answers, but rather appreciate her honesty and are excited for the opportunity to work together. (p. 440)

This creates a significant challenge for teachers because using geospatial technology can be as much about facilitating inquiry or project-based learning as it is about using new tools for scientific visualization (Kolvoord, Charles, and Purcell, Chap. 18). Baker and Kerski (Chap. 15) describe teachers' motivation to take the time to learn how to use GIS because of the potential for inquiry offered through the use of this tool:

> How did educators in the 1990s learn to use GIS given the lack of professional development? Eight responses indicated that they were self-taught. These educators were Innovators, willing to spend the time to experiment and willing to complicate their lives by working closely with community leaders, GIS professionals, their own IT staff, and administrators because they saw, early on, the value in the inquiry-based methods that GIS could support. (p. 362)

Finally, all of this implies that teachers must be able to facilitate *students constructing their own knowledge*. Project-based and inquiry-based instructions create rich opportunities for knowledge construction, and geospatial technologies are well suited to support this goal. Using geospatial technologies for group projects, students work together to solve problems, analyze data, and develop explanations – negotiating ideas and constructing knowledge through these social interactions. Knowledge construction also occurs on the individual level (Cobb, 1994). Supporting student learning requires a teacher to understand the affordances created by a specific technology and the ways in which that tool can best be used by students to encourage construction of knowledge individually or socially. The teacher of focus in the chapter by MaKinster and Trautmann (Chap. 16) addressed this in describing his approach toward using Google Earth to explore watersheds:

> I can use words and describe a watershed; however, [understanding the concept of a watershed] on their own requires the students to want to listen to me. In a public school I have a continuum of students in terms of willingness and ability. By using Google Earth, I don't need to explain a watershed; they see and experience it for themselves. My perspective reflects that of Kahlil Gibran from The Prophet, I can't give you my understanding; you have to arrive at it for yourself. I'm merely there to help [students] along the way. (Teacher Interview)

Supporting student learning requires a teacher to understand the affordances created by a specific technology and the ways in which that tool can be best used by students to encourage construction of knowledge, individually or collectively.

20.3.6 Technological Pedagogical Content Knowledge (TPACK)

Much of the research literature has focused on defining TK, PK, and CK and on describing how these come together to form TPACK. Little attention has been paid to serious exploration and exposition of the epistemological foundations of *Technological Content Knowledge* and *Technological Pedagogical Knowledge* (reviewed in Voogt et al., 2013). Defining TPACK is challenging because it involves combining three types of knowledge. Each of the characteristics listed under TPACK in Table 20.1 include all three dimensions of technology, pedagogy, and content. This book provides a comprehensive exploration of how these three types of knowledge come together to produce meaningful opportunities for teachers and students. These findings can be used to inform further design, implementation, and study of professional development opportunities in support of teaching science with geospatial technology. The two cases described below further illustrate ways in which TPACK manifests itself when using geospatial technologies to teach science.

Urban Street Tree Project. The Urban Street Tree Project at Boston College and the Urban Ecology Institute (Houle and Barnett, Chap. 2) integrates technological, pedagogical, and content knowledge to engage students in meaningful learning based on the recognition that city street trees play significant positive ecological roles (McPherson et al., 1997). This project engaged students and teachers throughout Boston in conducting an urban street tree inventory using tablet PCs and CITYgreen, a software package developed by American Forests that is an extension of ArcGIS desktop. Participants collect data on tree location and condition to evaluate the economic value of street trees on outcomes such as storm water runoff, energy savings, and air pollution removal. As described by Houle and Barnett (Chap. 2),

> The students can also evaluate the impact of street trees on air quality and the rate of carbon sequestration and determine how much carbon is stored in their urban street tree sample; however, what is perhaps most powerful about this project is that once students have collected their data (or used data from an existing street inventory for a given neighborhood, schoolyard, or park) and conducted an initial baseline data analysis, they can then ask "what if" questions. For example, in the city of Boston there has been significant news coverage of the "Big Dig," a decade-long road construction project in which the city has diverted the major interstates that were running through city into underground tunnels and is currently in the process of converting the reclaimed land into green space. Through the use of CITYgreen, students can now model both the economic impact and the ecological benefits of the Big Dig. In another example, students can explore the impact of planting trees around their own school or neighborhood and evaluate the impact on the school's energy savings over time. (p. 27)

The Urban Street Tree Project provides an authentic context for student inquiry by having students contribute to a citywide debate regarding one of the largest construction projects in the country. When considered from the perspective of TPACK (Table 20.1), the Urban Street Tree Project provides one example of how technology can be used to *represent science and environmental concepts in ways that are compelling and engaging within the context of project-based or inquiry-based lessons* (Table 20.1). The project team has worked with teachers and professionals to *design and implement instructional sequences using geospatial technology that enable students to make connections to larger and more complex environmental problems and/or scientific issues* (Table 20.1). Using the same technologies as professionals, they pose ecological questions about their local environment and document the impact of a project at their school or in their home neighborhood.

The Urban Street Tree Project uses tools that reflect the best of what geospatial technologies have to offer. Using interactive software on a tablet PC, students enter data in the field and explore or analyze those data using the same software and Google Earth back in the classroom. The power of the GIS and visualization tools is described by Houle and colleagues (Chap. 2):

> …it is now possible to combine these systems with computational modeling tools. These computer systems make it possible for urban ecologists to explore multiple potential solutions to problems by asking "what if?" questions and obtaining feedback that informs the decision making process (Maguire, 1991). In these ways, geospatial tools support the practices of urban ecologists, and thus potentially provide access to those practices for students and teachers learning about the ecology of complex urban relationships. (Beckett & Shaffer, 2005) (p.17)

When viewed from the perspective of TPACK, teachers are supporting *students in generating explanations or conclusions as they interpret geospatial scientific* *data and evidence* (Table 20.1). Student motivation is high because they get to ask and investigate the same content-focused questions pursued by professionals, wrestling with science and environmental concepts such as *air quality, carbon sequestration, storm water,* and *tree growth over time*. They make intuitive connections between the places in which they live and the representations they see and interact with on the screen. These and other affordances foster student ownership and enhance the teacher's ability to provide authentic learning opportunities.

Eyes in the Sky. The Eyes in the Sky project (McAuliffe, Chap. 6) is another example of a project exemplifying how TPACK manifests itself in relation to geospatial technologies. The focus on a local and regionally relevant environmental disaster provided teachers and students with a motivational context for learning as they used a variety of geospatial data analysis techniques:

> …teachers used GIS and image analysis to investigate the Aspen Fire on Mount Lemmon near Tucson, AZ. This fire burned more than 80,000 acres in the summer of 2003, destroyed hundreds of homes and businesses and caused millions of dollars of damage. Using two key GIS analysis techniques—feature querying and spatial querying—teachers explored how the fire spread and determined the daily extent of damage during the twenty-six days the fire burned out of control. Participants compared infrared and true-color images of the fire, readily distinguishing burned areas from healthy vegetation. In the process, they learned how GIS is routinely used to help firefighters and other agencies create strategic plans when dealing with natural hazards, including locating resources and determining areas with the highest risk. (p. 114)

Again, this scenario highlights the Eyes in the Sky approach to engaging teachers and students with geospatial technology through *instructional sequences that enable students to make connections to larger and more complex environmental problems* (Table 20.1; Bodzin, Anastasio, and Kulo, Chap. 13). Fire and fire management are persistent concerns to those who live in the southwestern USA, and geospatial technologies provide powerful tools for analyzing past events and predicting effects of possible mitigation measures.

McAuliffe and colleagues (Chap. 6) explicitly state their desire to provide teachers and students with the technological skills necessary to conduct significant data analysis using GIS software. Their philosophy was based on providing users with tools that enabled them to see and analyze geospatial problems:

> …the Eyes in the Sky professional development program included activities and investigations that specifically highlighted geospatial data analysis techniques, such as measuring distance and area, constructing and deconstructing multispectral images, and performing queries. The suite of geospatial data analysis techniques explicitly taught during the Eyes in the Sky program could then be applied by teachers and students to many different investigations of environmental issues. (p. 115)

Within such a context, teachers had to manage small groups, support students using the technology, and ask questions in ways that contributed to student understanding of key science and environmental concepts. Teachers were using *geospatial technologies to both teach specific science concepts and implement appropriate teaching strategies effectively* (Table 20.1). Participating teachers could choose whether to use the Aspen Fire project or use the same data analysis techniques and skills within a context that was more relevant to their students and curriculum. This type of formative and summative assessment is a great example of how the project team and the teachers were able to incorporate *authentic geospatial technology-based assessments that provided students with opportunities to apply what they've learned and mirror practices and products of real-world science* (Table 20.1).

The Urban Street Tree Project and the Aspen Fire scenario highlight the ways in which successful geospatial inquiry requires teachers to balance and integrate their knowledge of technology, pedagogy, and science content. Within any given project, and almost at any given time, teachers simultaneously rely on all three of these knowledge domains individually or collectively. Success depends on the extent to which they can integrate their knowledge to determine the best ways to teach a specific concept or skill, selecting from a range of pedagogical approaches and technological options. Depending on the course, grade level, or academic ability of a teacher's students, he or she must *adapt existing geospatial technology and data to improve its effectiveness in representing science concepts for specific learners* (Table 20.1). Both the Eyes in the Sky and the Urban Tree Project illustrate the ways in which a multitude of understandings and skills converge in order for a teacher to implement projects that reflect true integration of all three knowledge domains (Fig. 20.1 and Table 20.1).

20.4 Conclusion

Creating meaningful contexts for learning using geospatial technology requires teachers to integrate knowledge about technology, pedagogy, and science. This integration is represented as TPACK. Defining TPACK is challenging due to the number and types of knowledge that contribute to successful teaching and learning. Here we have defined TPACK specifically in relation to teaching with geospatial technology to provide a framework within which project designers and researchers can consider each dimension when designing and studying professional development experiences and related curricular materials.

Teachers often bring considerable pedagogical and content knowledge to the table when participating in professional development. The challenge for project leaders is to go beyond facilitating teacher learning about technology, aiming instead to help teachers integrate their new technological knowledge with what they already know in terms of what and how to teach in order to facilitate the adoption and enactment of geospatial technologies into the curriculum. They likely will learn new science or environmental concepts and pedagogical strategies as well, but the extent to which this is a goal varies considerably from one project to the next and from one teacher to another. The projects presented in this volume collectively provide a strong foundation upon which to base future efforts to engage teachers and students in meaningful and successful geospatial inquiry and to determine the outcomes and results.

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