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

J. MaKinster (✉)
Hobart and William Smith Colleges, 300 Pulteney St., Geneva, NY 14456, USA
e-mail: makinster@hws.edu

N. Trautmann
Cornell Lab of Ornithology, 159 Sapsucker Woods Road, Ithaca, NY 14850, USA
e-mail: nmt2@cornell.edu

J. MaKinster et al. (eds.), *Teaching Science and Investigating Environmental Issues with Geospatial Technology: Designing Effective Professional Development for Teachers*,
DOI 10.1007/978-90-481-3931-6_20,

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

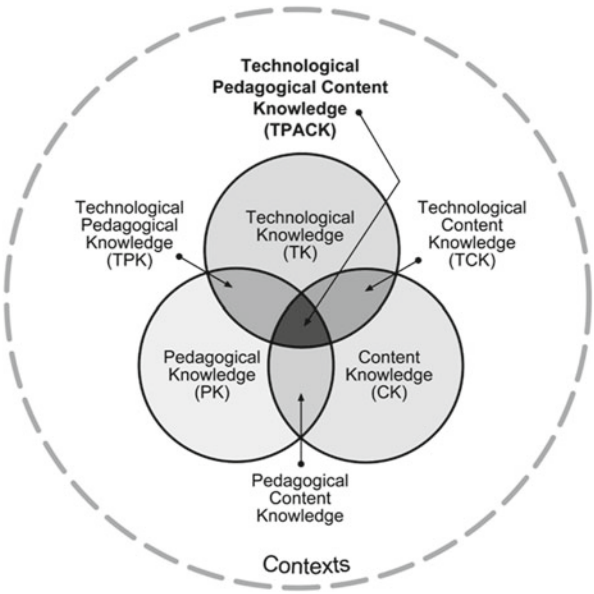

Fig. 20.1 Technological pedagogical content knowledge diagram from Koehler and Mishra (2009) (Reproduced by permission of the publisher, © 2012 by tpack.org)

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.

References

Barab, S. A., Squire, K., & Dueber, B. (2000). Supporting authenticity through participatory learning. *Educational Technology Research and Development, 48*(2), 37–62.

Barnett, M., MaKinster, J., Trautmann, N., Vaughn, M. H., & Mark, S. (2013). Geospatial technologies: The present and future roles of emerging technologies in environmental education. In B. Stevenson, M. Brody, J. Dillon, & A. E. J. Wals (Eds.), *International handbook of research on environmental education*. New York: Routledge.

Beckett, K. L., & Shaffer, D. W. (2005). Augmented by reality: The pedagogical praxis of urban planning as a parthway to ecological thinking. *Journal of Educational Computing Research, 33*(1), 31–52.

Borthwick, A., Charles, M., Pierson, M., Thompson, A., Park, J., Searson, M., et al. (2008). Realizing technology potential through TPACK. *Learning and Leading with Technology.* September/October 2008. *36*(2), 23–26.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher, 23*(7), 13–20.

Cox, S. (2008). *A conceptual analysis of technological pedagogical content knowledge*. Unpublished doctoral dissertation. Provo, UT: Brigham Young University.

Edelson, D. C., Schwille, K., Bruozas, M., Lach, M., Taber, M., Gordin, D. N., et al. (2005). *Investigations in environmental science: A case-based approach to the study of environmental systems*. Armonk: It's About Time.

Gess-Newsome, J., & Lederman, N. G. (1999). *Examining pedagogical content knowledge*. Dordrecht: Springer.

Koehler, M. J., & Mishra, P. (2008). Introducing TPCK. In: AACTE Committee on Innovation and Technology (Ed.), *The handbook of technological pedagogical content knowledge (TPCK) for educators* (pp. 3–29). Mahwah: Lawrence Erlbaum.

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, *9*(1). Retrieved May 5, 2009, from http://www.citejournal.org/vol9/iss1/general/article1.cfm

Loughran, J., Berry, A., & Mulhall, P. (2007). Pedagogical content knowledge: What does it mean to science teachers? In R. Pinto & D. Couso (Eds.), *Contributions from science education research* (pp. 93–105). Dordrecht: Springer.

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education, 31*(2), 289–307.

Maguire, D. J. (1991). An overview and definition of GIS. In J. Maguire, M. F. Goodchild, & D. W. Rhind (Eds.), *Geographical information systems* (pp. 9–20). New York: Wiley.

McPherson, E. G., Nowak, D., Heisler, G., Grimmond, S., Souch, C., Grant, R., et al. (1997). Quantifying urban forest structure, function, and value: The Chicago urabn forest climate project. *Urban Ecosystems, 1*, 49–61.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A new framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

National Research Council. (2000). *Inquiry and the national science education standards*. Washington, DC: National Academy Press.

Palfrey, J., & Gasser, U. (2010). *Born digital: Understanding the first generation of digital natives*. New York: Basic Books.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(1), 4–14.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–22.

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*, 673–695.

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical content knowledge taxonomies. *Electronic Journal of Science Education, 3*(4). Retrieved December 27, 2010, from http://unr.edu/homepage/crowther/ejse/vealmak.html

Veal, W. R., van Driel, J., & Hulshof, H. (2001). PCK: How teachers transform subject matter knowledge. *International Journal of Leadership in Education, 4*(3), 285–291.

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge – A review of the literature. *Journal of Computer Assisted Learning, 29*(2), 109–121.