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ARTICLE

GIS professional development for teachers: lessons learned from high-needs schools

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ABSTRACT
University faculty partners from the Departments of Geography and Instruction and Teacher Education at a large, public university collaborated with K-12 teachers and the leadership of a rural school district in order to investigate the crosscutting content of science, mathematics, and geography through the integration of web-based GIS technologies. The project explored the critical connections among technology, pedagogy, and content with a particular emphasis on developing technology-enhanced, inquiry-based lessons in which the teachers and their students used GIS technologies to analyze, visualize, and present data in real-world contexts. The findings highlight the importance of well-structured professional development that builds community, integrates diverse content and pedagogical expertise, provides feedback and coaching, and is of sufficient duration to effect change.

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Introduction

As technology permeates society, so have its applications in the classroom. By providing broad avenues for learning, technology allows teachers to support a wide-range of learners in their classroom (Pilter, Hubbell, & Kuhn, 2012). One example of how technology has revolutionized both the way an individual interacts with their location in space and time is mapping technology (i.e. GIS technology). During the not-so-distant past, an individual would explore location using static maps and globes, anchoring the map reader in place. This is no longer the case as now mapping technology compels an individual to analyze location with a flexibility and precision that is transformative. Moreover, it allows for the simultaneous exploration of multiple content areas through meaningful, relevant, and thought-inducing tasks that are framed in the exploration and analysis of geographic data with specific attributes (Coulter & Kerski, 2005). It is with an emphasis on coherence that we discuss our work aimed at addressing teachers and students' awareness of crosscutting content while using mapping technology.

Through a grant-funded project, university faculty partners from the Departments of Geography and Instruction and Teacher Education at a large, public university collaborated with K-12 teachers and the leadership of a rural school district in order to investigate the crosscutting content of science, mathematics, and geography through the integration of web-based GIS technologies such as Esri's ArcGIS Online. In order to avoid solely discussing "flashy" technology tools or by stressing an overreliance on technology skills, the project emphasized knowing how to appropriately incorporate technology as well as how the technology can be used in the K-12 teachers' unique settings/content areas. As such, the underlying emphasis of the project was to explore the critical connections among technology, pedagogy, and content with a particular emphasis in developing technology-enhanced, inquiry-based lessons in which the teachers and their students use GIS technologies to analyze, visualize, and present data in real-world contexts.

Teaching with GIS

Benefits of GIS to students

Exciting uses of GIS in the K-12 classroom are appearing more regularly than ever before. Kerski, Demirci, and Milson (2013) ably explore many examples in their global survey of GIS in secondary education. A singular example at this level is the Geospatial Semester in Virginia where the participating students pursue extended projects in areas of interest; the research skills that they develop appear to be equivalent to or greater than students enrolled in Advanced Placement® courses (Kolvoord et al., 2013). Other successes have

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been recorded at the middle level (Goldstein & Alibrandi, 2013) and for elementary grades (Jadallah et al., 2017). The wherewithal to advance GIS in K-12 education is due to a variety of perceived benefits to students, again well-summarized by Kerski et al. (2013). These benefits include, among others, support for inquiry-based learning, the study of real-world problems, cooperative and collaborative learning, and the development of spatial thinking skills.

Despite benefits and the noted successes, the use and implementation of geospatial technologies in the K-12 school environment continues to remain low (Baker et al., 2015; Kerski, 2003; Kerski et al., 2013). Well-known historic challenges remain which hamper the adoption and integration of geospatial technology into the school curriculum. For instance, funding continues to be a challenge. Online GIS options have eliminated some of the cost barrier, but computers and networks still require acquisition and support. Teachers also cite both a lack of time and motivation to participate in professional development (Höhnle, Fögele, Mehren, & Schubert, 2016; Kubitskey, Fishman, Johnson, Mawyer, & Edelson, 2014), a critical undertaking for what can be a complicated process (learning to use GIS effectively).

A newer wrinkle relates to student assessment, a top priority in many local education agencies (LEAs). This focus on assessment, and its attendant testing, potentially can leave little room for innovative pedagogical techniques if seen as too time consuming and irrelevant. This is a surmountable problem as Goldstein and Alibrandi (2013) have been able to demonstrate relevancy in this realm. For example, the researchers found that Florida middle-school students with GIS as part of their curriculum achieved significantly higher scores in reading and on final course grades in science and social studies. The funding challenge has improved, and the assessment conflict is addressable. What remains is creating well-trained teachers who are capable of introducing and sustaining GIS use in the K-12 classroom.

Strategies for teacher professional development

How do we get teachers to adopt and use geospatial technology? What structures are necessary for successful implementation? Others have asked these or similar questions (Baker et al., 2015; Hong & Stonier, 2015). It seems clear that the benefits of classroom implementation will not come to fruition if teachers are not prepared and well-trained for geospatial technology use.

Baker et al. (2015, p. 124) explain that a teacher must decide that an "instructional learning activity is best suited to achieve desired student learning goals." In other words, teachers (and administrators) must have curricular buy-in for the implementation of geospatial strategies and techniques. Furthermore, professional development that combines concepts related to technological pedagogical content knowledge (TPACK; see Figure 1) (Baker et al., 2015; Doering, Koseoglu, Scharber, Henrickson, & Lanegran, 2014; Koehler & Mishra, 2008; Voogt, Fisser, Pareja Roblin, Tondeur, & Van Braak, 2013), in which teachers are not only trained "about" GIS, but are trained to teach "with" GIS using pedagogically sound techniques, is critical (Baker et al., 2015; Hong & Stonier, 2015; Sui, 1995; Trautmann & MaKinster, 2010).

As the name indicates, the TPACK framework includes three main components, content, pedagogy, and technology, by extending Shulman's (1986) notion of pedagogical content knowledge to include technology. TPACK furthers a teacher's understanding of these three components by emphasizing the importance of the dynamic relationships between them; it has been described as the intersection of technology, pedagogy, and content knowledge. As a result, the TPACK framework shows that technology integration requires much more than technology skills. To this point, Mishra and Koehler (2006) contended that a teacher solely introducing technology into their practice is insufficient; teachers need to know how to appropriately incorporate technology as well as how the technology can be used in their unique educational settings. As Coulter and Kerski (2005, p. 330) surmised, "…technology is a tool or resource, suitable for specific

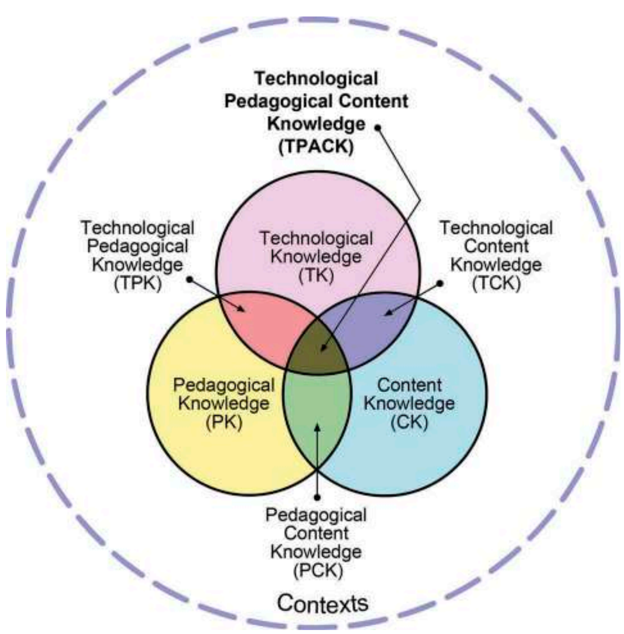

Figure 1. Technological pedagogical content knowledge. Reproduced by permission of the publisher, © 2012 by tpack.org.

situations where the work either couldn't be done without the tool or couldn't be done as well."

Niess (2005) identified the following four considerations for teachers who want to teach with technology: (a) a purpose for incorporating technology when teaching mathematics or science; (b) knowledge of students' understanding, thinking, and learning mathematics or science with technology; (c) knowledge of curricular materials that integrate technology; and (d) knowledge of instructional strategies and representations for teaching and learning mathematics and science with technology. Similarly, Mason et al. (2000) identified the following principles necessary for the integration of technology in the social studies class: (a) extend learning beyond what could be done without technology, (b) introduce technology in context, (c) foster the development of the skills, knowledge, and participation as good citizens in a democratic society, (d) contribute to the research and evaluation of social studies and technology, and (e) include opportunities for students to study relationships among science, technology, and society. It is with the final principle in mind that the TPACK framework supports a fruitful intersection of content areas (i.e. mathematics, science, and geography) when students explore geospatial technology (Doering et al., 2014; Hong, 2014; Hong & Stonier, 2015).

Henry and Semple (2012) and Riihelä and Mäki (2015) reiterate the importance of easing the learning associated with using GIS in the classroom. Teachers and students may not be used to working with databases and this type of software, at least not in non-geography courses. These sets of authors submit five important characteristics for successful GIS implementation in the classroom:

- The GIS software [used in classrooms] should not appear intimidating.
- A teacher should be able to learn the basic features of the tool in one to two hours.
- Learning to operate the GIS software should not get in the way of using it for instructional purposes.
- The geospatial data needed to use the GIS should be preprocessed and included integrally.
- Technical and administrative support should be available as teachers begin to explore the use of GIS in classroom instruction.

To these points, Hong (2014) adds the need to involve teachers in the design of training materials and their own activities. Other recent work has focused on what type of GIS training can be reasonably accomplished in a given time frame (Millsaps & Harrington, 2017).

In this project, we integrate the aforementioned design elements and also include those from Höhnle et al. (2016). These include: (a) time/duration – appropriate time to be taught, to explore, to develop; (b) professional learning communities – a support mechanism during training; (c) institutional framework – district and school level backing; (d) integration of diverse expertise – technology and content area experts; (e) subject matter knowledge – connecting GIS to established curriculum for relevancy; and (f) feedback/coaching – lesson observation and suggestions for improvement. These elements, in some form, have been corroborated by Hong and Melville (2018).

Project background

Schools and teacher participants

Eighteen teachers from five schools – one primary, two elementary, one middle, and one high school – initially volunteered to participate in the project (Table 1). Two of the teachers, both of whom taught at the elementary level, were from a neighboring school district. Both rural school districts are classified as high-needs LEAs and are part of counties with a median household income below the state average. Funding for this project was provided, in part, due to this LEA classification, as well as a highly variable student achievement rate on state test assessments (generally below the state average, especially in science), and alignment with the districts' technology plan.[1] The participants had as few

Table 1. Participant background.

Participant	Grade	Content area	Conference[a]	Full Training[b]
Female	K-2	Media/Library	✓	✓
Female	K-5	ESOL	✓	✓
Female	3–4	Mathematics	✓	
Female	3–5	Mathematics	✓	
Female	4	All Subjects	✓	
Female	5	Mathematics	✓	
Female	5	English/Social studies	✓	
Male	6	World History	✓	
Female	6	Mathematics	✓	✓
Female	6–8	Computing	✓	
Male	7	World History		✓
Female	7	Mathematics	✓	✓
Male	8	Science		
Female	8	Mathematics	✓	
Male	9–10	Mathematics	✓	✓
Female	9–10	English	✓	
Male	9–12	Social studies	✓	✓
Male	9–12	Social studies	✓	✓

[a]Each participant was asked to present their GIS-enhanced lesson at either a state-level social studies or mathematics conference. All expenses to attend were covered.

[b]Eight participants completed all aspects of the project, including full participation in Year 2 summer training. Attrition reasons varied: pulled by district into other professional development, lack of continued interest, ill-health, moved to another state.

as four and some more than 20 years of teaching experience.

This project began with the premise that geography should be integrated into the curriculum wherever geography is found. This includes a stand-alone geography course as well as any other content area (e.g. mathematics, English/Language Arts, physical science). Further, we believe that certain geospatial technologies are interdisciplinary in nature and leveraged this project to investigate with the teachers not only how to utilize GIS, but how to conceptually teach with GIS. As such, the teachers represented grades kindergarten through grade 12 and taught a wide variety of content areas and instructional settings including science, mathematics, social studies, English, and computing. To this point, one participant in the project was a media specialist and another was a teacher of English for Speakers of Other Languages (ESOL) in one of the elementary schools (this county has the state's highest percentage of Hispanics as part of its total population).

A pre-workshop questionnaire found that the participants were generally confident about their spatial and technology skills, but also confirmed that room for growth was possible. For example, the following are a few of the results from a series of yes/no items:

- I enjoy looking at maps and globes (100% yes)
- I use spatial terms such as scale, distribution, pattern, and arrangement (61% yes)
- When trying to solve some types of problems, I tend to consider location and other spatial factors (78% yes)
- I am comfortable teaching with maps (83% yes)
- I am comfortable teaching with technology (78% yes)
- I know what spatial thinking is (67% yes)

Although the participants evinced positive thoughts overall regarding the potential for spatial-oriented instruction, only one teacher had taken more than one geography course during their collegiate studies. More telling was that several had taken no geography courses at all.

Project implementation

The general program consisted of a one-week geospatial technology professional development (PD) institute followed up with one-day PD sessions throughout the school year aimed at refining lesson ideas, a presentation at a state-wide educator conference, and a second one-week institute the following summer (see Table 2). The

Table 2. Activities timeline.

Date	Activity
July 2015	Institute: participants were introduced to spatial thinking concepts, geospatial technology (specifically online geographic information systems), and cross-curricular integration with geography, ELA, math, and science. Lessons were developed using existing state academic standards that combined the new technology with the content area.
September 2015	One day session to refine lessons, trouble-shoot technology.
September 2015	Eight participants presented work at state social studies conference.
October 2015	Six participants attended geography education conference to learn more geography content.
October 2015	One day session to refine lessons, trouble-shoot technology.
November 2015	Eight participants presented work at state math conference.
February 2016	One day session to refine lessons, trouble-shoot technology.
February 2016	Six participants attended geography education conference to learn more geography content.
March 2016	One day session to refine lessons, trouble-shoot technology.
July 2016	Institute: participants were introduced to GeoInquiries (online mapping activities using GIS platform learned earlier). New lesson strategies were developed using existing state academic standards that combined the new technology with the content area.
Various dates 2015/2016	Classroom observations to suggest ways to improve technology use and delivery with developed lessons.

teachers recruited to participate were incentivized with a $100 stipend for each session attended for up to $1,700.

Throughout the project period, the K-12 teachers participated in professional development exploring ways geospatial technologies could be integrated into their content areas while also being aligned to the state's college and career readiness standards. A major emphasis of the project was for the university faculty to support the K-12 teachers in developing technology-enhanced, inquiry-based lessons, in which the teachers and their students use GIS technologies to analyze, visualize, and present data in real-world contexts. As such, the instructional team designed learning experiences to include segments on geographic information systems, cartographic visualization, science, technology, engineering, mathematics, and integrated lesson development.

The instructional team consisted of two geography faculty (i.e. human geography, environmental geography), two education faculty (i.e. social studies education, mathematics education), and a GIS specialist. All instruction and observation were carried out by this group, with additional observation conducted by the two district-level curriculum coordinators and one external evaluator. Four project goals were proposed:

(1) Changes in Teacher Content Knowledge: Teachers would deepen their content knowledge

of science, mathematics, and geography, aligned with appropriate college and career readiness standards

(2) Changes in Teacher Pedagogical Knowledge: Teachers would learn to develop and implement technology-enhanced, inquiry-based lessons, in which students use GIS technologies to analyze, visualize, and present their data
(3) Changes in Teacher Practice: Increase the rate and quality of implementation technology-enhanced, inquiry-based lessons in the classroom
(4) Changes in Student Learning Outcomes: Students would use web-based GIS technologies to better learn science, mathematics, and geography content

These goals were evaluated by pre/post assessment of the participant's spatial thinking skills, an iterative review of their lesson development, one-on-one debriefing conversations, and observations of the lessons as taught.

The general work product expected after the training was two complete inquiry-based lessons plans by the end of the second summer session. Given the varied teacher backgrounds, ages of students taught, and the different disciplinary areas covered, the lessons differed considerably in complexity and topic (see Table 3). Esri's ArcGIS Online software and several pre-made datasets were used to establish user ease; however, each teacher ultimately added data from other and/or local sources to connect to their existing instruction.

Results

Two stories

In this section, we provide two participant vignettes to highlight through their eyes how this project has impacted their instructional practice and content knowledge expertise. We follow this with a more general discussion of the findings provided via observation, survey, and the external evaluation.

Stephannie – ESOL

Stephannie is an elementary teacher; her small, rural school is located nine miles from the nearest population center where approximately 3,500 residents live. She has been teaching for 8 years total, with two of those years in Taiwan. She decided to participate in the GIS professional development as a way to integrate technology into her ESOL classes. Stephannie taught students in each grade from kindergarten through fifth grade, and she was hoping that online mapping "would allow them to see and experience places and things in real time that they have never seen before." She believes that the GIS lessons allowed her "to birth independent learners, by placing the learning in the hands of [her] students through the interactive technology."

Stephannie reported that her students were very eager to work with the interactive maps, finding the material to be fun. While she was able to work with other teachers over the course of the project, she does have one lament:

> To enhance the GIS training process, a dream come true would be to be able to collaborate with other ESOL teachers as we learn. ESOL tends to be an isolated, almost forgotten role in schools and often times we are left on our own to create effective curriculum for our students. If I could plan GIS lessons with other ESOL teachers, it would be incredible!

This is an important point for future work. Although we focused on many different disciplinary content areas across a wide range of grade levels during this professional development, there are more student populations to consider in the future. In addition to

Table 3. Select lesson topics.

Grade Level	Title	Synopsis
K	Our Community Walk	Students walk to visit the Town Hall, a police station, a fire station, a library, a courthouse, a museum and a church. As a precursor to this experience, students use this interactive map to see these places beforehand.
1	The Amazing Escape of the Crafts	"The Daring Escape of the Crafts" is the true story of a married slave couple who successfully escaped to Philadelphia dressed as a white man and his slave.
1	Schools and Neighborhoods around the World	Students identify and compare homes, schools and community buildings in their present home with homes, schools and community buildings in their birth countries.
4	Heading West	Students travel west on The Oregon Trail while making numerous stops along the way.
6	Integers in the Real World	Students look at different locations around the world to discover positive and negative integers.
7	Geometry and Measurement: Area of 2D shapes	Students explore areas of 2-dimensional shapes. They use the land features of the school to help the grounds crew.
8	Earthquakes-Comparing Magnitude and Depth: Exploring Scatter Plots and Lines of Best Fit	Students use information about earthquakes' magnitude and depth to investigate if there is a correlation between the two data sets using scatter plots and line of best fit.
9	No-Fly Drone Areas	Students investigate drone use, map no-fly areas, and debate the responsibility the United States government to keep citizens safe while not violating individual rights.

ESOL students, students with special needs or those with individualized education programs come to mind.

Stephannie's lesson was focused on having first-grade students identify and compare homes in their current community with those in their birth country, and she used just one computer and a projector in her classroom (see Figure 2).[2] Per this state's social studies literacy skills, the students were tasked with recognizing a map and describing the locations and conditions of places.

A simple web map (see Figure 3)[3] was sufficient for this task. The students were queried on differences between land and water and different map symbols; they could zoom in on their home community and make comparisons to other places (e.g. there are far more roads in Mexico City); and they could compare the shapes and colors of houses, fire stations, and other community buildings. From a geographic perspective, the technology was used to teach location, place and region, distance and direction, and density. The students were able to reason using maps while simultaneously supporting their usage and understanding of English.

Stephannie represents another – albeit unplanned – outcome of this work. As she became more comfortable in developing and teaching inquiry-based curricula, she was able to parlay this emphasis on geography into more teaching and learning experiences for her students. For instance, in 2016 she spent several days at the National Geographic Society in Washington D.C. to work on curriculum for emphasizing her state's standards as part of the Giant Traveling Map program. This type of leadership opportunity has been described by others (i.e. Yow & Lotter, 2016) and is an aspect of professional development that continues long after the training is completed.

Brandy – mathematics

Brandy has been a middle-level teacher for 5 years. As one of the early career (i.e. 5 years or less in the field) teachers in the participant cohort she also exhibits a propensity toward trying new and innovative technology like GIS, a trait noted elsewhere in research (Strachan & Mitchell, 2014). Brandy's content area background is in mathematics, and she created a Story Map where students explored different locations around the world to discover positive and negative integers in real life. These locations include the Dead Sea and Greece, among others (see Figures 4 and 5). Her sixth grade students individually used computers to explore the "use [of] integers to represent quantities in real-world situations" (the specific language of the learning indicator).

Brandy designed her learning goals to use the technology to address and go beyond the mathematics content standards by having her students compare how integers have different meanings in mathematical contexts (see Leonard, Russell, Hobbs, & Buchanan, 2013 for more on place-based learning, GIS, and mathematics). In so doing she integrated social studies, science, and reading to her existing mathematics instruction. In her lesson, Mount Everest and the

Figure 2. Elementary students using a web map to explore their homes versus those in other countries.

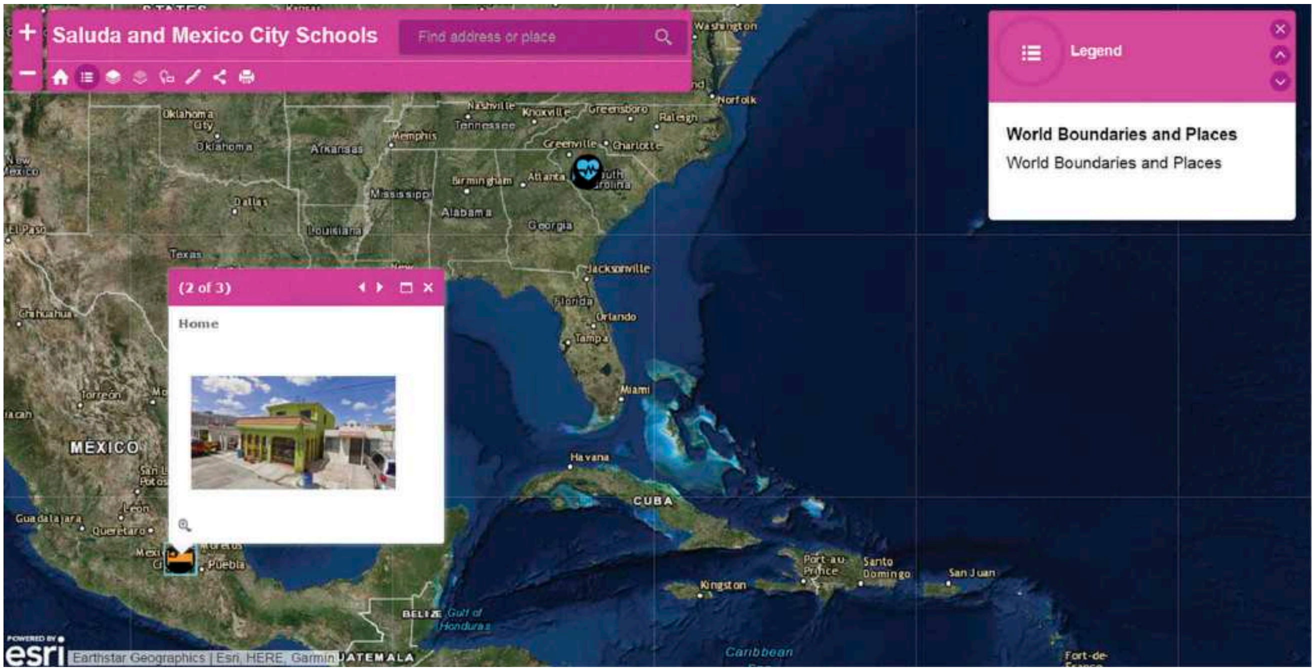

Figure 3. Sample web map showing a picture of a home in Mexico City. Data provided courtesy of Esri and its licensors.

Dead Sea served as elevation providing context to integers where students could explore elevations that are above and below sea level. She also developed a lesson where questions about Greece took the students to a linked article on debt where the negative integers were explored as a budget deficit. During both lessons, Brandy's students explored integers to represent quantities in real-world situations.

As a teacher, Brandy "wanted to be able to use technology to make real-world connections with [her] students…The GIS training sounded like technology that would be more useful as time goes on and giving students experience with it was important to [her]." Like others in her cohort, she believes that her pedagogical approach also has evolved as a result of the professional development:

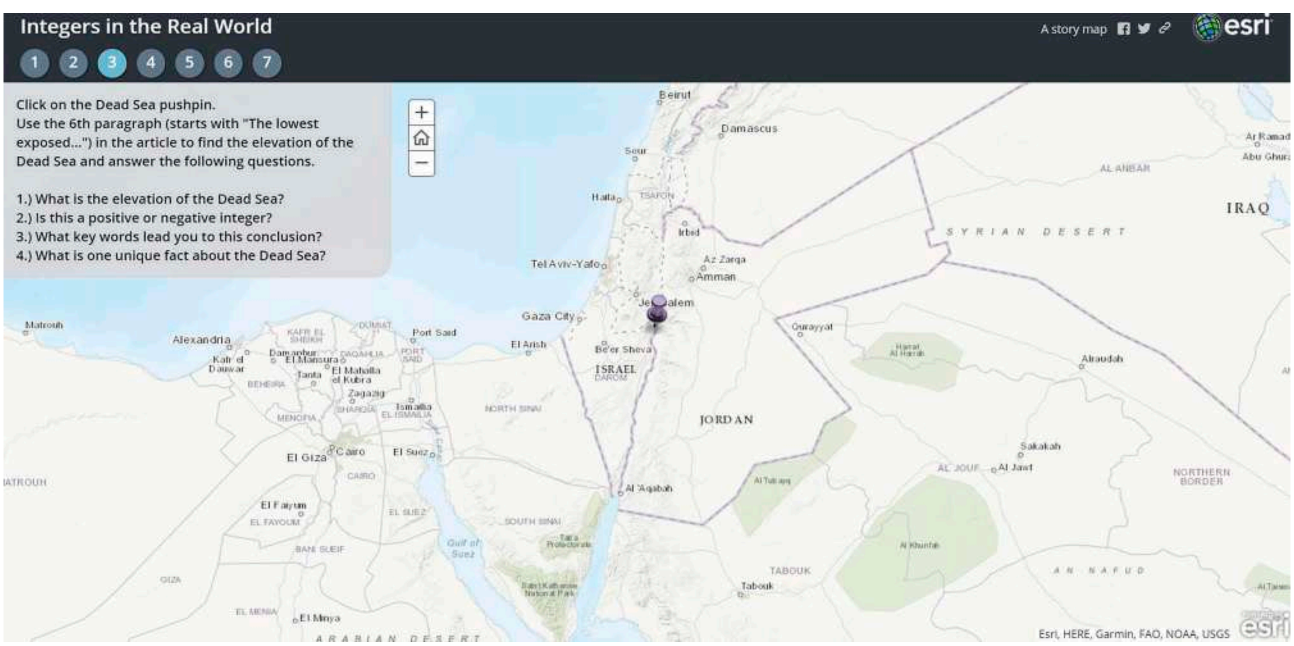

Figure 4. Story map using the Dead Sea to teach integers in a middle-level mathematics course. Data provided courtesy of Esri and its licensors.

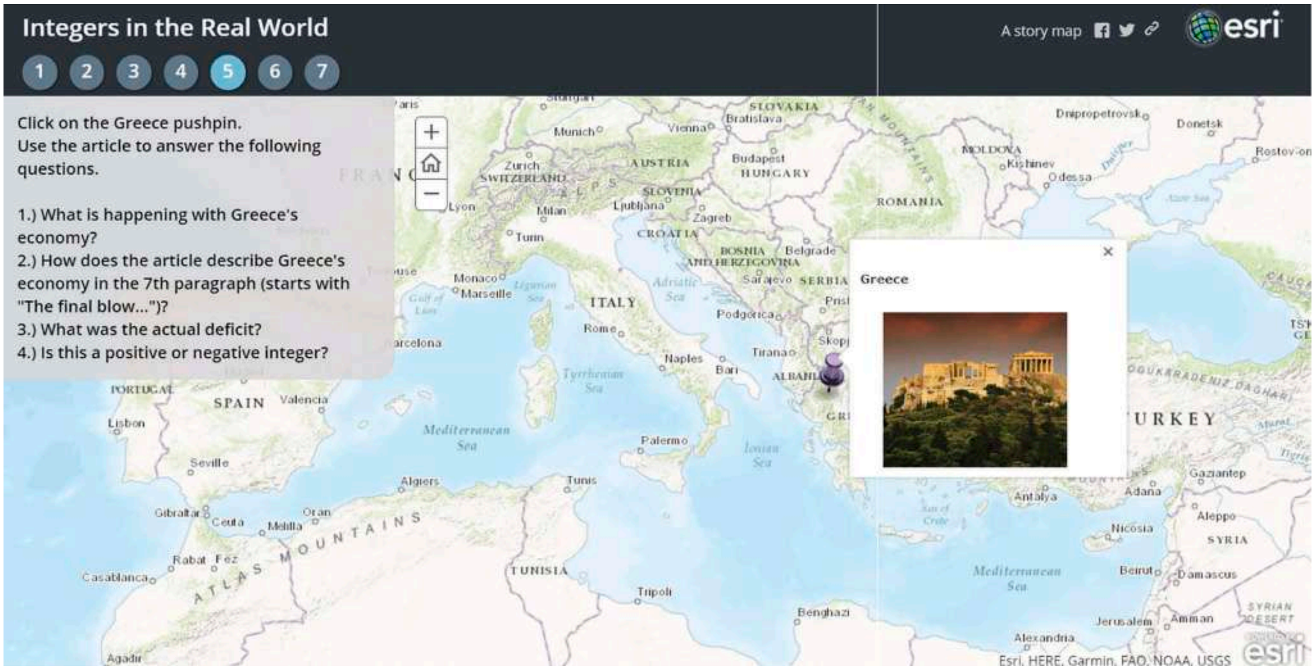

Figure 5. Story map using Greece's economy to teach integers in a middle-level mathematics course. Data provided courtesy of Esri and its licensors.

> I was able to develop lessons that were inquiry-based. Students had to use the technology to make connections and discover the material. It changed my lessons from the traditional classroom to a student-led classroom. . .My students responded well to the instruction. There was a learning curve at first since it was not what they were used to, but they eventually got the hang of it. They really enjoyed discovering things for themselves and then making connections to other curriculum and just everyday life.

Brandy, just like Stephannie, leveraged her experiences in the GIS professional learning community not only for collaboration and interaction, but also as a pathway for undertaking teacher leadership opportunities (Brysch & Boehm, 2013). During the past year she has presented a workshop on GIS to the other teachers in her school. This is an example of "turnaround training" (Hansen-Thomas, Casey, & Grosso, 2013) where teacher quality can be supported and improved by teachers training other teachers (York-Barr & Duke, 2004). One other major leadership accomplishment occurred when Brandy represented her state in 2017 at a Geo-Inquiry Process Institute at the National Geographic Society.

Overall/group outcomes

The two vignettes provide echoes of what truly matters for effective teacher professional development when using geospatial technology across a variety of curricular content areas. Our group findings are similarly instructive, and we present them here to add to the growing lists of indicators of effectiveness for GIS teacher training (Höhnle et al., 2016; Hong & Melville, 2018) and professional development more generally (Ball & Cohen, 1999; Elmore & Burney, 1999; House, 1994; Little, 2001).

Duration/time resources

While the need for effective training is more relevant than ever, GIS workshops are often short in duration where little or no follow up or ongoing support is provided (Baker et al., 2015). Success teacher implementation requires long-term support instead of one-time professional development sessions. During this project, two full weeks of professional development as well as several follow-up sessions over the course of one year allowed participants to grow in their confidence and competence with GIS software. It also allowed the participants to experiment with different techniques to improve their pedagogy. This finding substantiates that of Walshe's (2017, 16) work with pre-service geography teachers where she found "that the gradual yet repeated exposure to GIS with increasing complexity across the year supported the development of their practice" (see also Harte, 2017).

Professional learning communities

Change in teacher practice is both an individual process and one that can improve with support. A strong cohort of learning peers was developed among these participants, with teachers from different disciplinary areas assisting and working with each other. These learning collaborations can also extend beyond the school. For instance, during this project, sixteen of the eighteen participants attended and presented at either the state level social studies or mathematics professional teaching conferences. Prior to the project, most of the teachers had not attended an academic conference so attending and presenting at one allowed the teachers entry into a larger community of content area colleagues than the rural ones they had been participating in prior to the project. With the guidance and support of the university instructional team, each teacher was responsible for presenting their inquiry-based lessons at one of the conferences. Doing so promoted the collaboration and exchange of integrated lessons that addressed the college and career readiness content standards. Moreover, since none of the participants had ever presented at a conference before, this approach resulted in sharing of grade-level lessons as well as promoting leadership development.

Institutional framework

Encouraging and improving educational use of GIS requires "buy-in" beyond the classroom teacher; administrative support is necessary (Hong & Melville, 2018). In all aspects of this project, district as well as school-based leaders and curriculum coordinators supported these efforts. This has led to a continued relationship between the project leaders and school district leadership around a new project.

Integration of diverse expertise

This project brought together both university experts from mathematics education, technology education, geospatial technology, learning sciences, social studies education, and environmental geography to support teachers as they explored ways in improving their disciplinary content knowledge and technology pedagogy. Importantly, project directors recognized the expertise and experience of the participants and used this to jointly create educational materials of best fit for their particular subject area contexts (e.g. mathematics, science, history, etc.).

Subject matter knowledge

Each participant began the project by working to integrate the new technology into existing teaching. This connection to the existing curriculum raised the feeling of relevance. No "canned" lessons were used, and as a result, inventive and creative solutions were found to elevate previous teaching (see Hong, 2014 on this point). For example, an eighth-grade mathematics teacher used the GIS technology to investigate scatter plots and a line of best fit. Students compared earthquake magnitude and depth to investigate whether a correlation between the two data sets existed. Not only did the students learn the state mandated mathematics content (graphing data on a scatter plot, describing patterns on a scatter plot), but they improved their mental map of the world and explored the scientific reasons behind the seismic pattern. Furthermore, many of the teachers extended student learning by having them collect data for mapping and analysis. This problem-focused approach using GIS technology provided students with real-world contexts that connect technology with the importance of geographic thinking. The participants also showed an increased use of geography concepts in their teaching and increased proficiency in GIS use.

Feedback/coaching

Several opportunities for coaching were provided by both the project team and the district support staff. Each teacher was observed using the GIS technology with their students and provided instructional feedback by the project team. The teachers responded positively to instructional suggestions for improving delivery to growing their confidence in using some of the more powerful, and admittedly challenging, features of the GIS software when teaching their students.

In sum, the project has resulted in a cohort of teachers willing to (a) invest the time necessary; (b) professionally support each other; (c) coordinate with administration; (d) work with and seek out external expertise; (e) grow their own subject content knowledge, proficiency with technology, and pedagogical expertise; and (f) accept critical feedback aimed at improving their instruction.

Meeting project goals

Earlier in this paper, we presented four project goals and we use this section to discuss those results.

Changes in teacher content knowledge

The first goal of the project was for teachers to deepen their content knowledge of science, mathematics, and geography. Given the varied backgrounds of these teachers, we focused on changes in geography concepts and spatial thinking including where these overlap within their own content areas.

Twelve geographical concepts were identified at the beginning of this project as foundational elements of high quality teaching and learning in geography. These included:

- Location
- Place and Region
- Distance and Direction
- Scale
- Overlay
- Distribution and Pattern
- Use of GIS
- Map projection
- Density
- Diffusion
- Spatial Correlation
- Reasoning Using Maps

The classroom observations found that the teachers collectively taught all twelve of the geographical concepts during the lessons they had developed in the 2015 summer workshop. The number of geography concepts included in each lesson ranged from as few as three concepts to as many as eight concepts; on the average each lesson included five geography concepts from the ones listed. Although we do not have baseline observations for comparison, the results of these classroom observations during the project suggests that the participants did improve their geographical content knowledge and were able to connect this knowledge to the state academic content standards in their content area.

We also had each participating teacher complete portions of the Spatial Thinking Ability Test (Lee & Bednarz, 2012) at the beginning of the first summer workshop in 2015 and again at the conclusion of the project in 2016. Because of participant attrition, we were able to collect only eight pairs of pre/post content knowledge data. A small (4.2%) average improvement in teacher knowledge was measured by this instrument. This meager gain has implications for greater emphasis on these skills during professional development, the potential for more follow-up training sessions, and even the need to further refine the instrument (Tomaszewski, Vodacek, Parody, & Holt, 2015).

Changes in teacher pedagogical knowledge

The second goal was for teachers to learn to develop and implement technology-enhanced, inquiry-based lessons, in which students use GIS technologies to analyze, visualize, and present their data. During both summer workshops, the teachers explored the capabilities of the ArcGIS Online platform and designed lessons that incorporated this technology. The participating teachers demonstrated a range of creative teaching uses in every documented classroom observation. With the exception of the use of ArcGIS Online, no specific pedagogy was advocated during the workshops, and the observation data shows that this approach can be integrated effectively in many ways, across the curriculum. The teachers were encouraged to consider how the students could actively engage with the ArcGIS Online platform to create their own geographical content, which would both promote independent learning and provide opportunities for students to demonstrate learning. In many cases, the participants did that, designing lessons that afforded their students opportunities to create their own map-based learning experiences. An end-of-workshop survey indicated that the participating teachers generally (although not always) encouraged learning through hands-on experience, and that they used a mixture of traditional and new assessment methods.

Changes in teacher practice

The third goal was to increase the rate and quality of implementation technology-enhanced, inquiry-based lessons in the classroom. ArcGIS Online was new to all the teachers, so the fact that all observed lessons integrated this platform demonstrates that the teachers were able to adapt – and in some cases, transform – their classroom practice through its use. In many cases, it also allowed them to experiment with new student-focused approaches to teaching content throughout the curriculum, and sometimes, to develop collaborative connections among the disciplines.

Changes in student learning outcomes

The fourth goal was for students to use web-based GIS technologies to better learn science, mathematics, and geography content. While we do not have end-of-course or other tests scores to assess student academic achievement, we can report that 88% of the participants said their students were more attentive and involved in classroom activities as a result of the professional development, and 63% said their students' work had improved noticeably. Lessons that engaged real-world scenarios – in other words, authenticity – were reportedly better received by the students (Figure 6).

Overall, our teachers generally expressed satisfaction with the program, with all agreeing with the statement "I participated in hands-on learning that I now use in my own classroom," and "I learned ways to integrate technology into my classroom." All respondents also said they would recommend this program to other teachers, with 75% saying that they feel they are more effective teachers.

Conclusion

The project described in this paper introduced participating teachers to a web-based GIS platform that

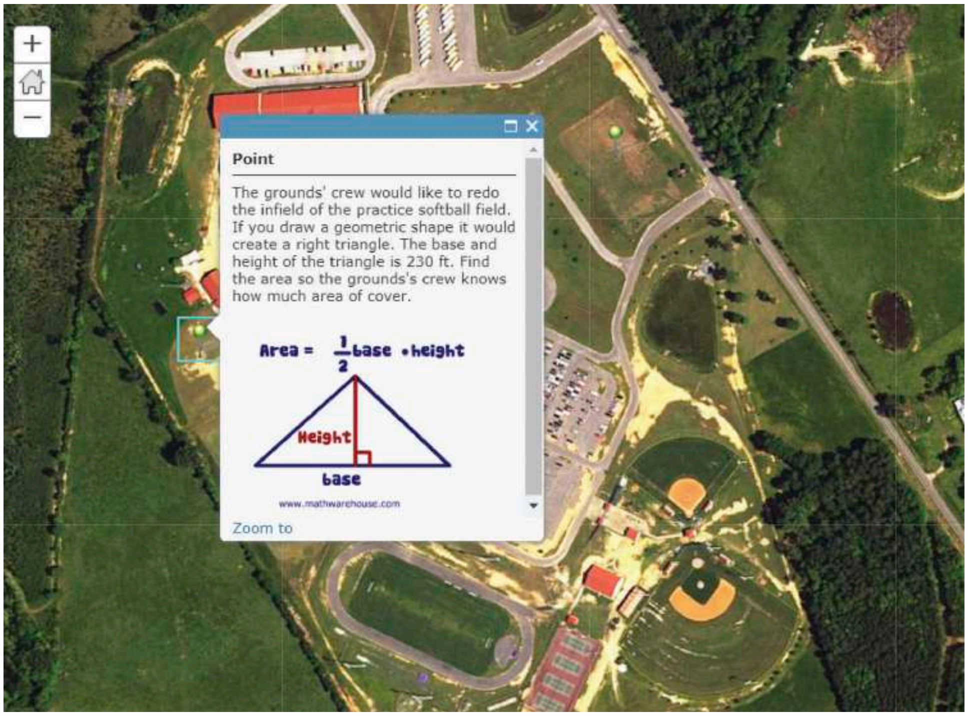

Figure 6. An example of a mathematics problem placed into a "real-world" context. Data provided courtesy of Esri and its licensors.

allows users to explore maps and map data. It also allows users to create their own maps. The teachers were challenged, first, to learn how to use this powerful and complex system, and then to design lesson applications for it in the context of their own teaching. Since the teachers represented grade levels from kindergarten through high school, as well as an array of academic disciplines, the project could not promote a cookie-cutter approach to using the tools made available by ArcGIS Online. Participant feedback during the summer workshops and during the school year sessions indicates that they successfully took on this challenge, creating lessons and units that in some cases pushed their capabilities as teachers. They also demonstrated that this technology has great potential as a tool for teaching and learning.

We recognize, however, there are a few areas for additional consideration. First, none of these teachers used the higher-level analytical capabilities of GIS (e.g. buffer). Most lessons created by the teachers were developed with static maps or story-boarded representations that were read by students with only limited amounts of interactivity. We initially planned to explore these capabilities in the second summer institute, but found that the teachers still required assistance with some of the introductory processes. Recall, too, that these participants were attempting to not only think on technology pedagogy, but also were working on their content where some had little background in thinking geographically. While this project exceeded the amount of "seat" time and coaching compared to other projects (see the critique by Höhnle et al., 2016), we conclude that mastering spatial analysis skills and tools in even this longer professional development period is a tall order and would require substantially greater investment in time and exploration (see Hong & Melville, 2018). In the future, it may be more beneficial to work with only one instructional level (e.g. middle level). However, we do note positively that spatial representations are included in the curriculum to some degree where they did not exist before (mathematics, social studies, ESOL).

Geography consists not just of content (e.g. place awareness, physical systems, social systems), but also skills related to spatial thinking. A second concern, then, is whether GIS use improves spatial thinking skills and/or geography concept knowledge. A pre/post spatial thinking assessment evidenced very minor improvement by the participants. This unremarkable result is not surprising given current literature debates about whether GIS uniformly impacts spatial thinking improvement across its varied categories (scale, overlay, rotation, etc.; see also Metoyer & Bednarz, 2017 on these points). We do see evidence that participants learned to include geography concepts in their teaching (location, distribution, pattern, diffusion, etc.) and report using some of this language more frequently. To do so for their students means personal growth as well. Importantly, several participants took advantage of optional geography content workshops to improve their content knowledge. Two went one step further, completing a program to become a National Geographic Certified Educator. In the end, throughout the project each participant was provided the opportunity to investigate where geography and technology cuts across multiple content areas.

We find that advancing the use of GIS in the K-12 classroom remains a worthwhile endeavor with an understanding of the following:

- Professional development in geospatial technologies will take more time than expected and require follow-up and coaching for greater effectiveness
- Developing geographic thinking and working with traditional geographic concepts (scale, pattern, region, diffusion, etc.) is equally important to developing technological proficiency
- Cross-curricular links can be facilitated by using GIS to create learning opportunities of greater interest to students

These findings, among others described in this article, will be useful to others sharing our concern for better teacher training and subsequent student use of GIS in K-12 classrooms.

Notes

1. This project also supported the district's technology plan which specifically calls for students to "engage in authentic learning activities that are aligned with state standards and that integrate technology into the content", for teachers to "demonstrate technology integration skills in the classroom", and for the district to "provide teachers with access to web 2.0 tools and resources necessary to integrate web 2.0 tools into the curriculum". Professional development in geospatial technology use meets each of these and several other aspects of the technology plan, and can be integrated across multiple disciplinary areas.
2. Demirci (2011) reported study results to show that GIS exercises could be effectively taught on a single computer where there is a lack of computing resources available.
3. While guided by the project team, each teacher involved created their own lesson idea and the map products necessary.

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References

Baker, T., Battersby, S., Bednarz, S., Bodzin, A., Kolvoord, B., Moore, S., & Uttal, D. (2015). A research agenda for geospatial technologies and learning. *Journal of Geography*, 114, 118–130.

Ball, D., & Cohen, D. (1999). Developing practitioners: Toward a practice-based theory of professional education. In L. Darling-Hammond & G. Sykes (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 3–32). San Francisco, CA: Jossey-Bass.

Brysch, C., & Boehm, R. (2013). The Learning Cluster Method (LCM) as a means of extending the capabilities of an online professional development system in geography. *Papers in Applied Geography*, 36, 264–270.

Coulter, B., & Kerski, J. (2005). Using GIS to transform the mathematical landscape. In P. Elliott (Series Ed.) & W. J. Masalski (Vol. Ed.), *Technology-supported mathematics learning environments: Sixty-seventh yearbook* (pp. 329–344). Reston, VA: National Council of Teachers of Mathematics.

Demirci, A. (2011). Using geographic information systems (GIS) at schools without a computer laboratory. *Journal of Geography*, 110, 49–59.

Doering, A., Koseoglu, S., Scharber, C., Henrickson, J., & Lanegran, D. (2014). Technology integration in K-12 geography education using TPACK as a conceptual model. *Journal of Geography*, 113, 223–237.

Elmore, R., & Burney, D. (1999). Staff development and instructional improvement: Community District 2, New York City. In L. Darling-Hammond & G. Sykes (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 3–32). San Francisco, CA: Jossey-Bass.

Goldstein, D., & Alibrandi, M. (2013). Integrating GIS in the middle school curriculum: Impacts on diverse students' standardized test scores. *Journal of Geography*, 112, 68–74.

Hansen-Thomas, H., Casey, P., & Grosso, L. (2013). Multiplying the effect of professional development: Teachers training teachers. *TESOL*, 4, 129–150.

Harte, W. (2017). Preparing preservice teachers to incorporate geospatial technologies in geography teaching. *Journal of Geography*, 116, 226–236.

Henry, P., & Semple, H. (2012). Integrating online GIS into the K-12 curricula: Lessons from the development of a collaborative GIS in Michigan. *Journal of Geography*, 111, 3–14.

Höhnle, S., Fögele, J., Mehren, R., & Schubert, J. (2016). GIS teacher training: Empirically-based indicators of effectiveness. *Journal of Geography*, 115, 12–23.

Hong, J. (2014). Promoting teacher adoption of GIS using teacher-centered and teacher-friendly design. *Journal of Geography*, 113, 139–150.

Hong, J., & Melville, A. (2018). Training social studies teachers to develop inquiry-based GIS lessons. *Journal of Geography*. doi:10.1080/00221341.2017.1371205

Hong, J. E., & Stonier, F. (2015). GIS in-service teacher training based on TPACK. *Journal of Geography*, 114, 108–117.

House, P. A. (1994). Empowering K-12 teachers for leadership: A districtwide strategy for change. In A. F. Coxford (Series Ed.) & D. B. Aichele (Vol. Ed.), *Professional Development for teachers of mathematics: 1994 yearbook* (pp. 214–226). Reston, VA: National Council of Teachers of Mathematics.

Jadallah, M., Hund, A., Thayn, J., Studebaker, J., Roman, Z., & Kirby, E. (2017). Integrating geospatial technologies in fifth-grade curriculum: Impact on spatial ability and map-analysis skills. *Journal of Geography*, 116, 139–151.

Kerski, J. (2003). The implementation and effectiveness of geographic information systems technology and methods in secondary education. *Journal of Geography*, 102, 128–137.

Kerski, J., Demirci, A., & Milson, A. (2013). The global landscape of GIS in secondary education. *Journal of Geography*, 112, 232–247.

Koehler, M. J., & Mishra, P. (2008). Introducing TPCK. In AACTE Committee on Innovation and Technology (Ed.), *Handbook of technological pedagogical content knowledge (TPCK) for educators* (pp. 3–29). New York: Routledge.

Kolvoord, R., Jant, E., Uttal, D. (2013, July). *Researching the impact of GIS on students' spatial thinking skills.* Paper presented at the Esri Education GIS Conference, San Diego, CA.

Kubitskey, B., Fishman, B., Johnson, H., Mawyer, K., & Edelson, D. (2014). Curriculum-aligned professional development for geospatial education. In J. MaKinster, N. Trautmann, & M. Barnett (Eds.), *Teaching science and investigating environmental issues with geospatial technology: Designing effective professional development for teachers* (pp. 153–171). Dordrecht, Netherlands: Springer.

Lee, J., & Bednarz, R. (2012). Components of spatial thinking: Evidence from a spatial thinking ability test. *Journal of Geography*, 111, 15–26.

Leonard, J., Russell, N., Hobbs, R., & Buchanan, H. (2013). Using GIS to teach place-based mathematics in rural classrooms. *The Rural Educator*, 34, 10–17.

Little, J. W. (2001). Professional development in pursuit of school reform. In A. Lieberman & L. Miller (Eds.), *Teachers caught in the action: professional development that matters* (pp. 23–44). New York: Teachers College Press.

Mason, C., Berson, M., Diem, R., Hicks, D., Lee, J., & Dralle, T. (2000). Guidelines for using technology to prepare social studies teachers. *Contemporary Issues in Technology and Teacher Education*, 1, 107–116.

Metoyer, S., & Bednarz, R. (2017). Spatial thinking assists geographic thinking: Evidence from a study exploring the effects of geospatial technology. *Journal of Geography*, 116, 20–33.

Millsaps, L., & Harrington, J. (2017). A time-sensitive framework for including geographic information systems (GIS) in professional development activities for classroom teachers. *Journal of Geography*, 116, 152–164.

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

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education*, 21, 509–523.

Pilter, H., Hubbell, E. R., & Kuhn, M. (2012). *Using technology with classroom instruction that works* (2nd ed.). Denver, CO: McRel.

Riihelä, J., & Mäki, S. (2015). Designing and implementing an online GIS tool for schools: The Finnish case of the PaikkaOppi Project. *Journal of Geography*, 114, 15–25.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4–14.

Strachan, C., & Mitchell, J. T. (2014). Teachers' perceptions of Esri Story Maps as effective teaching tools. *Review of International Geographical Education Online*, 4, 195–220.

Sui, D. (1995). A pedagogic framework to link GIS to the intellectual core of geography. *Journal of Geography*, 94, 578–591.

Tomaszewski, B., Vodacek, A., Parody, R., & Holt, N. (2015). Spatial thinking ability assessment in Rwandan secondary schools: Baseline results. *Journal of Geography*, 114, 39–48.

Trautmann, N., & MaKinster, J. (2010). Flexibly adaptive professional development in support of teaching science with geospatial technology. *Journal of Science Teacher Education*, 21, 351–370.

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, 109–121.

Walshe, N. (2017). Developing trainee teacher practice with geographical information systems (GIS). *Journal of Geography in Higher Education*, 41, 608–628.

York-Barr, J., & Duke, K. (2004). What do we know about teacher leadership? Findings from two decades of scholarship. *Review of Educational Research*, 74, 255–316.

Yow, J. A., & Lotter, C. (2016). Teacher learning in a mathematics and science inquiry professional development program: First steps in emergent teacher leadership. *Professional Development in Education*, 42, 325–351.