

A Curriculum-linked Professional Development Approach to Support Teachers' Adoption of Socio-Environmental Science Investigations

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Program Abstract

We present a curriculum-linked professional development approach to support the adoption of socio-environmental science investigations using a geospatial curriculum approach with mobile field data collection and Web GIS analysis. First year implementation findings are presented.

Proceedings Abstract

Many teachers have not had professional development experiences that foster sufficient geospatial pedagogical content knowledge to implement science curriculum using geospatial technologies that promote science learning and the development of geospatial thinking skills. To address this, we have developed and implemented an approach to promote teachers' professional growth with curriculum-linked professional development to support the adoption of novel socio-environmental science investigations (SESI) using a geospatial curriculum approach. SESI are based on the pedagogical frameworks of place-based education, socioscientific issues-based instruction, and citizen science. Our curriculum development follows a design partnership model and focuses on collaborative design and implementation of curriculum in keeping with models of school-based reform. Four teachers in an urban high school participated during the first year of this design, development, and curriculum implementation process. Three SESI investigations were developed and the prototype versions were implemented during the last eight weeks of the 2016-2017 school year with 150 ninth grade students. To examine teachers' growth in their geospatial science pedagogical content knowledge, we administered the Geospatial Science-Technological Pedagogical Content Knowledge (GS-TPACK) instrument to all participating teachers at the beginning and end of the school year. The participating teachers also completed a questionnaire designed to analyze the perceived impact of the professional development to support their geospatial pedagogical content knowledge related to teaching the SESI investigations. Findings from the GS-TPACK instrument revealed growth in teachers' geospatial technology use, geospatial technology content knowledge, and geospatial technology pedagogical content knowledge. In response to the questionnaire items, the teachers all discussed how the geospatial technologies have aided their ability to implement spatial thinking into their classroom environments and teaching methods.

Introduction

Educators have recognized that geospatial technologies have the capacity to enhance teaching and learning efficacy by: (a) enabling powerful, multidisciplinary mapping visualization, (b) deepening student understandings of important discipline-based content, and (c) enhancing inquiry in natural and social sciences (Baker, Kerski, Huynh, Viehrig, & Bednarz, 2012; National Research Council, 2006). Geospatial technologies provide a suite of dynamic mapping tools that can be used as learning technologies in educational settings. Often they are used for inquiry-based investigations, learning that involves problem-solving, and gathering and analyzing geo-referenced data. Many learning projects that integrate geospatial technologies use authentic data to investigate contemporary issues in local contexts, thus enabling learners to understand how local issues fit into larger regional and global issues (e.g., Atzmanstorfer, Resl, Eitzinger, & Izurieta, 2014).

Learning geospatial technologies often involves both spatial thinking, including geospatial thinking, a subset of spatial thinking. Promoting spatial thinking is inherent to environmental science, geography, and other content disciplines where there is a heavy reliance on cognitive thinking skills that include knowledge about space, the ability to use tools of representation properly, and reasoning skills (National Research Council, 2006). According to Golledge (2002), knowledge about space consists of the recognition and elaboration of the relations among geographic spatial primitives, such as place-specific identity, location, or magnitude, and the advanced concepts derived from these primitives such as arrangement, organization, distribution, pattern, and geographic association. Geospatial thinking involves using tools of representation for making inferences about space, geospatial patterns and geospatial relationships related to the Earth's surface. These representations include map visualizations that are used as tools to organize and understand data that is georeferenced to the Earth's surface. The capacity to visualize data patterns and

relationships on the Earth's surface is integral to the process of geospatial thinking and involves spatial abilities such as geospatial visualization, orientation and geospatial relations which can be facilitated by GIS (Albert & Golledge, 1999).

Previous studies have confirmed that spatial ability, measured by visualization and reasoning tasks, is a significant factor in science subject achievement (Lubinski, 2010; Wai, Lubinsky, & Benbow, 2009). For many concerned with widening access to and involvement in the sciences, these findings are significant, especially since it is confirmed that gender plays a role in some spatial abilities (Voyer, Voyer, & Bryden, 1995). This has led to calls for explicit attention to improving spatial thinking skills in girls, including recognition that spatial skills are not innate but can be developed (National Research Council, 2006); encouraging young people to engage in learning activities that use spatial thinking skills (Hill, Corbett, & St. Rose, 2010); and using geospatial tools to promote critical thinking, analysis, and reasoning in problem solving (U.S. Department of Labor, 2010). A recent meta-analysis conducted by Uttal et al. (2013), concluded that spatially enriched curriculum succeeds in increasing STEM performance and participation.

The use of GIS to spatially investigate Earth and Environmental sciences during classroom investigations has proven effective in the development of accurate scientific understandings about complex Earth and environmental science concepts with secondary learners (Bednarz, 2004; Bodzin & Fu, 2014; Bodzin, Fu, Kulo, & Peffer, 2014; Edelson, Pitts, Salierno, & Sherin, 2006; Kulo & Bodzin, 2013; National Research Council, 2006). However, there are numerous barriers to classroom teachers' adoption and implementation of geospatial technologies in the science curriculum with their students. These include the complexity of technology and software interfaces, difficulty in accessing datasets, time constraints for learning how to use mapping software applications to effectively teach students, and identifying geospatial learning activities that align to the adopted classroom

curriculum (Baker & Bednarz, 2003; Patterson, Reeve, & Page, 2003; Trautmann & MaKinster, 2010). In addition, teachers may also lack the pedagogical content knowledge (PCK) conducive to teaching with geospatial technologies in classroom settings (Bodzin, Peffer, & Kulo, 2012). Without appropriate teacher professional development, the implementation of geospatial technologies with classroom students, especially in a high needs school environment, is not likely to succeed.

In many U.S. school districts, there is limited time available within a school year to provide inservice teachers with quality face-to-face professional development to adopt new science education technology-integrated curricula. To address this common reality, we have developed and implemented a more efficient approach to promote teachers' professional growth with curriculum-linked professional development that supports the adoption of novel socio-environmental science investigations (SESI) using a geospatial curriculum approach. SESI are inquiry-based investigations designed to take advantage of recent developments in powerful, mobile geospatial technologies to promote STEM-related workforce skills. The content of SESI focuses on social issues related to environmental science. The pedagogy is inquiry-driven, with students engaged in map-based mobile data collection followed by analysis with Web-based dynamic mapping software to answer open-ended questions. The investigations are multi-disciplinary, involving decision-making based on the analysis of geospatial data.

SESI activities are based on the pedagogical frameworks of place-based education and socio-scientific issues-based instruction. Place-based education focuses on local or regional investigations, is designed around engaging students in examining local problems (Sobel, 2004), and utilizes fieldwork to gather evidence in that local setting (Semken, 2005). Socio-scientific issues are socially relevant, real-world problems that are informed by science (Sadler, Barab, & Scott, 2007). Addressing them requires the use of evidence-based

reasoning, and provides a context for understanding scientific information through an active approach to learning, while placing science content within a social context in a way that supplies both motivation to and the ownership of learning by the student (Sadler, Barab, & Scott, 2006; Zeidler & Nichols, 2009). Place-based education connects learners to their immediate environment and can provide opportunities to empower students by giving them the content ownership and confidence to address important socio-scientific issues in their community.

In this paper, we describe a curriculum-linked professional development approach that was designed to support secondary teachers' adoption of the SESI investigations in a high needs school environment and also present a detailed example of one SESI investigation. In this study, we examine the effectiveness of the curriculum-linked professional development approach in providing teachers with professional growth experiences to enable them to implement the prototype SESI investigations in their classrooms with diverse high needs urban students that includes reluctant learners, students with Individualized Education Plans and students who are English language learners.

Geospatial Science Pedagogical Content Knowledge

When curriculum materials are expected to take on the role of change agent and transform teacher practice – as in a systemic reform initiative – the challenges of effective implementation are exacerbated (Davis & Krajcik, 2005). Research has shown that teachers face many obstacles when using curriculum materials that are based on an instructional approach to teaching and learning that differs from their own experiences (Stein, Grover, & Henningsen, 1996). This is especially true when teachers enact instructional materials that utilize geospatial technologies to support inquiry-based learning environments. Teachers may experience technical issues pertaining to software interface design, have insufficient time to become adept at using geospatial software applications, have difficulty integrating the

learning materials into their own school curriculum, or lack pedagogical content knowledge (PCK) conducive to teaching with geospatial technologies in classroom settings (Baker & Bednarz, 2003; Patterson, Reeve, & Page, 2003; Trautmann & MaKinster, 2010).

Effectively teaching about science topics that are geospatial in nature requires specific technological PCK (Mishra & Koehler, 2006) and implementation supports to incorporate geospatial technologies into the classroom. Teaching science with geospatial technologies involves geospatial science PCK, a specific type of technological PCK. Teachers with geospatial science pedagogical content knowledge have a more complete understanding of the complex interplay between science PCK and geospatial PCK and can teach science and related disciplines using appropriate pedagogical methods and geospatial technologies (Bodzin et al., 2012). This involves understanding how to model geospatial data exploration and analysis techniques and to effectively scaffold students' geospatial thinking and analysis skills. The idea of geospatial PCK transcends content disciplinary boundaries since geospatial technology can interact with other discipline-based pedagogical content (for example, geography and history) in ways that may produce effective teaching and student learning opportunities.

Curriculum Approach for Geospatial Learning

Our geospatial curriculum approach for learning builds on our previous design work and the National Science Foundation's (NSF) Geotech Center's Geospatial Technology Competency Model (Bodzin, 2011; Bodzin et al., 2012; Kulo & Bodzin, 2013; Bodzin, Fu, Bressler, & Vallera, 2015). The curriculum approach incorporates design principles in each investigation to promote geospatial thinking and reasoning skills (see Figure 1). These principles include,

- (1) Use motivating contexts and personally relevant and meaningful examples to engage learners.
- (2) Design image representations that illustrate visual aspects of social studies and Earth and environmental scientific knowledge.
- (3) Design Web GIS data to make geospatial relations readily apparent.
- (4) Scaffold students to analyze geospatial relations (Jonassen, 1999; Quitana et al., 2004).
- (5) Develop curriculum materials that better accommodate the learning needs of all students, while also expanding the geospatial PCK of teachers.

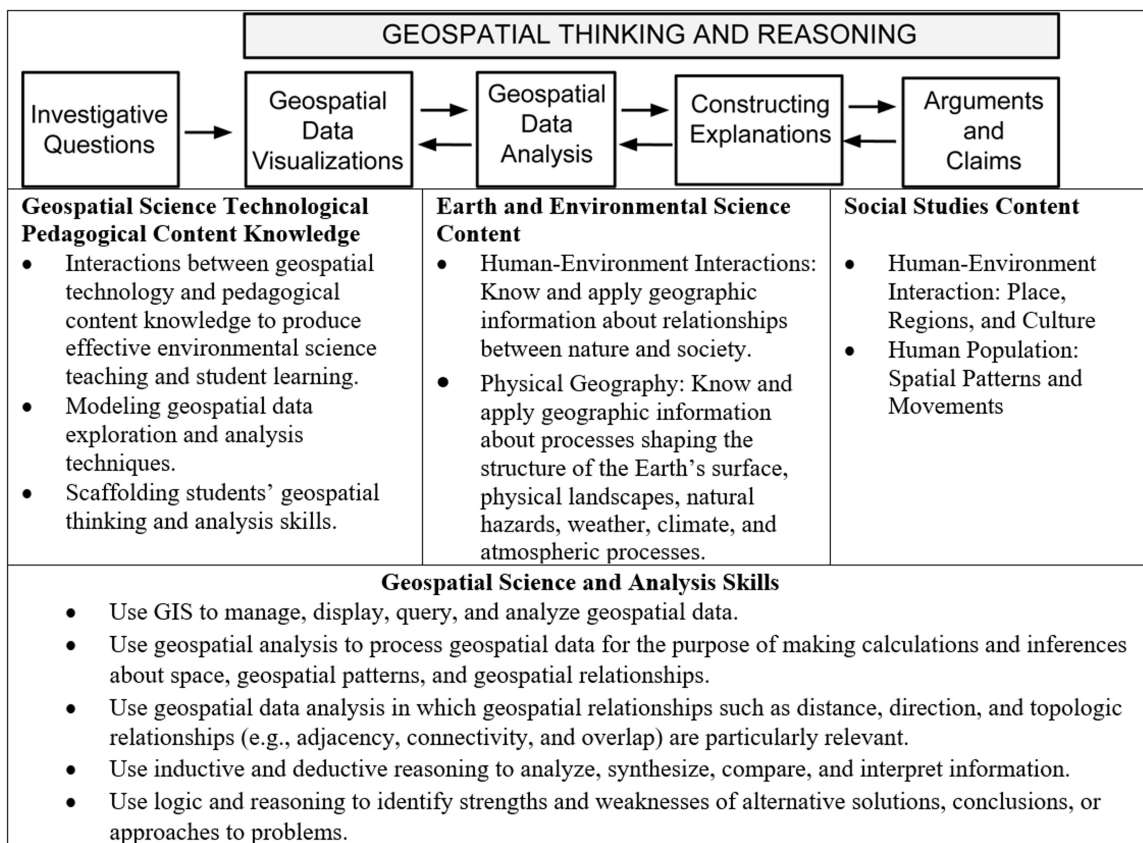


Figure 1. Key components of the geospatial curriculum approach.

A primary goal of this curriculum approach is to develop geospatial learning activities in such a way that the software and hardware become transparent to the user. The initial geospatial data visualizations for our investigations are designed to be quick and intuitive for

both students and teachers to use, thus decreasing interface issues that were reported by users of other GIS platforms (Baker & Bednarz, 2003; Bednarz, 2004). The learning activities include teacher support materials that use Web-based videos, text, and graphics to promote and support teachers' learning of important socio-environmental science subject matter and specialized geospatial PCK that they typically lack. Each learning activity is designed to include baseline instructional guidance for teachers and provide implementation and adaptation guidance for teaching a variety of learners, including reluctant readers, English language learners and students with disabilities.

We also employ a novel form of hybrid professional development (PD), with both face-to-face and online learning, in a design partnership model (Bodzin & Cirucci, 2009). Such PD approaches have been found to be effective in assisting teachers with the adoption of new curricula with spatial technologies in science classrooms (Bodzin et al., 2012; Fishman et al., 2013; McAuliffe & Lockwood, 2014) because they offer teachers learning opportunities with geospatial technologies over a longer time period than a more common short-term summer institute. Our PD approach acknowledges that classroom teachers are pedagogical experts capable of adapting curriculum materials to meet the needs of their students (Penuel, Fishman, Yamaguchi, & Gallagher, 2007). The PD includes active learning experiences by teachers, the opportunity to collaborate with peers, use of classroom-based instructional materials focused on SESI, the opportunity to reflect on teaching practice, and sufficient time to implement what has been learned (Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel et al., 2007).

Research Questions

To date, there have been no published classroom studies that elucidate how teacher PD designs and experiences with integrated mobile and Web-based geospatial technologies can lead to classroom implementation of mapping technologies with their students in a high needs

school environment that includes reluctant learners, students with disabilities and English language learners. In addition, a recent research agenda in the field of geospatial technologies and learning called for future studies that further understanding of which types of pedagogical implementation supports may help teachers more effectively implement successful pedagogical approaches to promote student geospatial thinking and analysis skills (Baker et al., 2015).

Consequently, this study was guided by the following research questions:

- (1) How did the professional development process impact teachers' geospatial pedagogical content knowledge?
- (2) How did geospatial curriculum approach impact teachers' in-class cartographic practices?
- (3) How did teachers enhance students' geospatial science and analysis skills during the SESI implementation?

Methodology

Setting, Participants, and Context

The context for our work is a high needs urban public high school in the northeastern United States. The school aims for both student academic engagement using a personally relevant curriculum and student personal and professional development through application of their skills in real-world environments. For example, students are expected to study not only national but local history; they learn about local government and are required to meet with city officials and propose civic action for improving their communities.

The students attending this school are all economically disadvantaged—all students receive free breakfast and lunch. Approximately two-thirds of the students identify as Hispanic or Latino. We specifically worked with all 140 students in the 9th grade. Among

these students, the district identified 21% as English language learners, and 19% had Individualized Education Plans. These students represent populations that are traditionally underrepresented in STEM-related fields (Connors-Kellgren, Parker, Blustein, & Barnett, 2016). Many students are reluctant learners; they can be unmotivated to learn, do not complete tasks, avoid challenging work, and do not seem concerned with achieving in school (Sanacore, 2008).

We collaborated with the school's two science and two social studies teachers to develop the geospatial SESI investigations for implementation in the 9th grade classrooms. The science and social studies teachers were all early career teachers, with teaching experience ranging between two and four years. Both social studies teachers hold master's degrees and both science teachers hold bachelor's degrees. One of the science teachers had prior experience with GIS in his university coursework. The lead teachers in each department had four years of teaching experience, compared to two years' experience for their respective partners. Both lead teachers participated in all aspects of the PD and attended all training, planning, and development sessions and completed all online PD components. They also assisted with outdoor data collection during some of SESI investigations during their planning periods. The 9th grade science and social studies teachers participated in all phases of the project and were the primary classroom instructors for all classroom implementation sessions.

Implementation

The professional development included both face-to-face and online components. The face-to-face sessions focused primarily on the curricular co-design process of three SESI investigations. A main focus of these sessions was designing learning materials to accommodate the needs of students with disabilities and English language learners. Throughout the materials development process, we elicited iterative feedback from the

teachers by reviewing the materials with them and conducting walk-throughs of data collection, using iPads with built-in GPS running Esri's Collector app. This was followed by customized data analysis using map visualizations in Esri's ArcGIS.com. As we completed the initial development of materials for each SESI investigation, we worked with the teachers to conduct a prototype implementation with a group of 10th grade students. These prototype tests provided feedback on the data collection interfaces and a student perspective on the learning activity's tasks and support materials.

The online components of the professional development activities include assigned readings to provide teachers with knowledge of the importance of teaching and learning with geospatial technologies, content background readings, and exemplar geospatial learning activities from peer-reviewed teacher practitioner journals. In addition, the teachers reviewed selected geospatial curriculum learning activities from the design and development group's past projects to help them understand the working components of the geospatial curriculum approach.

Three prototype SESI investigations were developed and implemented during March-May of the 2017 school year. These included:

- (1) *Urban Heat Island Investigation* – Students investigate the school property to identify different types of ground surface heat radiation towards understanding urban heat islands
- (2) *Trees and Ecological Services. How do trees and vegetation provide ecosystem services to the community?* - Students investigate the area around their school to identify different types of trees and explore the environmental and societal benefits that trees provide in their city. They also investigate the relationship among trees and crime in their city.

- (3) *Zoning and Me. What does my local zoning look like? How is city zoning determined near me?* - Students investigate the neighborhood around their school and identify what type of land-use zone they are in (residential, business, industrial, green space, etc.). They determine how different zones are distributed around their school and compare their observations with the official zoning map for their city.

In the next section we present the Urban Heat Island Investigation in detail as an example of a SESI activity.

Sample SESI activity: Urban Heat Islands

In the Urban Heat Islands (UHI) SESI activity, students learn about heat absorption and re-radiation from different parts of the natural and built environment, culminating in a proposed change to local neighborhoods to reduce the heat island effect.

The first step in the lesson is a presentation from the teacher about the scientific concepts involved: What is temperature and how do we measure it? What is the difference between air temperature and ground surface temperature, and what are the sources of the heating and cooling effects on both? What is a heat island, and why is it an urban phenomenon rather than a rural phenomenon?

After the content background presentation, students download a map of a sampling area to the Collector for ArcGIS app. Next, they go outside with GPS-enabled iPads and infrared surface temperature thermometers. Working in pairs or trios with ample adult mentors for each class, students go to an assigned zone on the school property (Fig. 2) to obtain temperature readings from various surfaces found within their zone, including grass, asphalt, concrete, bare soil, and other surfaces that the students observe.

Once back in the classroom, the data from the individual iPads is synced into a class-wide dataset. Next, the students work in groups to examine the collected data using

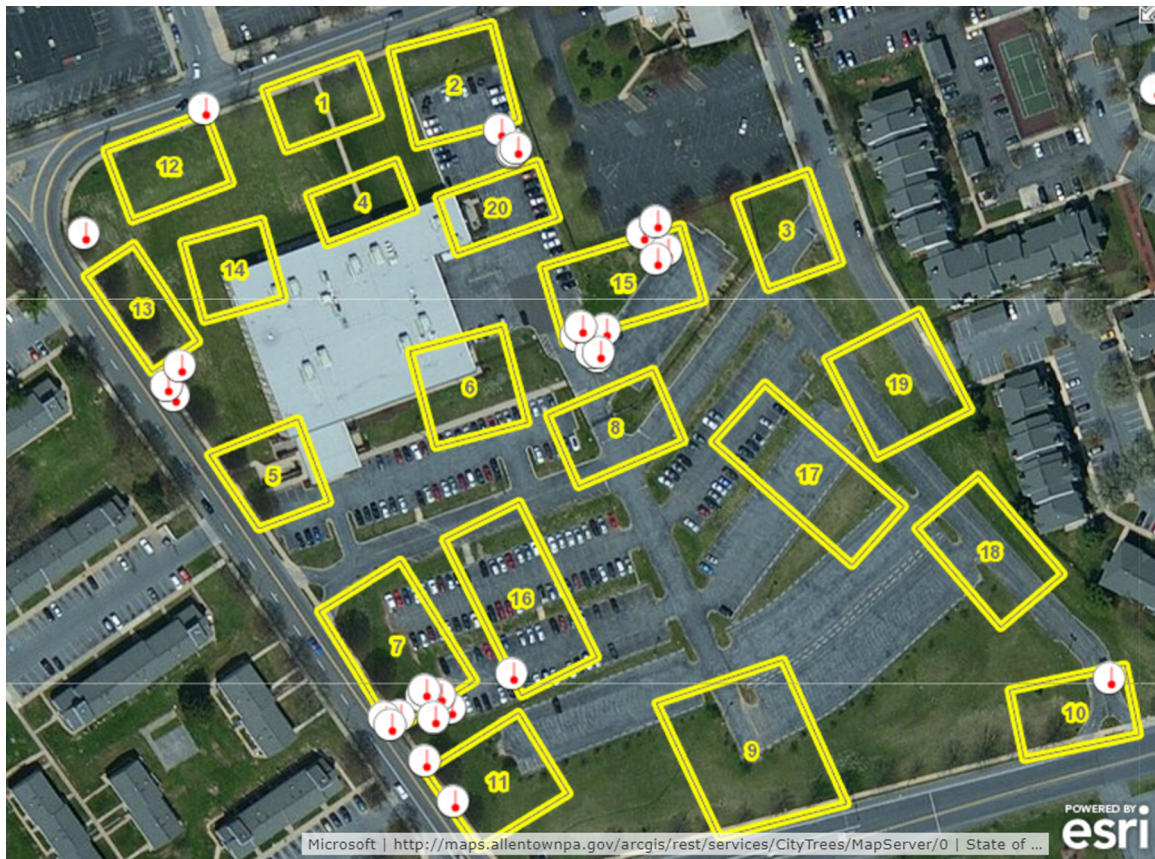


Figure 2. Zones for student data collection around the school (indicated by yellow polygons) and instances of student data collection points (indicated by white circles)

ArcGIS.com and observe the patterns in temperatures recorded on different surfaces (for example, dark asphalt vs. light asphalt or concrete vs. grass) and under different conditions (shaded vs. unshaded or morning vs. afternoon). Figure 3 shows the contrasts that students could observe between shaded areas, such as the tree-lined area on the western edge of the data collection area (yellow and light orange colors), versus the hotter temperatures recorded in the middle of the parking lot (red and dark orange colors). Collected data is retrieved by clicking on the individual points, providing a pop-up box, as in Figure 3. The selected data point (red circle with blue box outline just above the pop-up) was collected at 11:24 a.m. on a clear day with a surface temperature of 41.5 degrees Celsius. At this time, ground surface temperature was much higher than the air temperature of 23.0 degrees Celsius. This difference is due to the amount of sunlight absorbed and retained in that dark asphalt surface over the course of the day since sunrise. In contrast, surface temperatures of areas shaded by

trees are well below the air temperature. The analyzed data is used to reinforce the initial teacher presentation about heat absorption and re-radiation, and how albedo and shaded areas can reduce this effect.

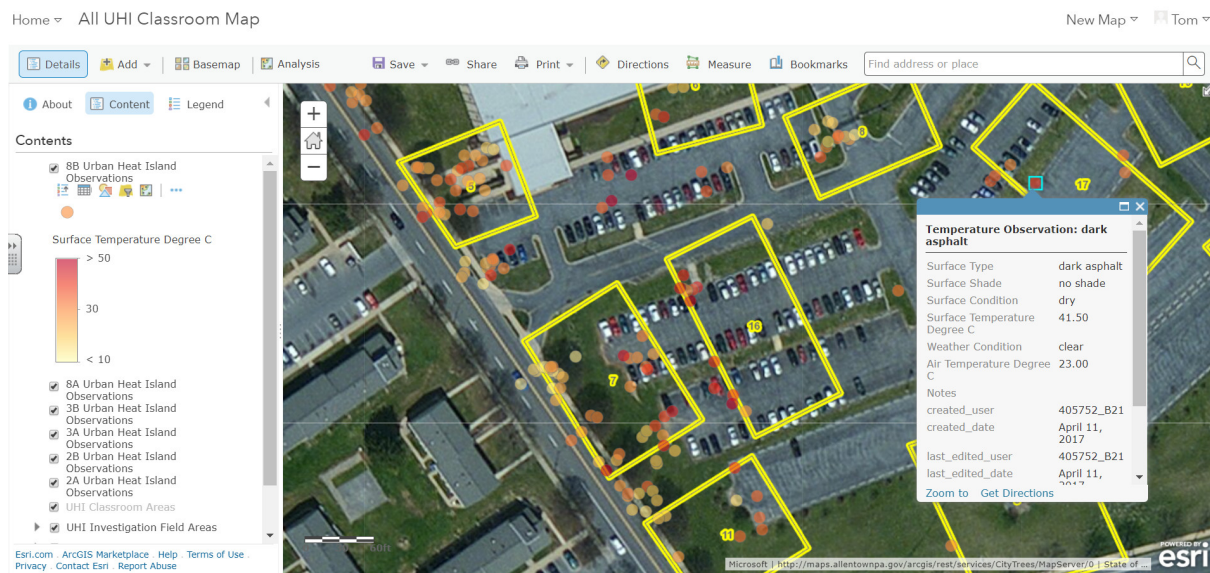


Figure 3. Data collected during the UHI investigation. Colored data points display surface temperature.

In the next step of the investigation, students analyze a GIS map of the land cover in their city. This map displays both built environment features (structures, roads, impervious surfaces such as parking lots) and natural features that help reduce the urban heat island effect (vegetation and tree canopy, particularly trees that shade structures and roads).

Working in groups, students examine an assigned neighborhood in their city (see Figure 4) to examine the land cover and discuss how it contributes to the urban heat island effect.

After discussing the existing land cover and possible mitigation strategies, students propose several changes for their assigned neighborhood. For example, students could suggest creating shade by adding rows of trees within parking lots, converting dark rooftops to light-colored rooftops, modifying large commercial structures such as office buildings to



Figure 4. Land cover map allowing students to study urban heat island effects across the entire city. The blue polygons are assigned neighborhoods for student groups to examine a suburban neighborhood (west side of map), a commercial district (center), and a dense residential district (east).

incorporate green roofs, or offer any other recommendations that increase reflection and decrease solar energy absorption by a surface. Students then use the suite of draw tools to make these changes on their ArcGIS.com map and submit their recommendation to their teacher (Figure 5).

Data Sources & Analysis

To examine teachers' growth in geospatial science PCK, we administered a modified version of the Geospatial Science-Technological Pedagogical Content Knowledge [GS-TPACK] instrument (Bodzin et al., 2012) to the participating teachers at the beginning and end of the school year. The GS-TPACK instrument is designed to measure teachers' perceived knowledge of how geospatial technology interacts with their PCK in ways that produce effective science teaching and student learning opportunities. The original instrument included 26 items. Additional items were added to the original instrument to differentiate satellite imagery and Google Earth. Since the SESI investigations were taught by both



Figure 5. Sample student product from the Urban Heat Island activity. To reduce the UHI effect in his assigned zone, this student has added tree canopy (the regular polygons), tree canopy over the roads (purple lines), and green roofs (the irregular polygons).

science and social studies teachers, the language of some the items was modified to be less science-specific. The modified instrument used in this study included 29 Likert-type items that were scored with a six-point scale of 1 (Strongly Disagree) to 6 (Strongly Agree). The reliability (Cronbach alpha) of the GS-TPACK instrument used in this study was .899.

Teachers' cartographic practices were observed in several ways. First, the researchers were present for all classroom sessions of the SESI investigations and supported teachers in the hands-on sections of the activities. During these classroom sessions, researchers kept detailed daily logs of classroom events and observed teacher practices related to geospatial PCK. These logs included how teachers modeled geospatial data exploration and analysis techniques and how they scaffolded students' geospatial thinking and analysis skills. Second, the participating teachers completed an end-of-year questionnaire regarding their instructional practices and geospatial PCK related to teaching the SESI investigations. The

Appendix presents the items on the questionnaire. Finally, teachers completed a reflective task modeled on the Graphical Assessment of TPACK Instrument (Foulger, 2015) and participated in a semi-structured focus group. In the reflective task, teachers were provided with circles representing geospatial technological PCK components and were asked to demonstrate the interrelatedness of their knowledge bases of content knowledge, pedagogical knowledge, and geospatial technology knowledge to represent their thinking at two points in time: prior to the start of the curriculum design approach versus at the end of the school year, having completed the professional development and classroom implementations. Images of the teachers' resulting Venn diagrams of their circle placements were captured. The focus group discussion was recorded and transcribed, then reviewed in a line-by-line coding to identify statements exposing components of GS-TPACK and cartographic practices. The findings generated from both the quantitative and qualitative analyses were then member-checked with the individual teachers.

Findings

Finding 1: Strong growth in teachers' geospatial pedagogical content knowledge

Findings from the GS-TPACK instrument revealed growth in teachers' geospatial technology use [Pretest mean = 42.25, SD=7.63; Posttest mean = 53.50, SD=3.42], geospatial technology content knowledge [Pretest mean = 46.50, SD=5.20; Posttest mean = 47.25, SD=2.50], and geospatial technology pedagogical content knowledge [Pretest mean = 35.75, SD=2.63; Posttest mean = 37.00, SD=1.83]. For the entire GS-TPACK instrument, the total mean increased significantly [Pretest mean = 124.50, SD=10.66; Posttest mean = 137.75, SD=7.41] with a large effect size (Cohen's $d = 1.44$). Table 1 displays the mean responses for each item in the GS-TPACK instrument. Table 2 displays the pre- and post-GS-TPACK instrument total scores for each teacher.

Table 1

Responses from the pre- and post-administration of the Geospatial Science - Technological Pedagogical Content Knowledge (GS-TPACK) instrument

N = 4 teachers. Scale: 1 (Strongly Disagree) to 6 (Strongly Agree)

Item	Pre SESI Mean (SD)	Post SESI Mean (SD)
Geospatial Technology Use		
1. I can use a variety of geospatial technologies.	3.50 (1.00)	5.00 (0.00)
2. I can analyze satellite imagery using geospatial technologies.	3.75 (1.26)	4.75 (0.50)
3. I can use satellite imagery as an instructional tool.	4.00 (1.41)	4.75 (0.50)
4. I can use GIS as an instructional tool.	3.25 (0.96)	4.75 (0.50)
5. I can use Google Earth as an instructional tool.	5.00 (0.82)	5.25 (0.96)
6. I can navigate from one location to another in Google Earth.	5.25 (0.50)	5.25 (0.50)
7. I can use Google Earth for classroom investigations.	4.75(0.96)	4.75 (0.96)
8. I can use satellite imagery for classroom investigations.	4.25 (1.50)	4.75 (0.50)
9. I can use GIS for classroom investigations.	3.00 (1.16)	4.75 (0.50)
10. I can create maps using GIS.	2.50 (1.00)	4.25(0.50)
11. I can analyze data using GIS.	3.00 (1.16)	5.25 (0.50)
<i>Geospatial Technology Use Total</i>	<i>42.25 (7.63)</i>	<i>53.50 (3.42)</i>
Geospatial Technology Content Knowledge		
1. I am comfortable answering student questions during investigations that use geospatial technology.	4.25 (0.96)	4.50 (0.58)
2. I can think of many concepts that students can learn more effectively with geospatial technologies than without these applications.	4.75 (1.26)	4.50 (0.50)
3. I can think of many concepts that can be taught effectively using satellite imagery.	5.25 (0.50)	4.75 (0.50)
4. I can think of many concepts that can be taught effectively using Google Earth.	5.25 (0.50)	5.00 (0.00)
5. I can think of many concepts that can be taught effectively using GIS.	4.75 (0.50)	5.00 (0.00)
6. I can use geospatial technologies to investigate real-world issues.	5.00 (0.82)	5.00 (0.00)
7. I can plan lessons that make effective use of satellite imagery.	4.50 (1.29)	4.75 (0.50)
8. I can plan lessons that make effective use of Google Earth.	4.75 (0.96)	4.50 (0.58)
9. I can plan lessons that make effective use of GIS.	3.25 (0.96)	4.50 (0.58)
10. I am comfortable managing my classroom when using geospatial technology for student learning.	4.75 (0.50)	4.50 (0.58)
<i>Geospatial Technology Content Knowledge Total</i>	<i>46.50 (5.20)</i>	<i>47.25 (2.50)</i>
Geospatial Technology Pedagogical Content Knowledge		
1. I can <i>design</i> lessons that effectively combine content, geospatial technologies, and teaching strategies.	4.25 (0.50)	5.00 (0.00)
2. I can <i>teach</i> lessons that effectively combine content, geospatial technologies, and teaching strategies.	4.75 (0.96)	4.75 (0.50)
3. I can choose geospatial technologies to use in my classroom that enhance how and what students learn.	4.50 (0.58)	4.25 (0.50)
4. I can choose geospatial technologies that enhance both the content and teaching strategies of a lesson.	4.00 (0.82)	4.25 (0.50)
5. I can use geospatial technology to teach content effectively using a variety of teaching strategies.	4.50 (0.58)	5.00 (0.00)
6. I can effectively assess student learning in projects that make use of geospatial technologies.	4.25 (0.96)	4.50 (0.58)
7. I can adapt my use of teaching strategies when using geospatial technology for student learning.	5.00 (0.82)	5.00 (0.00)
8. I can help other teachers coordinate their use of content, geospatial technologies and teaching strategies.	4.50 (0.58)	4.25 (0.50)
<i>Geospatial Technology Pedagogical Content Knowledge Total</i>	<i>35.75 (2.63)</i>	<i>37.00 (1.83)</i>

Table 2

GS-TPACK Pre- and Posttest Scores by Teacher

	Pre	Post
10th grade science teacher	129	139
10th grade social studies teacher	124	138
9th grade science teacher	135	146
9th grade social studies teacher	110	128

In responses on the questionnaire, all teachers stated that the geospatial technologies aided their ability to implement spatial thinking into their classroom environments and teaching methods. They also commented that the SESI investigations helped them to “understand the importance of teaching the students about what is in their community, why its location in the community is important” and how understanding spatial components of environmental issues such as urban heat island effects can help learners understand how to improve their local environment in ways that benefit their community. The teachers provided many different examples with regard to how the SESI investigations promoted their geospatial thinking and reasoning skills. These included increasing awareness and providing insights into urban heat effects in cities, and being able to use map visualizations with students to discuss land use change over time in a city. One teacher noted that using the SESI investigations prompted her “to start to explore ways similar investigations/tools might enhance learning in the areas I [and other colleagues] teach.” The teachers also noted that the “outside data collection, implementation of technology, and the facilitated, in-classroom analysis made the classroom feel more student led and engaging.”

While these changes in teachers' GS-TPACK were clear indicators of growth in their professional knowledge, we were primarily interested in their in-class performance with their students, specifically their use of geospatial tools. Looking across the multiple data sources of researcher memos, teacher focus group, and teachers' responses to reflective questionnaires, we identified two changes in teachers' in-class cartographic practices, one related to increased use of maps in curriculum implementation, and one related to the use of maps as media for inquiry learning. These changes are discussed next.

Finding 2: Increased map use by teachers, both within and outside the SESI activities

All four teachers engaged in increased map use. For the 9th grade teachers, this included not only the implementation of the three SESI investigations, but also in other parts of the curriculum they implemented independent of the SESI investigations. For example, a science teacher employed Google Earth to teach a unit on land use change, and the social studies teacher used ArcGIS.com to teach a lesson on state Congressional districts. Both teachers reported that this was their first time using dynamic maps such as Google Earth and GIS in the classroom setting. Even the participating 10th grade teachers, who were not directly involved in the day-to-day instruction of SESI activities, reported novel uses of Google Earth in their classes. The 10th grade science teacher reported that his participation in the design and development process inspired him to integrate Google Earth into his biology class. The 10th grade social studies teacher reported wide-ranging impacts. She stated "several activities that did not originally have a map component, I was inspired to add on, and [there were] others where the pre-planned mapping element was enhanced." For example, she incorporated students' hands-on use of Google Earth into a previously planned end-of-year diversity activity, in which students mapped their family ancestry.

This increase in map use indicated greater teacher awareness and interest in cartographic tools. However, we were interested in not just the quantity but also the characteristics of map use. Accordingly, we next examined the data for the ways in which the teachers used maps.

Finding 3: Teacher use of maps as media for inquiry, not didactic instruction

All four teachers reported more inquiry-oriented use of maps with their students. For the 9th grade teachers, the map-based inquiry was a direct result of implementing the three SESI investigations. The data collection process with the Collector App on the iPad involved managing and displaying mapped-based data. ArcGIS online maps were used to query and analyze geospatial data as they worked through the data analysis process. Inductive and deductive reasoning were used to interpret map-based data that aided in decision-making about driving questions of each SESI investigation. The 10th grade teachers reported enhanced use of maps to pose questions and illustrate scenarios to their students. The 10th grade social studies teacher put this trend in concrete terms, describing an evolving use of maps: “In the past, [my] technology-supported inquiry about geography was nothing more than looking for the right Google image, or the right map and putting it up.” A more advanced use of maps “might then be a sequence of several maps to show things changing.” After working on this project, however, she embraced the use of dynamic maps: “more interactive geographic technology, right? Just have everything in one spot about it, as opposed to just, ‘Okay we need 8 maps to talk about this,’ so that has been an evolution.” For this teacher, the maps themselves were indicators of the level of inquiry in her teaching, progressing from a show-and-tell single map to a show-and-question sequence of maps to a fully interactive map that included embedded georeferenced data layers ready for analysis in a full inquiry. The 10th grade science teacher provided an example of this full inquiry in describing his use of Google Earth:

I had them redesign the front of the school to help lower the temperature [heat] that the school building gives off. This required them to look at the school map and use their data to determine what would be best to lower the temperature [heat].

The most striking example of inquiry use of maps came in the 9th grade science classroom. During the analysis phase of the UHI activity, the research team observed that the science teacher was using the filtering function of ArcGIS.com to have students look at temperatures as they varied by surface material (for example, light versus dark asphalt), and even time of day (smaller differences in the morning versus larger differences at the end of the day). We were surprised to observe this, as we had not demonstrated this feature to the teachers during the professional development sessions. Had the teacher discovered this on his own? Did he learn this from his previous exposure to GIS during his undergraduate program? During the focus group, he revealed that he learned about filtering from one of the students:

[My student] taught me how to implement filtering before we had even talked about it in the [professional development] group. ...I mean, he is a very tech-savvy kid to begin with, and it was interesting and nice having him in my classroom. He'd be like, "Hey, teacher? You know you can do this [filtering], right?"

This closely-observed example of teacher-student interaction during the UHI activity encouraged us to closely examine how the 9th grade science and social studies teachers supported their students' thinking processes as they worked with the GIS. Reviewing the qualitative data, we identified a clear trend in these teachers' instructional strategies.

Finding 4: Teacher modeling to guide students' analysis in GIS

In the 9th grade classrooms, where the SESI activities were implemented, we observed both teachers using explicit modeling of the ArcGIS.com suite of tools to provide students with a way of displaying data and also of visualizing geospatial relationships among the datasets.

The teachers would gather the students' attention to the front of the classroom prior to

beginning the data analysis portion of the investigation. The ArcGIS.com map would be displayed on the screen at the front of the room and students were instructed to close their laptops. The teacher would first walk students through the data layers and the legend. Specific data points would be clicked on and guiding questions would be used asking students to interpret a georeferenced data point. Teachers demonstrated the use of specific tool features such as how to add features, and select appropriate colors for the development of their map visualizations and change colors of a designated area. As the students (and teachers) became more familiar with the technology, the teachers would sometimes call upon students to come up to the front of the room to model geospatial data exploration and analysis techniques. The 9th grade science teacher, who had prior exposure to GIS, was the first to adopt this strategy; it then spread to other classrooms.

The use of scaffolding by the teachers was observed to assist students with geospatial analyses during the investigations. The teachers' scaffolding in addition to classroom modeling assisted students with completing geospatial analysis tasks, especially when students were to compare the relationships among data layers. Helpful scaffolds and modeling included prompts to focus learners on specific geospatial aspects of the ArcGIS.com data displays. Procedural scaffolds also assisted learners with completing step-by-step instructions for manipulating the tools to assist with geospatial pattern finding and data analysis. This seemed especially helpful for students who were English language learners.

Discussion

The above findings are indicative of a highly successful effort to bring an inquiry-driven geospatial classroom curriculum to life in an urban school with reluctant learners, students with disabilities, and English language learners. Both the quantitative and qualitative data suggest that the teachers' participation in the design and development process, along with the

integrated professional development, resulted in strong growth in the teachers' geospatial science technological pedagogical content knowledge. The teachers perceived that their geospatial TPACK, that is, their understandings of how geospatial technologies can be used effectively in science and social studies classroom instruction to achieve learning goals, was also enhanced as a result of their direct interactions with the geospatial curriculum materials. This self-reported growth was mirrored in their classroom practices, where we observed changes in both the frequency and the character of their use of cartographic tools. We are particularly encouraged by the fact that the 10th grade teachers, whose classrooms did not implement the SESI activities, were still able to report differences in the way they taught, as they incorporated more maps and more inquiry-driven uses of dynamic maps. For these teachers, their new cartographic practices clearly corresponded with increases in their GS-TPACK. In contrast, the 9th grade teachers' cartographic practices are at least partially attributable to their participation in implementing the SESI activities. For both grade levels, however, the combined participation in the design and development process and the integrated professional development were effective in developing their understanding, confidence, and capabilities in implementing geospatial inquiry learning in their classrooms.

A key indicator in the teachers' mastery of geospatial inquiry was the use of modeling. As the teachers modeled the use of the GIS for their students, they demonstrated their own understanding of the tool, the dataset, the underlying curricular concepts, and the pedagogical design. They enacted the synthesis encapsulated within GS-TPACK, making it visible to their students. The fact that the 9th grade science teacher was the first to implement student participation in his modeling appears to correlate with his relative GS-TPACK. As the sole participant with prior GIS experience, he began the project with the highest level of GS-TPACK (138 out of a possible 174) and also had the highest posttest score (146).

The results from our work with these four teachers have several broader implications for similar projects. First, our results highlight the importance of professional development in context. Curriculum materials are connected to teachers' daily work, thus situating teacher learning within their own practice providing ongoing content and pedagogical support (Beyer, Delgado, Davis, & Krajcik, 2009). Because our geospatial curriculum approach worked within teachers' curricular context it promoted the pedagogical design capacity of the teachers—that is, their ability to perceive and mobilize curriculum materials and resources for effective instructional enactment (Brown, 2009). The geospatial curriculum approach enhanced geospatial PCK for all participating teachers and as a result, novel technology-rich geospatial investigations were implemented with urban 9th graders. Finally, this research demonstrates that the earlier work supporting science teachers as they adopt geospatially-enabled curriculum materials (e.g., Bodzin et al., 2012; Fishman et al., 2013; McAuliffe & Lockwood, 2014) can and should be extended to social studies teachers as well, supporting their interdisciplinary geospatial learning activities.

Second, similar to other studies (Bodzin et al., 2015, Bodzin et al., 2014), results indicate that participation in the full design and development process, and not just stand-alone professional development, was instrumental to the teachers' growth in GS-TPACK, enacted cartographic practices, and scaffolding of students' use of GIS through teacher-modeling. Inservice science teachers may not have sufficient professional development opportunities to acquire appropriate PCK, geospatial PCK, or the technological capabilities that are necessary to successfully implement geospatially-integrated instruction with urban high school students that include reluctant readers, English language learners and students with disabilities. In our project, teachers' extended work in designing, developing, piloting, and implementing the SESI activities brought a far deeper level of engagement than the typical episodic, non-curriculum linked professional development used by school districts

(Wei, Darling-Hammond, & Adamson, 2010). Augmenting the geospatial PCK of inservice teachers is critical if early-career teachers are to effectively implement socio-environmental investigations using mobile and Web-based geospatial technologies. The geospatial curriculum approach, therefore, provides an effective means to achieve successful implementation or an inquiry-driven pedagogy that promotes student geospatial thinking and analysis skills as described by Baker et al. (2015).

Conclusion

There is a recognized deficiency in quality curriculum and support materials for teaching contemporary, age-appropriate, integrated socio-environmental science issues to promote spatial thinking skills (Baker et. al, 2015) and STEM workforce skills that are aligned to the Next Generation Science Standards (NGSS Lead States, 2013). The results of this study demonstrate that a curriculum-linked geospatial curriculum approach is effective in promoting geospatial PCK with classroom teachers who are then better able to implement geospatial learning experiences with urban students who are traditionally underrepresented in STEM disciplines and careers. The use of mobile and Web-based mapping technologies provided students with the opportunity to investigate local socio-environmental science issues using authentic data, while concurrently instilling important geospatial thinking and mapping analysis skills. We believe this approach makes the school curriculum timely, more engaging for reluctant learners, and more relevant for today's urban youth.

As we continue this project into future iterations, we will expand the scope to include impacts on student outcomes. While we are gratified that we can support the teachers' learning and that we have observed changes in the teachers' in-class cartographic practices, our future studies will examine what differences emerge in student achievement. This inquiry is in line with the broader research agenda in spatial thinking (Baker et al., 2015) and will help address the gaps in STEM participation from traditionally under-represented groups.

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Appendix: Questionnaire Items

What worked well?

What didn't work as well?

What did you learn along the way?

What improvements do you have in mind for our next steps this summer and next year?

1. Thinking about your learning as a teacher...
 - a. In what ways do learning with the Web GIS mapping and analysis tools help you think spatially?
 - b. Can you provide some examples from the SESI investigations that promoted your geospatial thinking and reasoning skills?
2. Thinking about your instructional practices with your students...
 - a. How did the SESI investigations help you to promote geospatial thinking and analysis skills with your students?
 - b. How did the Web GIS investigation enhance what you typically do in your classroom?
3. And just reacting holistically to the activities that we completed this spring...
 - a. List 3 things that you liked most about Web GIS investigations.
 - b. List 3 things that you liked least about Web GIS investigations.