Features and Methods of Designing Effective GIS Professional Development through the Technological Pedagogical Content Knowledge (TPACK) Framework

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Abstract

This article reports on the development and implementation of professional development (PD) based on the Technological Pedagogical Content Knowledge (TPACK) framework, as well as the subsequent assessment of the PD. Twenty-four middle- and high-school teachers attended our PD and studied teaching with a geographic information system (GIS), with the aim of deepening student engagement and learning in social science and science. We collected and analyzed attendees' reflective journals. Results suggested that teachers understood the significance of GIS in terms of both benefits for their teaching and for student learning. Furthermore, the participants learned how geospatial technological knowledge could interact with pedagogical content knowledge to create meaningful integration of GIS with classroom instruction. The findings of this study provide implications useful for further research on PD in the GIS domain. The insights on features and methods of designing effective PD should contribute to building the capacity of geography education and research.

Keywords: professional development, TPACK, instructional technology, GIS, geographic literacy, GIS

Introduction

The committee of the *Road Map for 21st Century Geography Education Project* set recommendations for building research capacity and capability in geography education. In its report, the committee suggests research on the characteristics of effective teaching of geography in response to the following question: "what areas of research will be most effective in improving geography education at a large scale? (Bednarz, Heffron, & Huynh, 2013, p. 7)." Educators who have more extensive teaching experience and knowledge are more likely to influence students' learning. Based on implications from past research, the report proposed further investigation to determine the knowledge teachers should have and the practices which constitute teaching that helps students to become geographically literate (Bednarz, Heffron, & Huynh, 2013). We believe these issues are of principal concern in shaping the quality of teacher education in field of geography.

The National Center for Research in Geography Education (NCRGE) called for proposals aimed at implementing research recommended by the Road Map Project's agenda and which are interdisciplinary, collaborative, and potentially transformative (Solem, 2017). In response to this request, our research group proposed a project regarding in-service teacher training. Our goal was to improve professional development (PD) first by coordinating collaboration between three researchers: a member of the faculty at University of Southern California (USC) with extensive GIS experience, another USC faculty member specializing in STEM education, and a geography education expert from the California Geographic Alliance. We then targeted middle- and high-school teachers as a method to infuse geospatial literacy and technologies into science and social science PD. We envisioned that identified characteristics of effective PD through the proposed research would solidify research on teacher education and support the effective and broad implementation of PD to incorporate GIS into instruction and curricula.

Future research should investigate the types of knowledge teachers should gain in this area and how they should use this knowledge. Furthermore, we need to understand how geographers and educators should support their attainment and deployment of knowledge (Bednarz, Heffron, & Huynh, 2013). High-quality PD can strengthen teachers' capabilities to use technology in their classroom. However, many PD facilitators have overlooked teachers' knowledge, resulting in superficial and ineffective PD (Borko, 2004; Guskey, 2002). We adopted the Technological Pedagogical Content Knowledge (TPACK) theoretical framework (Koehler & Mishra, 2009) to examine what knowledge should be taught and how instruction should be organized. Although past research adopted the TPACK framework to train teachers in GIS (Hong & Stonier 2015; MaKinster & Trautmann 2013), which can be regarded as a method to expand geographic literacy to other subjects, there still little research on the effectiveness of PD based on the GIS domain framework. Although our research was exploratory, we added insights on features and methods for designing effective PD about GIS to the existing knowledge in research on geography education. The insights specifically explicate what types of geospatial technologies should be covered in PD and how PD facilitators assist teachers in meaningfully and coherently incorporating GIS into their teaching.

Literature

Since Mishra & Koehler (2006) developed the concept of TPACK (Figure 1), many educators and PD facilitators have used this theoretical framework in a wide range of disciplines. They regard technological knowledge (TK) as an indispensable teaching component and extension to pedagogical content knowledge (PCK) suggested by Shulman (1986). TPACK conceptualizes knowledge necessary for integrating new technologies with teaching and addresses three core components and four derivative ones. The first three components are TK, pedagogical knowledge (PK), and content knowledge (CK). The other four are PCK, technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPACK). Each of the TPACK components is defined in Mishra and Koehler (2006) and Koehler and Mishra (2009). That said, Cox and Graham (2009) scrutinized the components to clarify them since there were variations among different researchers' interpretations. Among the seven components, the definitions of CK, PK, and PCK are consistent between Mishra and Koehler's work and that of Cox and Graham (Table 1). PK concerns the processes and practices of pedagogies such as inquiry-based learning and problem-based learning. Also, PK encompasses an understanding of student learning styles, classroom management methods, and teacher assessment of student learning. One difference between PK and PCK concerns whether the knowledge is independent of a specific subject or topic. Unlike PK, PCK focuses on knowledge about pedagogies situated in CK, the knowledge of concepts and representations in a particular subject area. Here, teachers should consider what teaching strategies would fit a subject area. Specifically, they should reflect on the knowledge students already possess, any misconceptions the students may have, and the difficulties they might face in their learning.

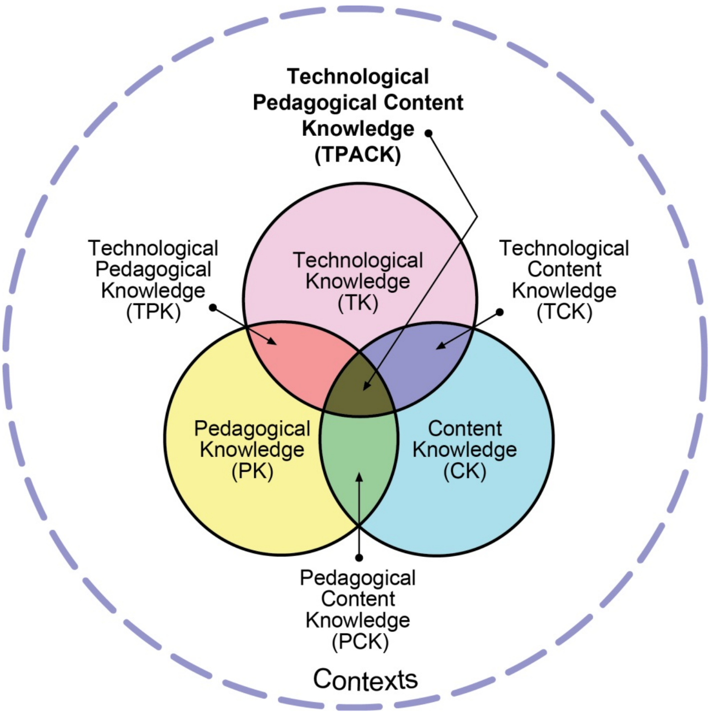

Figure 1. Technological Pedagogical Content Knowledge (Reproduced by permission of the publisher, © 2012 by tpack.org)

Although, there is agreement on the interpretation of PK, CK, and PCK between Mishra and Koehler's work and Cox and Graham's study, they reach different conclusions regarding TK. Mishra and Koehler (2006) defined TK as follows: "technology knowledge (TK) is knowledge about standard technologies, such as books, chalk and blackboard, and more advanced technologies, such as the Internet and digital video (Mishra & Koehler, 2006, p. 1027)." Although this definition includes non-digital tools, Koehler and Mishra (2009) and Cox and Graham (2009) limit TK to information technologies and emerging technologies, respectively. Furthermore, there is a discrepancy between these two studies in their perspectives on the use of TK. Mishra and Koehler (2006) pay particular attention to a teacher's knowledge and ability to process information using tools such as word processors, web browsers, and email systems; on the other hand, Koehler and Mishra (2009) focus on teacher use of TK for higher-order thinking such as problem-solving, as opposed to gaining skills for operations. Voogt, Fisser, Roblin, Tondeur, and Braak (2013) report divergent views on TK were found in their systematic review of the studies that used the TPACK framework.

These differences in interpretation are inherent to the derivatives of TK including TCK, TPK, and TPACK. TCK allows teachers to identify a technological tool best suited for teaching specific content as well as the best methods of representing concepts with the technology. As TCK combines TK and CK, it requires teachers to consider the manner in which TK and PK influence and constrain one another. Ultimately, by using TPACK, teachers should be able to coordinate CK, PK, and TK constructively and flexibly. Although TCK, TPK, and TPACK can on the whole be regarded as having a reciprocal relationship among their components according to the research, various researchers might regard them differently due to the differences of interpretation of TK. Researchers should examine consequences of this ambiguous quality of TK and discuss the issue to reach a clearer definition of this concept.

Table 1. Knowledge covered in each TPACK component

Components	**Mishra & Koehler (2006) / Koehler & Mishra (2009)**	**Cox & Graham (2009)**
Content Knowledge (CK)	Subject matters to be learned or taught	Content-specific representations
Pedagogical Knowledge (PK)	Processes and methods of teaching and learning	Pedagogical activities that can be generalized across multiple subjects
Pedagogical Content Knowledge (PCK)	Reciprocal relationships between CK and PK	Learning activities situated in a particular subject area
Technological Knowledge (TK)	Generic and emerging technologies	Generic and emerging technologies
Technological Content Knowledge (TCK)	Reciprocal relationships between TK and CK	Content-specific representations that can be taught or learned with emerging technologies
Technological Pedagogical Knowledge (TPK)	Reciprocal relationships between TK and PK	Generic pedagogical activities that teachers can engage in using emerging technologies
Technological Pedagogical Content Knowledge (TPACK)	Interactions among TK, CK, and PK to teach constructively and flexibly	Coordination of TK, CK, and PK to facilitate student learning

In terms of TK related to geospatial technologies, previously, teachers had learned skills for operating GIS software, mapmaking techniques, and methods for applying geospatial knowledge to teaching practice (Hong & Stonier, 2015; Trautmann & MaKinster, 2010). In Hong and Stonier's PD, teachers specifically used a web-based GIS and created web maps after learning the principles of thematic mapping methods such as graduated-color mapping and graduated-symbol mapping. Furthermore, the PD of both research groups emphasized examination of how teachers associated the geospatial technologies with PK and CK, rather than treating geospatial technology as an isolated component of teaching. Both groups reported the TPACK framework was used to develop teacher knowledge for effective and meaningful instruction employing GIS. However, more research is still needed on the design of geospatial PD based on TPACK. In the present study, we examined each TPACK component in the context of geospatial technologies and considered the proper arrangement of these components in designing effective PD in the GIS domain.

Method

We conducted a one-day on-site PD session in January 2018 and four monthly online PD sessions from February to May 2018. We advertised the on-site PD session on Los Angeles County Office of Education's (LACOE) website and recruited seventeen female and seven male in-service teachers from middle- and high schools in the greater Los Angeles area. Of the twenty-four participants, twenty-one teachers were qualified science or social science teachers. On average, they had taught in their subject area for 9.8 years. The other three attendees were an administrator, an instructional coach, and a substitute teacher. We set learning goals for the on-site and online PD, respectively. By the end of the on-site session, teachers should gain understanding of the following: 1) what GIS is and how it can effectively support instruction in social science and science; 2) what geospatial technologies can be used for teaching social science and science; and 3) how to implement geospatial inquiry-based learning to deepen student engagement and learning in social science and science. Of the twenty-four teachers, ten teachers also attended the online sessions. The learning goals were to attain knowledge and skills for implementing student-driven learning through advanced use of GIS. In each of the sessions (except for the final online session), we asked the attendees to write a reflective journal entry on what they had learned in the past sessions.

The first goal of the on-site session was to introduce GIS. In the lecture, we specifically explained the ways in which technological advancement has empowered GIS in the current Internet era, the type of intellectual merits and social impacts GIS has provided, and the benefits K-12 students would derive from GIS-based learning. The second goal was to provide practical instruction on the use of ArcGIS Online (AGO), a web-based GIS. To this end, we offered the teachers pre-made geographic inquiry-based learning lessons. The participants performed basic operations for handling web map layers as well as searching for geographic information and incorporating this information in these lessons. Optionally, some of the participating teachers worked on an exercise in which they created a simple web map. To increase their knowledge web-based resources, all attendees visited several geospatial portals and explored features such as web maps and apps available on these websites. The third goal of the on-site session concerned usage of web-based GIS, and how it may enable interaction or constrain the content and pedagogical aspects of teaching. We explained how our pre-made lessons utilized the learning cycles suggested by the Next Generation Science Standards (NGSS) and the California History-Social Science Framework (H-SS Framework) and how these lessons are designed to help teachers implement both the standards and framework. Furthermore, we discussed what types of geographic knowledge, skills, and reasoning students could learn through geographic inquiry-based learning. Lastly, we grouped participating teachers into several groups and asked them to discuss essential pedagogical elements needed to design successful lessons enhanced with GIS, such as student learning, classroom management, and assessment.

In the PD session, we specifically emphasized what challenges and misconceptions students might face in the geographic inquiry processes in order to have the teachers consider the pedagogical content knowledge unique in geospatial technologies. We articulated that these challenges and misconceptions can be identified in the following three areas: 1) the misinterpretations of geospatial representations, 2) cartographic characteristics causing difficulty in map interpretation, and 3) limited knowledge of geospatial vocabulary needed to describe spatial patterns. In the first area, students might have difficulty interpreting features such as contour lines used to create three-dimensional images of landscape, choropleth maps featuring confusing color classification schemes, and the time-space maps used to visualize both movements of objects and processes of diffusion. In the second area there are a number of cartographic characteristics that might perplex students. We explained students might misunderstand the difference between mapping scales and geographic scales. Additionally, students might misinterpret representations caused by confusing map projections and the sometimes imperfect nature of geospatial data. As for the third area, we reviewed terms depicting spatial patterns and discussed their significance in the development of students' map literacy.

In the first three online PD sessions, we focused on technological knowledge needed for advanced use of web-based GIS. In the first session, we covered knowledge necessary to develop a web map. Relevant concepts and skills involved editing coordinates in a comma-separated values (CSV) file, importing the CSV file to AGO, searching for map layers through AGO, changing symbology, and sharing web maps on the Internet. The second online session focused on geographic data acquisition for mapmaking. Teachers explored multiple local geoportals, such as Los Angeles GeoHub, as well as federal agency geoportals and learned how to process downloaded data and generate spatial data in web-based GIS. In the third session, we introduced a web app that allows users to synthesize a wide variety of media, including web maps, and then the teachers created their own similar web apps using the techniques introduced in the past three sessions. Finally, we concluded with tips for expanding teachers' GIS capacities. In the last online session, we discussed the pedagogical aspects of student-driven learning through GIS. Specifically, we conducted a lecture on how teachers can manage web maps and apps developed by students as well as specific teaching strategies that can be implemented allowing classes to shift from teacher-led instruction to student-driven learning. As a summative activity of the PD, teachers discussed what should be considered for effective integration of GIS into both teaching and developing lesson plans in order to successfully engage students in learning through GIS.

We asked participating teachers to complete and submit homework online after each session except the last online session. In each monthly assignment, teachers identified web maps that they thought they could use in their classes or constructed web maps or apps. Plus, teachers wrote a reflective journal to contemplate what they learned in each session. We analyzed their journals within the context of phenomenology to understand how teachers perceived and experienced our PD. We assumed that the phenomenological approach would provide us with insights on the elements of effective PD. In the analysis, we began with reading their journals entirely while taking memos to identify major organizing ideas. Teachers reflected what technologies they mastered and how GIS would support their teaching. We identified the following three initial ideas: 1) awareness of the significance of GIS, 2) teachers' GIS skills and knowledge, and 3) knowledge for teaching with GIS. Next, we delved into the sentences that pertained to the three major ideas and assigned those sentences codes. Then, we reduced and combined those emergent codes into three themes.

The three themes were as follows: 1) positive influence on students' learning, 2) teachers' mastering new technological knowledge, and 3) teachers' incorporating GIS into teaching. The first theme was about teachers' realization of rationales for using GIS in teaching and possibility for students' better learning. They expected that GIS would develop students' map literacy and computer literacy through critical thinking in real-world contexts. We categorized the relevant codes into the following three sub-themes: 1) incentive for students' learning, 2) connections to the real world, and 3) the development of students' critical thinking. The second major theme was relevant to teachers' development of technological knowledge. The codes categorized as the second theme indicated that teachers mastered skills for processing data and creating web maps, familiarized themselves with GIS resources, and gained confidence in the use of GIS. The third theme suggested how teachers would implement GIS in the classroom. As for the theme, teachers expressed how GIS would support inquiry-based learning and how teachers would integrate their TK, PK, and CK for their classes. Consequently, we classified the related codes into the following two sub-themes: GIS for inquiry-based learning and teachers' TPACK integration.

Results

We collected the reflective journal entries from the teachers who attended our PD and coded them by adopting a qualitative method proposed by Creswell and Poth (2018). The results of the analysis suggested three themes. First, some of the participating teachers speculated on ways GIS could positively influence students' learning. The speculation is categorized into three sub-themes. The first is that students could be motivated to learn and would gain more confidence in their use of technology through GIS use. For instance, one teacher wrote, "I've learned that students can be greatly empowered by the use of this technology by allowing them to construct maps that address interests and issues that they find interesting/appealing/that apply to their lives." The second sub-theme concerns the ways students may use recent digital technologies and connect with real-world problems in their learning. For example, a teacher articulated an idea how students would exploit the power of GIS in a digital era. Crowdsourced geospatial data could have a positive impact on his science teaching and create future opportunities for students:

> *The iNaturalist looks like a great resource for data, and I might be able to use it with my class to create data on invasive species or something. The idea of the citizen scientist is something worth a lot more consideration too. Few of my students will be scientists, but I think many of them could participate in science and enjoy it.*

In this second sub-theme, one teacher expected students might use geospatial technologies in deciding whether to pursue GIS as a career. As for the third sub-theme, several teachers thought that solving problems through GIS, which allows better decision making in solving problems, would enhance the students' critical thinking skills. The following is an excerpt from one of the teacher journal entries: "Through critical thinking skills just in creating a map and adding layers is so hands on that the student will truly have to become engaged in the method and the lesson." The first theme suggested that teachers regarded GIS as not merely a subject to increase students' technological capabilities but also a tool to have students engaged in problem-solving for better decision making.

From the interpretation of teachers' inputs, it can be suggested that TK covers both geospatial computer skills and literacy for higher-order thinking.

The coding analysis also revealed a theme in the teachers' views of the types of geospatial TK. As teachers mastered new technical skills for the use of GIS, they were led to consider the positive impacts that come with the advancement of geospatial technologies. For example, one teacher explained how he would process longitude and latitude coordinates in a CSV file, create a map layer by using the coordinates, and create the symbols to represent map features such as locations of fossils or endangered species. Another teacher described how cloud computing and mobile devices allow people to easily create a web map and then share it with others, citing this as an example of a way to improve civic interaction and decision making:

> *More and more, spatial information is being used for sharing information and decision making. The ability to easily make maps and share data is changing the pace of civic interaction. People can easily report things on mobile device to make data collection much quicker and easier.*

The quote above suggests a teacher's understanding of advanced information technologies such as cloud computing and Web 2.0. For designing better PD, we suggest that facilitators consider what emerging technologies would underpin students' long-term success and how those technologies can strategically be introduced to teachers.

Lastly, the analysis of teachers' reflective journals provided us with insights into teachers' perceived preparation made for teaching with GIS. These entries articulated in concrete terms how pedagogical and content aspects of teaching could interact with GIS. As for this theme, we identified two sub-themes: GIS for inquiry-based learning and teachers' TPACK integration. Several teachers described how pre-made lessons would instantly allow them to engage students' inquiry-based learning. They considered that students would be able to develop their map literacy and skills while learning science or social science. One teacher stated as follows:

> *Inquiry based learning is the most effective way for students to learn as they can focus on an area of interest to them. Using Story Maps makes sense as they formulate a question and show their research and investigation by creating and collecting maps and images.*

Furthermore, several teachers hoped to develop lesson plans asking students to explore or make web maps related to a particular interest. On the other hand, a few teachers anticipated difficulty identifying web maps suitable for specific subject topics or associating geospatial inquires with the NGSS and H-

SS Framework. In terms of interacting with the components of TPACK, which is the second sub-theme, we found some conflicting opinions in the teachers' journals. A few teachers detailed how they would use GIS to teach a specific area of science or social science. A history teacher wrote that her students would analyze maps through a historical perspective to learn how drought increased large-scale starvation and death in the past. Another science teacher also articulated how he would integrate GIS into his teaching:

> *In the near future I will be using the earthquakes and volcanoes map described above to have the students try to recognize patterns. ... We will be looking at the incidence of earthquakes and volcanoes as clues or evidence as to what is happening to the Earth as a whole. We will also use the IRIS earthquake browser to view cross sections and areas in 3D as a big clue to subduction zones. ... It is nice to use a map to zoom in and introduce a virtual field trip to places and events around the world.*

Most teachers could integrate GIS and subject contents within the inquiry-based learning context. Presenting the combinations of TK and CK based on a specific pedagogical method might allow teachers to develop their TPACK knowledge successfully. For instance, teachers might learn how to integrate the TPACK components through an example of service-learning with suitable geospatial technologies and subject topics. We suggest that PD facilitators strategically design scaffolds for teachers' TPACK, which intends to develop meaningful lesson plans with GIS.

Discussion and Conclusion

We set three learning goals for in-service teachers who attended our PD, all concerned with development of a greater understanding of GIS. First, we aimed to clarify what GIS is and how it can powerfully support instruction in social science and science. Second, attendees should learn how geospatial technologies can be used for teaching social science and science. Third, we focused on methods to implement geospatial inquiry-based learning and student-driven learning to deepen students' engagement and learning in social science and science. The first two goals concerned teacher understanding of TK in the context of geospatial technologies. Specifically, the teachers learned the fundamentals of geospatial technologies by using web-based GIS such as AGO, Google Maps, and geojson.io. These programs allow users to easily explore geospatial data, create maps, and share their work with other users. Participating teachers quickly familiarized themselves with GIS and understood its significance in the context of K-12 education. In their reflective journals, they articulated possible benefits they believed students would receive through learning with GIS, how GIS could bring real-world issues and technologies into their classroom, and how students should be able to augment their critical thinking skills through active learning with GIS. In our PD, we explicated reciprocal relationships between the use of GIS and elements of student learning through lectures, hands-on exercises, discussion, and collaborative work. The emphasis on these reciprocal relationships might have contributed to the teachers' familiarization with GIS as TK.

The third learning goal concerned teacher understanding of how the components of TPACK interact each to create meaningful and consistent integration of GIS with teaching practices. In their journals, a few teachers confessed that they had struggled to align technological geospatial areas with their subject areas. On the other hand, some teachers described in detail how their students would learn about a specific subject topic by examining geospatial data and making web maps. Although we demonstrated how teachers could teach science and social science with GIS in several lesson scenarios, some teachers had difficulty identifying where GIS or maps could be incorporated into their curricula. In our next PD, we suggest using more cases of teaching with GIS and a greater number of examples showing the type of geospatial technologies and concepts that can be used for various subject areas in teaching. In the context of the TPACK theoretical framework, we would explicitly externalize how geospatial TK, CK, and TCK intersect with the CK of the teachers' subjects. Although geography educators and researchers have provided many sample lessons employing GIS, there is still room to examine ways to combine geographic literacy and technologies into other subjects. For example, we do not yet know if these geospatial technologies could also be helpful in teaching certain topics in other subject areas such as physics and chemistry.

The analysis of the teachers' reflective journals suggests that most teachers achieved the learning goals we set. By using TPACK as a theoretical framework, we focused on teachers' integration of the TPACK components rather than solely emphasizing the geospatial TK component. Our study provided insights on effective design and implementation of PD in relation to geospatial technologies. That said, there were limitations to our research. First, we recruited a small number of teachers and relied solely on self-reports in our evaluation of PD. We suggest that further research use both subjective and objective data for assessing PD and conduct a larger scale study. Second, we recommend that PD facilitators and researchers evaluate their PDs before and after their attendees implement the knowledge they gained through this development in their teaching. Although a few teachers indicated to us that they taught a subject with GIS after our PD, we did not systematically incorporate this aspect of their reporting into our analysis. It is quite possible that teachers will develop a deeper understanding after they utilize their knowledge of GIS in the classroom. Furthermore, researchers should examine how students' learning may change following the teachers' incorporation of this technology.

We sought to connect our PD study with research strategies suggested by the Road Map Project committee (Bednarz, Heffron, & Huynh 2013). Our first adopted strategy was to coordinate collaboration between the authors, who specialize in geography or STEM education. We strategically allocated a set of our expertise areas to design and implement PD for training K-12 teachers in the GIS domain. Second, we adopted TPACK as a theoretical framework, which has widely been used in a variety of subjects among many education researchers. Findings and implications obtained from our study should contribute to building knowledge within the theoretical framework. Lastly, we responded to the Road Map Project's recommended key research question: "what is necessary to support the effective and broad implementation of the development of geographic knowledge, skills, and practices?" (Bednarz, Heffron, & Huynh, 2013, p. 12) by conducting PD to promote teacher development of geospatial technological literacy. The insights on features and methods for designing and implementing effective PD suggest implications useful for furthering the capabilities of geography education and research.

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