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Shoulder to Shoulder: Teacher Professional Development and Curriculum Design and Development for Geospatial Technology Integration With Science and Social Studies Teachers

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For decades, educators have hoped to integrate geospatial tools into K-12 classrooms but struggled with barriers of time, technology, and curriculum alignment. The authors formed a design partnership with ninth-grade science and social studies teachers in an urban high school in order to conduct teacher professional development while also developing geospatially enabled curricula to enact in their classrooms. This article includes a description of the curriculum design principles and processes, as well as an explanation of the professional development strategies as participants worked should to shoulder in designing engaging classroom instruction to enhance students' geospatial thinking and reasoning skills. One of the activities presented is an example of the design and development process, and lessons learned from the pilot test implementation are presented. This article may inform similar work with geospatial technologies in teacher professional development and curriculum development.

Geospatial tools have been in the K-12 curriculum for several decades, yet they remain underutilized by educators. For example, the *Geography for Life* (Geography Education Standards Project, 1994) Standards called for integration of geographic information systems (GIS) into classroom instruction, but this expectation has rarely been met (Milson & Kerski, 2012). In general, the barriers to integrating GIS – complexity of the technology, difficulty in accessing datasets, and steep instructional time demands of inquiry learning – have prevented all but the most ambitious teachers from using geospatial tools with their students. The literature documents successful cases of GIS curriculum integration (e.g., Baker & White, 2003; Bodzin, Fu, Peffer, & Kulo, 2013; Rubino-Hare et al., 2016), but most K-12 students graduate with no exposure to advanced geospatial technologies such as GIS.

Technological and social changes since 1994, however, have made the integration of GIS and other powerful geospatial tools far more accessible than before. First, the tools themselves have changed: GIS capabilities, which have traditionally required complex client-side software manipulating bulky datasets, are now readily available and easily accessed on the Cloud. Through tools such as Esri's ArcGIS.com, users can access an ever-increasing library of maps and data. Related tools such as global positioning system (GPS) capability have expanded from expensive dedicated devices such as GPS units to ubiquitous devices such as cellphones and automobiles.

These technical changes have opened a floodgate of geospatial activity in everyday life. Common activities such as using paper maps for driving have been supplanted by turn-based navigation. Even when driving to a familiar location in which the route is known, drivers will commonly consult a web map to check for traffic volume, construction zones, and accidents to determine shortest routes.

Search engines such as Google automatically return maps in response to any location-based query. Social media and other services routinely draw upon location data, and investigating suspicious behavior may begin with reviewing a user's location history (Kantra, 2016; Kielman, 2014).

These technological and social changes have created both challenges and opportunities for K-12 schools. The allure comes from the demand for geospatially ready STEM workers and academics (Baker, 2012; U.S. Department of Labor, Employment and Training Administration, 2016). The advent of more accessible, browser- and mobile-based geospatial technologies makes K-12 integration much more feasible than at any point in the past.

The remaining pieces of the puzzle are (a) untangling the challenges of integrating powerful, inquiry-driven instruction into K-12 curriculum and classroom teaching, and (b) developing models for teacher preparation and/or professional development to make this integration possible (see Baker et al., 2015). Only when teachers and developers work side by side, shoulder to shoulder, can both challenges be addressed at once.

Rationale

K-12 curricula and classrooms are crowded in several ways. The curriculum is crowded conceptually, packed with topics and skills that teachers must cover or risk poor performance by their students on high-stakes end-of-course assessments. These constraints leave little time for integrating novel GIS learning activities, even if they align with the curriculum.

The classroom is crowded both physically and temporally. The physical crowding occurs as underfunded school districts reduce personnel costs by increasing class sizes. The temporal crowding comes from the myriad demands of instructional time, classroom management, assessment routines, additional school events, and inclement weather that leads to school closings. Outside of the school day, the demands on teachers' time remain steep, as they evaluate student work, attend faculty meetings and sporting events, conduct parent conferences, participate in district-mandated professional development, and more.

Challenges Specific to Geospatial Curriculum Integration

Geospatial technologies and other new learning tools cannot easily enter this crowded space. First, teachers and students require time to learn the technologies' interface, data handling, analysis capabilities, and more. Second, the inquiry learning models that make the most effective use of geospatial technologies all require time both outside of the classroom, during teachers' scant professional development time, and inside the classroom, during instruction.

Finally, geospatial integration programs cannot dictate the school-adopted curriculum by altering the required content to meet the availability of maps and datasets. Instead, geospatial integration efforts must find the points of connection, entering into the existing curriculum by meshing with established expectations of content coverage and assessments that align to prescribed learning goals.

As a result, geospatial integration into K-12 classrooms involves a delicate harmonization of many variables, including curriculum-specified content, relevant available data and data collection opportunities, structuring low-threshold, inquiry-driven learning activities, and finding ways to weave in technology instruction along the way (e.g., Zalles & Manitakos, 2016).

Furthermore, successful integration requires specific technological pedagogical content knowledge (Mishra & Koehler, 2006) and support for teachers as they incorporate geospatial technologies into their classrooms. Teaching with geospatial technologies involves geospatial science pedagogical content knowledge, a specific type of technological pedagogical content knowledge. Teachers with geospatial science pedagogical content knowledge have a more complete understanding of the complex interplay between pedagogical content knowledge and geospatial pedagogical content knowledge and can teach content using appropriate pedagogical methods and geospatial technologies (Bodzin, Peffer, & Kulo, 2012). This knowledge involves understanding both how to model geospatial data exploration and analysis techniques and how to effectively scaffold students' geospatial thinking and analysis skills.

Previous Geospatial Curriculum Integration Efforts

Most recent geospatial curriculum integration efforts have consisted of a single unit or module of geospatially enhanced study (for example, Hammond, 2015; Milson & Curtis, 2009; Perkins Hazelton, Erickson, & Allan, 2010; Shin, 2006—see also the stand-alone *GeoInquiries* lessons created by Esri: esri.com/geoinquiries). These researchers and curriculum designers have found creative ways to harmonize the variables of content, data, technology, and teacher professional development.

These studies are smaller scale, however, and they fail to yield a design model that can be used to guide the generation of new geospatially enhanced instruction. Other researchers have been able to conduct larger scale projects by integrating geospatial tools across an extended instructional sequence or even an entire curriculum (Doering & Veletsianos, 2007; Goldstein & Alibrandi, 2013), resulting in curricular design principles (Doering, Scharber, Miller, & Veletsianos, 2009).

As an example, Edelson and his collaborators developed both curriculum and technology, integrating their WorldWatcher visualization environment into earth science instruction (Edelson, Pitts, Salierno, & Sherin, 2006) and their My World GIS into multiple instructional areas (Edelson, Smith & Brown, 2008). Their work was guided by the Learning-for-Use design framework (Edelson, 2001), which begins with learning principles and derives an instructional design process for generating geospatially enhanced inquiry learning.

One of the most extensive curriculum design projects with geospatial technologies has been delineated by Bodzin and collaborators (e.g., Bodzin, 2011; Bodzin & Cirucci, 2009; Bodzin & Fu, 2014; Bodzin et al., 2015; Bodzin, Fu, Kulo, & Peffer, 2014; Kulo & Bodzin, 2011, 2013). Their work, which focuses on Earth and environmental sciences, has articulated a geospatial curriculum approach for instruction and a teacher professional development model that uses educative curriculum materials (Bodzin et al., 2013; Bodzin, Anastasio, Sahagian, & Henry, 2016).

Building on this earlier work, we initiated a teacher-researcher collaborative project to design, develop, and test a series of novel socio-environmental science investigations (SESI; see also Sadler, Barab, & Scott, 2007; Zeidler & Nichols, 2009) using a geospatial curriculum approach and STEM-related mentoring. The project as described in this manuscript took place over the course of 1 year. The first 9 months were devoted to the design and development work, followed by 10 weeks of prototype implementation that occurred before the end of the school year.

Teacher professional development took place for several weeks over the summer, in biweekly development meetings, and during implementations. The resulting inquiry-based investigations are designed to take advantage of recent developments in powerful, mobile geospatial technologies to promote students' STEM-related workforce and academic skills. The content of these curriculum-aligned activities focuses on social issues related to environmental science. The pedagogy is inquiry-driven, with students engaged in hands-on work with data to answer open-ended questions.

These investigations can be implemented across multiple content areas common in secondary science and social studies curricula. These issues are multidisciplinary, involving decision-making based on the analysis of geospatial data, examination of relevant social science content, and consideration of social equity implications.

We used a design partnership model that included education professors with background on curriculum design and development with geospatial technologies, classroom teachers, content experts in the natural sciences and social sciences, and industry partners who use geospatial technologies in their occupations and who served as mentors in the classroom. Organizing this complex combination of teachers, mentors, researchers, and scientists and having them work shoulder to shoulder requires both a high level of trust and a clear design model.

Our work was guided by a specific curriculum approach for geospatial learning and proceeded under a design process that incorporated simultaneous teacher design participation and professional development. The goal was to produce well-designed geospatially integrated instructional materials for classroom use and to articulate design principles and processes that can be applied in other K-12 settings and teacher education classrooms.

Our teacher-collaborators work in an urban public high school serving a high-needs student population. For example, all students at the school receive free breakfast and lunch. We collaborated with the school's science and social studies departments to develop the geospatial learning activities for implementation with the entire ninth-grade class, approximately 140 students. The following sections present our curriculum approach for geospatial learning, the curriculum development process, the teacher professional development strategy. We then discuss our development work by highlighting one of the SESI investigations.

Curriculum Approach for Geospatial Learning

Our geospatial curriculum approach for learning was an extension of previous research (Bodzin, 2011; Bodzin et al., 2015; Bodzin, Peffer, & Kulo, 2012) combined with the National Science Foundation Geotech Center's Geospatial Technology Competency Model (U.S. Department of Labor, Employment and Training Administration, 2010). The resulting curriculum approach sought to promote students' geospatial thinking and reasoning skills by enacting classroom inquiry that embodied five design principles (listed in Figure 1):

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. Provide instructional scaffolds (Jonassen, 1999; Quitana et al., 2004) to help students analyze geospatial relations.
5. Develop curriculum materials to better accommodate the learning needs of all students, while also expanding the geospatial pedagogical content knowledge of teachers.

This curriculum approach aimed to develop geospatially enabled learning activities that foreground the curricular content learning and minimize the time devoted to teaching about rather than with the technology (see Sui, 1995). In addition to producing datasets and instructional materials for student use, our curricular approach calls for teacher support materials that advance their understanding of the socio-environmental subject matter addressed within each activity.

These educative curricular materials were all selected to be classroom-ready, as well as informative to the teacher: Web-based videos, text, graphics, maps, and other visual materials. When reviewing these materials, teachers can both enhance their content knowledge and begin making selections and adaptations for use in the classroom, particularly to support students who are reluctant readers, English language learners, and students with disabilities. The goal was to provide both a strong base of ready-to-use instructional materials and opportunities for modification and enhancement by teachers as they meet the needs of their particular classroom.

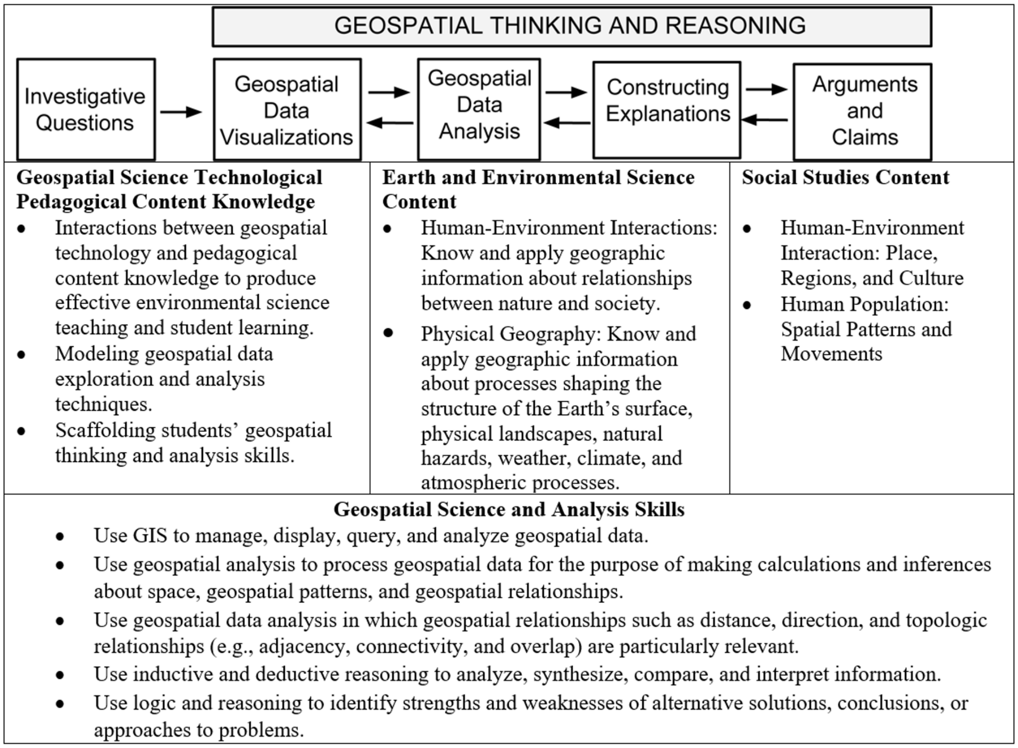


Figure 1. *Key components of the geospatial curriculum approach.*

The SESI Activities

The SESI activities focus on students' immediate urban environment and emphasize the *Next Generation Science Standards* (NGSS Lead States, 2013) crosscutting concepts and scientific practices to the disciplinary core ideas in Human Sustainabilit*y*, as well as the C3 Framework for Social Studies (National Council for the Social Studies [NCSS], 2013). (See Figure 2.) During SESI activities, students gather georeferenced data on social issues related to environmental science. The topics are multidisciplinary and focus on environmental management and social justice. The investigations require students to gather information relevant to urban planning decisions in their own communities. Students are then asked to take on the role of a decision-maker and inform their thinking and reasoning about decisions based on their analysis of the data they gather, its connection to relevant social and environmental science content, and consideration of the implications for social equity, political opportunity, and environmental sustainability.

We incorporated instructional strategies such as scaffolding to support students with their data analysis interpretations. The scope of the investigations were developed so that by the end of the school year an authentic communication component could be incorporated: Students share their findings about the health of their surrounding environment with the local community in a public forum, in order to start conversations that may empower the public to advocate for further research and political action (as also in Connors, Lei, & Kelly 2012; Kolok, Schoenfuss, Propper, & Vail, 2011).

Our overarching investigation focus was land use change in our city over the past 3 centuries. This topic lends itself to a series of subinvestigations (see questions posed in

Figure 2) that enable students to analyze past and present georeferenced data, carry out field data collection focused on important socio-environmental data, and analyze geospatial patterns and relationships in a Web GIS. All of these actions then come together to inform a decision-making step concerning the future of our community.

SESI Learning Activities	**NGSS Disciplinary Core Ideas (Achieve, Inc., 2013)**	**Scientific Practices**
Overarching: How has the environment and land use in our city changed over time, how is it being used now, and how can we plan for future sustainable land use? • What does my local zoning look like? How is city zoning determined near me? • Where are the best places for greenspaces? • How healthy is our natural and built environment? • How do trees and vegetation provide ecological services to the community? • How do we contribute to climate change? • How do our transportation routes and methods contribute to climate change?	HS. Human Sustainability • ESS3A. Natural Resources • ESS3B. Natural Hazards • ESS3C. Human Impacts on Earth Systems • ESS3D. Global Climate Change • ETS1.B. Developing Possible Solutions **Crosscutting Concepts** Patterns Cause and Effect Scale, Proportion, and Quantity Systems and Systems Models Energy and Matter **C3 Framework Social Studies** Spatial Views of the World D2.Geo.1.9-12 D2.Geo.2.9-12 D2.Geo.3.9-12 Human-Environment Interaction D2.Geo.4.9-12 D2.Geo.5.9-12 Human Population D2.Geo.8.9-12 Global Interconnections D2.Geo.10.9-12	Asking questions and defining problems Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Crosscutting explanations and designing solutions Engaging in argument from evidence Obtaining, evaluating, and communicating information

Figure 2. *Core NGSS & NCSS alignment to the Web GIS investigations.*

Integration and Inquiry

Given our goal of working across multiple content areas, we designed and developed learning activities for ninth-grade students in both science and social studies classrooms to run flexibly in one or both content areas. Each SESI activity focuses on a driving investigative question and specific content for implementation in a social studies classroom (e.g., urban zoning or land use change over time), a science classroom (e.g., ecosystem services, climate change effects, or urban heat island), or both (e.g., healthy natural and built environment or transportation routes).

Simultaneous to this content learning, each investigation develops students' geospatial process skills. These skills include accessing different geospatial applications (Collector for ArcGIS app on iPad and Web GIS maps on laptop computers), utilizing data collection procedures, displaying and navigating maps, annotating maps, analyzing data using different tools for pattern recognition and examining outliers, and constructing new data displays and visualizations. By planning learning activities that repeatedly use the same geospatial tools in inquiry-based learning, we could take advantage of sequence effects as we progressively introduced students to both the geospatial tools (interface, navigation, analytical capabilities, and so forth) and their active role in the learning process (becoming familiar with a dataset, asking questions when necessary, and constructing explanations and arguments). The continued focus on land use —past, present, and future — lends itself to a variety of pressing topics related to sustainability: transportation systems, the waste stream, water supply systems, seasonal flooding, and others. Even when working within a single curriculum area, all uses of geospatial technologies in classroom instruction inherently involve integration. One level of integration is curricular: When we use tools such as GIS or Google Earth, we seamlessly draw upon our existing knowledge of multiple disciplines, including geography, geology, geophysics, history, and mathematics.

The second level of integration is conceptual: Users cycle between lower level cognitive tasks such as identifying and recalling specific data points or geographic features, higher level cognitive tasks such as pattern recognition and inference, and metacognitive monitoring as they structure their analysis to confirm or disconfirm an initial understanding. In addition to the critical thinking required by geospatial analysis, the geospatial organization of the data requires an additional layer of spatial thinking, moving from spatial primitives to more sophisticated understandings of spatial networks and hierarchy required for geospatial reasoning. (e.g., Golledge, 1995).

A final level of integration is logistical: Users work with a collection of multiple maps and datasets generated by different people at different times and often for very different purposes. For effective use with diverse urban secondary learners, existing data layers often need to be customized in order for geospatial patterns to become more readily apparent. This customization might involve ordering layers in a Web GIS in a specific way, developing a better color scheme for data display, or combining data layers in a specified manner during analysis.

Inquiry-based learning provides an authentic process for this integration. During inquiry-based learning, students focus on a driving investigation question. They inevitably draw upon multiple areas of prior knowledge, cycle between concept development and analysis procedures, and (when appropriate) analyze the purposes and deficiencies of existing maps and datasets. To structure these processes, our geospatial curriculum approach (Figure 1) is used to guide our instructional development. In the learning activities, in order to promote capacity for the development of geospatial thinking and reasoning skills, we challenge students to use geospatial analysis for the purpose of making inferences about space, geospatial patterns, and geospatial relationships.

Role of Mentors

Our design partnership included volunteer mentors from businesses and universities in the local area to help promote STEM-related skills within the context of the students' learning experiences. Mentors can help students recognize how STEM learning connects to real problems, social contexts, and careers. In a recent study, about two thirds of teens indicated that they may be discouraged from pursuing a STEM career because they did not know anyone who works in these fields or understand what people in these fields do (Association for Career and Technical Education, 2009).

Connections to careers can bring purpose to students' learning and help guide them in thinking about their future. This strategy can attract students who may be marginalized in traditional education and presents an opportunity for engaging more students in STEM careers (National Association of State Directors of Career Technical Education

Consortium, 2013). Successful mentoring is characterized by "instrumental support" (Spencer, 2012, p. 298) in the form of role modeling, monitoring, guidance, advice, and learning through shared activities.

The mentors in our project work and research in STEM-related fields and use geospatial technologies in their occupation. For example, the local power company employs a forester to supervise and analyze the tree-related maintenance of the electrical grid. The mentors come into the classroom for multiple days during each SESI investigation. The mentors may share some content knowledge, help supervise data collection, guide students' exploration of the GIS data visualizations or analysis, or provide feedback on their explanations or final arguments. The forester, for example, can share his/her background and work with the class (thus developing students' background knowledge) and supervise data collection and analysis during the tree-related activities.

For logistical reasons, the mentors are not expected to be present for every component of a particular investigation. Accordingly, our model calls for mentor involvement when they are available, prioritizing sustained involvement rather than cycling a large number of single-visit mentors in and out across multiple learning activities. To support the mentors, we have developed training and orientation materials for them to complete prior to working with the students. Our hope is that positive, productive mentor experiences can increase the sustainability of the project, allowing teachers to collaborate with continuing mentors side by side to design and implement new geospatially enhanced instruction long after the project is completed.

Curriculum Development Process

As with other geospatial projects, our curriculum development followed a design partnership model. In this model, education researchers, instructional designers, content experts, and geospatial experts collaborate with classroom teachers to design and develop the SESI activities, along with consultation from school administrators and technology staff. Our partnership model focuses on collaborative design and implementation of curriculum in keeping with models of school-based reform (as also in Shear, Bell, & Linn, 2004).

Our partnership is a mechanism to leverage the diverse expertise of each contributor. This collaboration also promotes the learning of each partner in a process of codeveloping the curriculum and instructional practices that will be implemented in the classroom (see also McLaughlin & Mitra, 2001). In addition, this level of collaboration and coordination is necessary to manage multiple and overlapping issues of technical implementation, school management, and curriculum design and development.

The initial stages of our project were focused on managing the information technology infrastructure of the school. SESI activities required new iPads to be bound to the school district's network, while still allowing flexible updating and app management from members of our project team. The project also required an organizational account for the school to use Esri's ArcGIS.com Web GIS infrastructure. The access is free upon request to K-12 schools as a continued part of Esri's participation in the Obama-era ConnectED initiative (Fitzpatrick, 2014).

With an institution-level account, one can obtain a single URL for all work in the Web-based GIS environment to gain significant organizational advantages that include central control of shared resources such as datasets and maps that aid team management and the ability to manage both individual student accounts and class-level groupings. A final piece of infrastructure was developing websites for hosting instructional materials and the mentor orientation and training materials.

As the technical and logistical details were being worked out, we began charting our development cycle for the SESI activities. The first step was to gather information about the existing curriculum in both the environmental science and the social studies classes. In this area, the teachers were the experts, unpacking their content, objectives, and assessment practices for the design and development team.

The next step was a collaborative brainstorming process, identifying topics for the SESI investigations, locating datasets, and outlining ideas for data collection, visualization, and analysis. Following this brainstorming, we selected and organized the content, focusing on those topics that appeared to be the best fit for teachers' existing curriculum and had strong potential for engaging the students.

From these topic selections, the development team began sketching out the SESI investigations, addressing the following questions in a collaborative planning document:

- What are the enduring understandings?
- What are the learning objectives?
- What background content knowledge for both teachers and students would be required?
- What outside data collection opportunities would be incorporated?
- What preexisting datasets would we incorporate into students' visualization and analysis?
- What would be the instructional sequence for the learning activities?
- How would we scaffold students' work?
- What would be the role of the mentors?
- What would be the culminating artifact produced by the students?
- Where might time restrictions or complexity of analysis limit students' ability to complete instructional activities?

Simultaneously, we identified the tools we would need to support students' completion of the SESI activities. In addition to the GIS, we selected Esri's Collector app for data collection, additional software, such as Google Earth for supplementary visualization, and supplementary data collection tools, such as air and infrared thermometers, and tape measures. The end product from this stage was a complete package of materials for each SESI activity that included background content material to give the teachers a foundation in the content, an instructional sheet and videos to guide students' use of the geospatial tools, and a set of tasks for students to complete when examining the data visualizations, conducting analysis, and making initial explanations and claims.

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 and visualization. As we completed the initial development of materials for each SESI activity, we requested an initial prototype implementation with a teacher-selected group of 10th graders to provide us with usability feedback on the data collection interfaces and a student perspective on the learning activity's tasks and support materials. After initial prototype testing, we were ready to implement a complete prototype activity with the full class of ninth-grade science or social studies students.

The classroom prototype implementations followed a gradual release model. In this approach, the design and development team act as the primary instructors in the classroom until the regular teacher (either environmental science or social studies) feels ready to take on the task of guiding students through the day's activity.

For example, over the course of a day, a member of the design and development team might teach the class during Period 1, with the teacher providing instructional support. During Period 2, the teacher would take over part of the lesson, with the design and development team member playing a backup role as needed. By the last period of the day, the teacher would lead the entire lesson.

Following each prototype implementation, the teachers and the design and development team — occasionally joined by mentors as well — engage in a group reflection on the day's material, discussing what worked well and what parts of the learning materials need refinements for the next iteration.

Teacher Professional Development Approach

An essential feature of this project is our hybrid, curriculum-linked professional development process. This process incorporates both face-to-face and online learning and follows a design partnership model (see Bodzin & Cirucci, 2009). By integrating the teachers' professional development into the curriculum design and development activities, we are able to advance teachers' geospatial pedagogical content knowledge (Bodzin et al., 2012) in the authentic context of their curricular practice. This integrated approach is effective in supporting teachers as they adopt new curriculum and new spatial technologies (Bodzin et al., 2012; Fishman et al., 2013; McAuliffe & Lockwood, 2014). Our starting assumption is that our collaborating teachers are the pedagogical experts who will adapt curriculum materials as needed to meet the needs of their students (Penuel, Fishman, Yamaguchi, & Gallagher, 2007).

We support teachers in this adaptation process, but our primary focus is on the content and technology needed for the curriculum: how to use the GIS, for example, or the background understandings that underlie topics such as urban heat islands. We advance teachers' content and technology skills through active learning experiences with GIS, both in exploring background content and when working through sample materials for classroom instruction. We then provide opportunities for integration across teachers' understandings of the content, pedagogy, and technology through collaborative peer discussions and the opportunity to reflect on their own teaching practice (as also in Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel et al., 2007). By allowing teachers to provide reciprocal expertise, we support the high level of trust and engagement required to build and enact geospatial curriculum, shoulder-to-shoulder.

Outside the Classroom: Rapport-Building and Reciprocal Expertise

The first step in any successful professional development effort is rapport-building. We adopted the school's routines in our meetings with the teachers. First, all initial meetings with the teachers took place in their school building, typically in the lead teacher's classroom after school. These meetings lasted between 1 and 2 hours, depending upon the teachers' availability.

Second, we opened and closed these sessions in the same way that the school conducted its faculty meetings. The meetings began with a "check in," as everyone shared how their day or week was going or otherwise responded to an initiating question. At the end, everyone provided a "plus, minus, or delta," identifying whether the meeting had helped them reach a new understanding or left them with uncertainty or prompted new questions. By working with teachers in their spaces and following their established routines, the design and development team signaled that we were there as members of a community, collaborators working side by side, and not just visitors from a university.

Some of the design sessions explicitly focus on advancing teachers' understandings and skills. For example, the design and development team presented past geospatial projects, demonstrating how data are merged into a GIS, how to explore displayed data, and how to conduct a simple analysis. Other sessions took a more hands-on professional development strategy, such as walking through a data collection process as part of testing out a design concept.

Because the design and development team included some members who were relative novices in using geospatial tools, even the overt professional development sessions seemed like authentic discussions in which the stakeholders were pooling their expertise. Conversely, the teachers were the experts when discussing their students, the curriculum, and their assessment routines. Their voices provided the final word on decisions regarding instructional details such as the complexity of data sets or student grouping patterns for outside data collection.

In the Classroom: Instructional Modeling and Gradual Release

An important professional development tactic was the gradual release model of classroom prototype implementation. Allowing teachers to adopt elements of the instruction at their own pace enabled them to be comfortable with the process. Whenever they took over a new instructional step, they had support in the form of one or more design and development team members.

In this process, we observed one teacher adapting the prototype SESI investigation much more quickly than the rest. This teacher had more experience with geospatial tools and greater familiarity with the content; this background apparently created confidence to quickly take the central role in leading the SESI activities in his classroom. By the second prototype activity, he initiated and directed all stages of the instruction, only turning to the design and development team in the event of a technical glitch. The gradual release model allowed another teacher, with less prior experience with the technologies and topics of the SESI activities to take a slower process as she advanced her skills and comfort level.

In addition to these face-to-face activities, teachers completed several online professional development tasks. We provided selected readings in geospatial education and geospatially enabled curriculum, focusing on examples of classroom use of geospatial technology to study social studies and science topics. These readings helped convey the importance of teaching and learning with geospatial technologies, illustrations of classroom enactment, and some of the background content for the inquiry activities. In addition to these readings, teachers reviewed previously built geospatial curriculum learning activities drawn from the design and development group's past projects.

Development Work: From Blue Sky Through Prototype Implementation

Design

The Zoning activity is presented here to illustrate the curriculum development sequence and interwoven professional development in the process of prototyping a SESI activity. (The final instructional materials for this activity, along with all other SESI materials, can be viewed at eli.lehigh.edu/sesi.) This topic emerged after we framed an initial investigative question: "How has the environment and land use in our city changed over time, how is it being used now, and how can we plan for future land use that is environmentally, socially, and economically sustainable?" In the process of addressing this question, we turned to the idea of city zoning regulations.

Fortunately, the high school sits at a nexus of multiple differently zoned areas: business, government/institutional, residential, parks, and even light industrial (see Figure 3). All of these areas have changed drastically over time. For example, in consulting historic maps of the neighborhood, we discovered that the street had once housed a tannery and a silk mill where houses now stood, and a greenspace north of the school had once been an apparel factory.

Our challenge in this activity, was twofold. First, how could we bring students into a new, more analytical view of this familiar terrain? How could we transition them into viewing the city as a collection of zoned areas rather than merely an assortment of streets, houses, stores, and parks? Second, how could we show students the mutability of these zones? How could we show students that the city changes over time, so that they might accept the challenge of suggesting changes of their own?

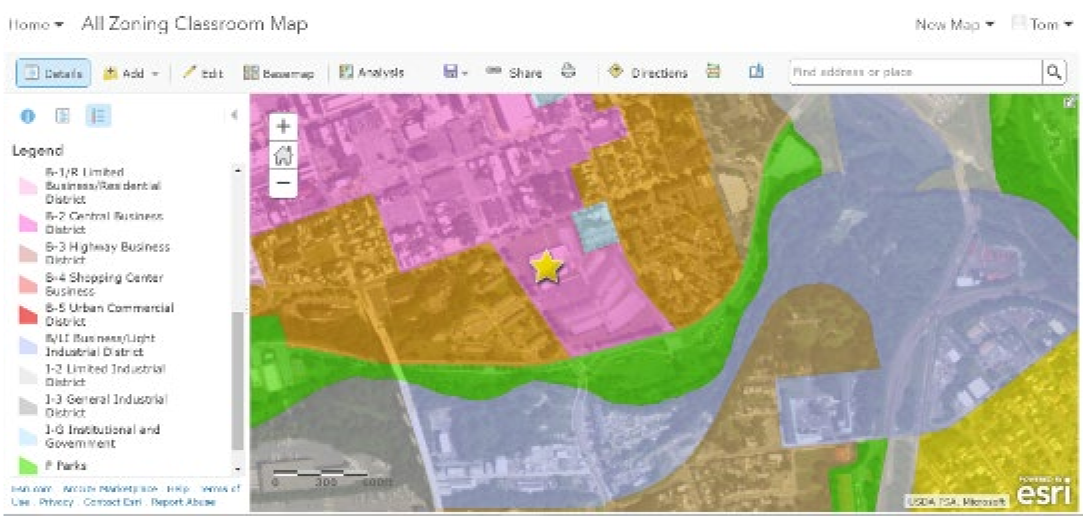


Figure 3. *Zoning map of city area near school; school location indicated by star.*

Having identified the major instructional goals for this activity, we began working through the steps in the curriculum approach. One of the first considerations was whether we could incorporate a data collection step. To model geospatial college and career experiences, we integrated students' direct collection of field data whenever possible. In the case of Zoning, we decided to direct teams of students to different points in the neighborhood around the school (see Figure 4). Students and mentors would travel to their assigned waypoints using Esri's Collector for ArcGIS app. When they arrived at the correct spot, they would line themselves up with the indicator on the waypoint, facing away from the street and towards the interior of the city block. They would then add a new record to the collective data layer, recording the ground surface they observed, the types of buildings, the number and size of trees, and so forth.

For the last investigative question, they categorized their observations: Were they looking at a business? A school? A park? Housing? This categorization is students' first decisionpoint in resolving the inquiry prompt: After collecting this structured observation, what inference can you make about the land use?

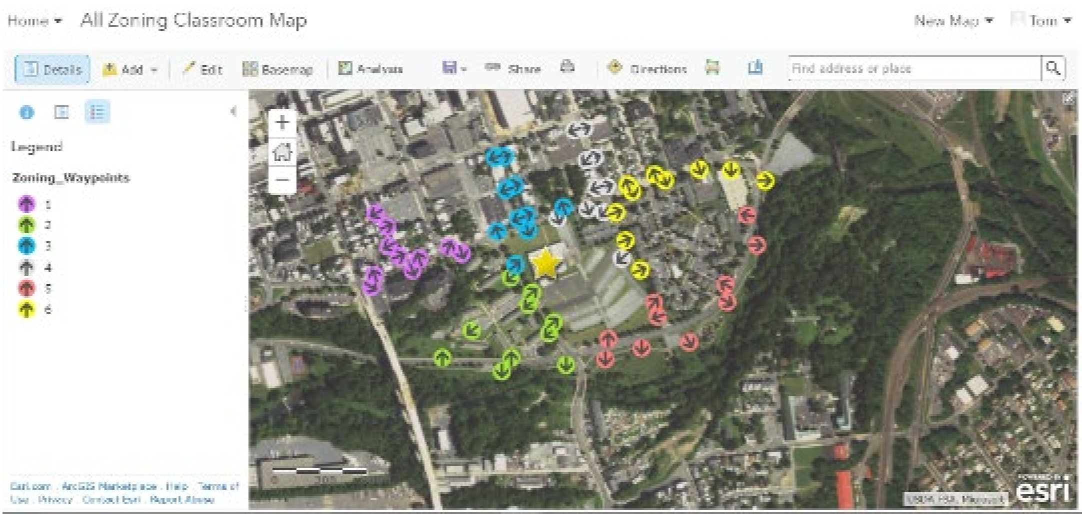


Figure 4. *Waypoints assigned to students for data collection regarding city zoning.*

Once students returned to the classroom, they would upload their group's data into a class-wide map. They would then examine the data for patterns, such as where the observations agreed or disagreed with each other. This pattern-seeking and negotiation of discrepancies is the second step in answering the inquiry prompt, inferring the different zoning and land use around the school.

When comparing their observations to the city zoning map, they would look for similar agreement or discrepancy between their collected data and the city's zoning map. (See Figure 5.) Why might these differences exist? Are differences due to error in student data collection or changes in the city's land use?

Finally, students would build upon this careful observation and inference to suggest a revision to the city's zoning, such as adjusting the zoning classification either to conform to the actual land use or to protect a local feature, such as a park located within a business district. Students would indicate their suggested change by using the drawing tools in ArcGIS.com. This redrawn zoning map would then be submitted to the teacher, along with a written explanation of what they changed and why.

Development

We developed supporting materials to complement this draft instructional plan. To direct students' data collection, data analysis, and final argument, we created a detailed set of instructions in a text document illustrated by screenshots and annotations. This text document guided students through each step of the learning activities. We also produced short, annotated videos to demonstrate the more complicated steps of the technology: opening the Collector for ArcGIS app, collecting and syncing data, and using the ArcGIS.com interface to change data visualizations, conduct analysis, and draw in new map features.

Figure 5. *Student zoning observations and city zoning map. Note locations where student observations disagree with each other (for example, business, residential, and school observations all occurring in the same place at the north edge) or disagree with the city zoning map (a park or school within the business district).*

Finally, we also produced an instructional worksheet that scaffolded students' progress through the data display, analysis, and argument phases by breaking them down into separate prompts for which they would write responses. All of these materials were posted to an unrestricted website, with local copies installed upon the class set of iPads for ease of reference.

Subsequently, the instructional plan and materials were pilot-tested with a small group of 10th-grade student volunteers. We provided a brief introduction to the activity and materials, distributed the iPads, went through the set-up routines, and took them outside for data collection. After collecting data at several waypoints, we then returned to the classroom to sync and display their data and walk through the remaining steps.

From this pilot testing, we learned that students largely ignored instructional videos and handouts. They were useful for us in producing the activity — and highly useful in explaining the activities to other teachers — but students preferred to learn from a demonstration by the instructor or from each other. In fact, peer scaffolding was our greatest asset: once one student knew how to do something, he or she would eagerly show others. This pilot implementation taught us that the soft scaffolds (see Brush & Saye, 2002) of teacher- or mentor-to-student interaction was then multiplied by peer-to-peer scaffolding; the hard scaffolds (that is print materials and videos) were superfluous.

In general, our concerns over the complexity of the interface and data handling were assuaged; with minimal initial guidance, students were up and running quickly. From this experience, we refined the data collection protocol: how quickly students work and how long they stay on task; this data informed how far out should students look when counting numbers of trees. When describing the surface, should they look down at their feet (often standing on a concrete sidewalk) or ahead at the terrain in front of them (which could be grass, trees, or an asphalt parking lot)? In the classroom, we also identified specific instructional opportunities, points at which students could observe and learn from discrepancies in the data.

Implementation

The refined Zoning activity was then implemented for the first time in six classrooms: three social studies classes and three environmental science classes. Again, the instruction sheets and videos were largely ignored; students preferred to learn through teacher or mentor modeling and/or peer scaffolding. Because class groups were much larger than the pilot group and included far more English language learners or other students with special needs, the introductory phases took far longer than anticipated. However, this activity was our first with the classes, and we viewed this extended time as a necessary initial investment. Students worked through logging into the Collector app, downloading maps, and learning how to manage the interface.

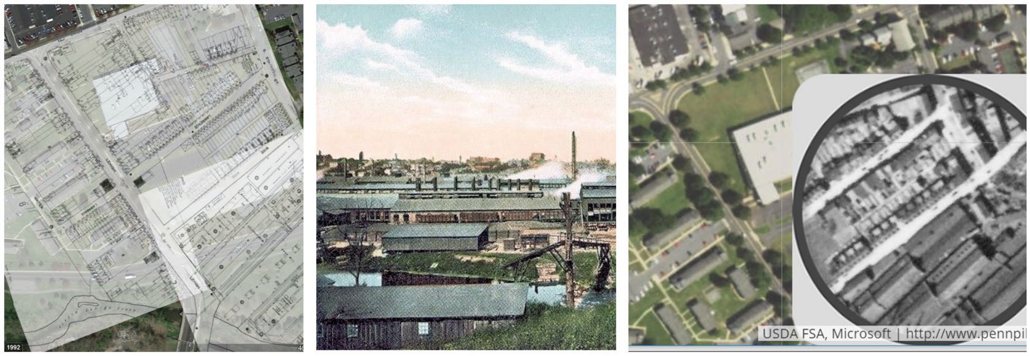
Once we were outside collecting data, our ninth-grade students were fully engaged. Moving into the visualization and analysis phase in ArcGIS.com again required significant time to model and support students' work, but the subsequent activities ran much more smoothly, allowing us to spend comparatively more time in advancing students' analysis skills.

Based on our review of students' final artifacts and on their work, we were only partially successful. We introduced students to the concept of zoning, giving them a different view of the familiar territory around their school; all students were able to understand and explain what the different zones represented. However, students' understandings of how the city has changed over time and how zoning has influenced that process did not progress as far. Anticipated refinements to the zoning activity, therefore, will include greater attention to historical maps and a more complete introduction to the topic.

Some classes had a chance to observe historic maps of the neighborhood from 1891, 1911, and 1932. (See Figure 6a for an example.) To this map, we have added historical photos, as well as an integrated aerial photograph StoryMap from 1938, 1958, and 1978 to strengthen both the Zoning activity and the Urban Land Use activity.

A deeper consideration of this past may reveal many of the changes that have marked the current location of the school. For example, the historic maps of the school's campus show two streets that are no longer there. These streets used to be lined with workers' houses for a wire factory, which sat at the foot of the school property along no-longer-existent rail lines (see Figure 6a-c). This factory made barbed wire, including much of the barbed wire used along the Western Front during World War One (Bartholomew & Front, 2002).

By expanding the students' knowledge of the past, we can reinforce their impact upon the future of the city, strengthening their work on the arguments and claims they make with the next iteration of the investigation. In addition, we also hope to connect with mentors from the city planning commission to enhance the mentorship experience and content background exposure for teachers.



a. b. c.

Figure 6. *Illustrations of planned expansion of urban history to be used in Zoning and Land Use activities. (a) Historic maps overlaid over satellite imagery, showing 1911 Sanborn Insurance maps; (b) postcard of the wire & steel company that were located at the foot of the current school campus; (c) aerial photograph StoryMap, showing a 1938 photograph inset into current satellite imagery. In the inset, note the tightly-packed workers' houses along the two streets north of the factory sheds.*

Conclusion

We found that the collaborative design and development of a geospatial curriculum approach is an effective means to accomplish the two requisite goals for geospatial technology integration: creating useful, sustainable geospatially enhanced curriculum and conducting meaningful professional development for teachers. This professional development must not only teach the knowledge and skills required, such as background content and geospatial data analysis, but also empower teachers' instructional decision-making as they adapt inquiry lessons for the unique circumstances of each class. The design principles developed in this project served as effective guidelines to create and modify instructional materials supporting the development of students' science and social studies content knowledge in addition to the developing important spatial thinking skills that are critical in many STEM-related careers. The design and development process of working side by side, shoulder to shoulder allowed us to combine effective teacher professional development with the simultaneous curriculum development, despite the many interacting communities of teachers, developers, scientists, and mentors.

As a result of this project, we have gained insights regarding the successes and challenges that the teachers of diverse urban learners may experience when using the SESI materials. We plan to modify certain activity structures for future classroom instruction.

1. We intend to provide learners with additional exploration time with Web GIS in combination with time-sequenced images of their geographic area to help them to better understand their area's local history. During our prototype implementation, which occurred during the last 3 months of the school year, we had curriculum time constraints that did not permit students to adequately explore different areas and aspects of their city. Additional exploration activities might provide learners with a better understanding of current zoning issues that have resulted over time from local commercial, industrial, and residential development.
2. More explicit instruction is needed to enhance learner understanding of important zoning concepts pertaining to how the city makes zoning decisions.

3. We intend to adapt additional time-sequenced images of other areas in the city to better illustrate land use change over time (see Figure 6).
4. We intend to provide teachers and students with additional requisite content background material and offer more guidance on interpreting images to help students understand the diversity of land use practices occurring in different regions of their city.
5. The information gained from the prototype implementation will help shape the classroom curriculum to be more coherent for the next school year. Because of our design and development timeline, the prototype investigations could only be implemented during the last 3 months of the school year.
6. We intend to bring these lessons back to our own classrooms, as teacher-educators, and enhance our integration and modeling of geospatial technologies in our teacher education courses (see Kerr, 2016).

Implications for Geospatial Design and Professional Development

For developers of geospatial instructional materials and teacher professional development, we encourage providing generous instructional support and guidance to both teachers and learners. Teacher support should include — but not be limited to — content, pedagogical, and technological support. The necessity of technology and pedagogy support are obvious: Teachers will need to learn new geospatial tools and how to implement them with their students. The learning process for teachers will require both outside-of-class instruction and discussion as well as inside-the-classroom teaching support.

The need for content support is more subtle: Geospatially enhanced instruction can transform the content under study by showing it in new ways with novel visualizations that may even make new issues more readily apparent to students. In the example of the zoning activity described in this paper, teachers faced new questions regarding the history of the city and the role and function of zoning. In essence, the curriculum expanded from urban land use to the history and reasoning behind urban land use. To understand this curricular expansion, we brought in university professors, urban planners, and city employees to meet with the teachers and the rest of the design and development team. The participating teachers also brought in new resources documenting aspects of the city's history.

Without this attention to the content of the geospatial projects — and specifically the ways in which the design, development, and implementation challenged our existing understandings of the curriculum — our final instructional activities would be far less rich and robust for learners.

Support for the learners can be embedded in the instructional handouts in the form of step-by-step instructions that include screen captures of how to perform specific geospatial learning tasks, as well as helpful hints and guided prompts to scaffold spatial analysis. Students more effectively learn techniques from their peers in real time, or by direct instruction from teachers, rather than from written instructions. Designers should take advantage of these learning approaches, rather than counting on individual students to follow a written instructional sequence.

Written or video-based instructions are useful for both design and development purposes (scaffolding the development team's thinking) and for professional development purposes (communicating the project to other teachers), but they are of limited use in the classroom with K-12 learners. The extent to which some students are unable or unwilling to gain effective instruction from written documents, or to which this is a passing trend in an increasingly networked and media-rich world, is beyond the scope of this project.

In addition to the embedded support for the learners, teachers integrating geospatial technologies in their classrooms need to provide abundant scaffolding, such as modeling the learning tasks and providing pedagogically appropriate examples to help their own learners develop spatial thinking skills. Finally, in determining the appropriate scope and sequence of instruction, developers need to work closely with classroom teachers who are grounded in the realities of classroom implementation issues that include curriculum time constraints and technology issues. An activity that works beautifully when conducted in a university classroom setting — which typically has more flexible scheduling, more robust IT capabilities, and smaller numbers of users — can come to a halt in a K-12 classroom, due to outdated operating systems, limited bandwidth, or unforeseen network restrictions on the number of simultaneous users.

By collaborating with teachers and working shoulder to shoulder in the classroom, we have been able to create far more practical and accessible materials for the benefit of students, teachers, teacher-educators, and developers. For a cross-curriculum design and development process to be successful, it is important that both teachers and curriculum developers have a shared goal and vision to promote learning using novel geospatial technologies with all classroom learners.

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