Socio-environmental Science Investigation to Promote Geospatial Thinking: Integrating ArcGIS Digital Technologies for Learning

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Program Abstract

In this related paper session, we present three different cases of the Socio-environmental Science Investigations (SESI) curriculum linked PD approach which supports secondary teachers' development and implementation of SESI investigations and projects using a variety of GIS tools in different geographic locations in the USA.

Proceedings Abstract

Teaching science utilizing digital technologies requires teachers to integrate technologies within their content area and instructional practices that lead to learning experiences for their students. A first step is to develop an approach for integration of digital technologies and then provide professional development (PD) focused on increasing teachers' use of practical teaching strategies aligned with their content and district requirements. Socio-environmental science investigations (SESI) provide a method to utilize geospatial technologies for curriculum aligned learning experiences.

SESI focuses on social issues related to environmental science, and involves inquiry-based investigations that are open-ended with students engaging in data collection and geospatial analysis. SESI activities are multi-disciplinary and involve decision-making based on the analysis of georeferenced geospatial data, examination of relevant social science content, and consideration of social equity implications.

In this related paper set, we present three different cases of the SESI curriculum-linked PD approach that we've designed to support secondary teachers' development and implementation of SESI investigations and projects using a variety of GIS tools in three different high schools located in different geographic locations in the USA. Each SESI investigation and project was collaboratively designed and developed between classroom teachers and science teacher educators, social studies teacher educators, and faculty with expertise in learning technologies. Each case illustrates the effectiveness of the curriculum-linked PD approach in providing teachers with professional growth experiences that enabled them to implement SESI investigations and projects in their classrooms with diverse high school students.

Introduction

Teaching science utilizing digital technologies requires teachers to integrate technologies within their content area and instructional practices that lead to learning experiences for their students. Thus, a first step is to develop an approach for integration of digital technologies and then provide professional development (PD) focused on increasing teachers' use of practical teaching strategies aligned with their content and district requirements. Socio-environmental science investigations (SESI) provide a method to utilize geospatial technologies for curriculum aligned learning experiences. SESI investigations are designed to prepare students to gain important STEM workforce skills. The learning activities provide opportunities for students to collaborate, seek evidence, problem-solve, master technology, develop geospatial thinking and reasoning (GTR) skills, and practice communication skills, all of which are essential for the STEM workplace.

Geospatial technologies such as GIS (Geographic Information System) are extensively used in agriculture, urban and regional planning, environmental resource management, surveying and cartography, conservation, national resource management, public health, transportation, and wildlife ecology, among others. A GIS consists of map information, a database, and a computer interface that ties them together to create a visualization tool for spatial analysis. A GIS is often regarded as a computer system that can capture, store, query, analyze, and display geographical information of two types, vector or raster. GIS allows users to select different layers of information to construct a map. The map is then displayed on a computer screen or Web browser and the data and information can be examined spatially. Coverages could include political boundaries, demographic information, rivers and streams, soil coverage, topography, water quality, or census data to support multidisciplinary science education.

Most of the information we have about our world contains a location reference, placing that information at some point on the globe. For example, when point source pollutant discharge information is collected, it is important to know where the discharge is located. This is done by using a location reference system, such as longitude and latitude, and perhaps elevation. Comparing the discharge information with other information, such as the location of marshes that may serve as breeding grounds for shellfish, may show that certain marshes receive higher levels of pollutant discharges that may not be beneficial for the survival of newly born shellfish. This inference can help us make the most appropriate decisions about how pollution discharge in the marsh might be regulated. A GIS, therefore, can reveal important new information that leads to better decision-making.

GTR skills are essential for occupations in which there is a heavy reliance on cognitive thinking skills that include knowledge about geospatially-referenced data and their relationships (Goodchild & Janelle, 2010; NRC, 2006). These skills involve important scientific practices highlighted in the Next Generation Science Standards [NGSS] (NGSS Lead States, 2013), and include data manipulation, analysis, data mining, computational thinking, and modeling that provoke and *require* critical thinking and problem solving that are connected to data referenced to Earth's surface or to the Earth's representation through map and globe visualizations (Huynh & Sharpe, 2013). GIS is now the standard for spatially referenced data management, but STEM curricula often contain learning experiences that do not match the analytic practices that are critical for success in STEM-based occupations (Aikenhead, 2005; Chin et al.,2004). Science curricula that engage students to collect and analyze data, and solve problems provide important skills that help prepare students for career opportunities and lifelong learning (National Research Council, 2011; National Science Board, 2015).

Socio-environmental science investigations focus on social issues related to environmental science. SESI involves inquiry-based investigations that are open-ended with students engaging in data collection and geospatial analysis. SESI activities are multi-disciplinary and involve decision-making based on the analysis of georeferenced geospatial data, examination of relevant social science content, and consideration of social equity implications. SESI 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; Semken et al., 2017). SESI investigations can provide opportunities to empower students to address important socio-scientific issues in their community. Socio-scientific issues are socially relevant, real-world problems that are informed by science and often include an ethical component (Sadler et al., 2007). They are sometimes controversial in nature but have the added element of requiring a degree of moral reasoning or the evaluation of ethical concerns in the process of arriving at decisions regarding possible issue resolution (Zeidler & Nichols, 2009). These issues require the use of evidence-based reasoning and provide a context for understanding scientific information using an active approach to learning, placing science content within a social context in a way that fosters motivation for, and the ownership of, learning by the student (Sadler et al., 2006; Zeidler & Nichols, 2009).

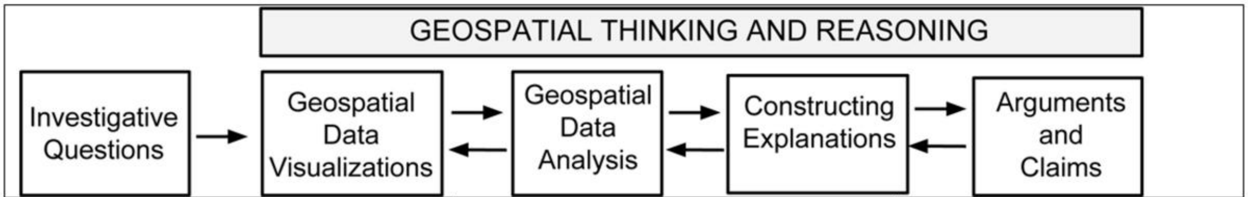
We have developed a design partnership model (Bodzin & Cirucci, 2009) for geospatial curriculum development that has been implemented for multiple Earth and environmental science projects (Bodzin, 2011; Bodzin et al., 2014; Bodzin et al., 2013; Hammond et al., 2019). In this model, university and school personnel work together from the very earliest stages, identifying topics that both align with existing curricula and involve understanding geospatial patterns and relationships in real-world data. The collaborative design group then identifies opportunities for students' hands-on use of geospatial data and analysis tools to master the curriculum-specified content through inquiry learning. During this stage, we adhere to our geospatial curriculum approach (Figure 1), which is informed by our work as well as the NSF Geotech Center's Geospatial Technology Competency Model (DiBiase et al., 2010). This design approach focuses on GTR and calls for a sequence of student engagement, moving from investigative questions through a cycle of examining data visualizations, performing geospatial analysis, constructing explanations, and supporting claims based on evidence through argumentation. This approach focuses on developing learners' GTR skills and is supported through PD to promote teachers' geospatial pedagogical content knowledge.

An essential feature of this project is our hybrid, curriculum-linked PD model. This process incorporates both face-to-face and online learning and follows a design partnership model (Bodzin & Cirucci, 2009; Hammond et al., 2018). By integrating the teachers' PD 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. Teachers with geospatial science pedagogical content knowledge (PCK) have a more developed 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 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 (e.g., geography and history) in ways that may produce effective teaching and student learning opportunities (Hammond et al., 2018). Our PD approach also acknowledges that classroom teachers are pedagogical experts capable of adapting curriculum materials to meet the needs of their students (Penuel et al., 2007).

During the PD, teachers learned to use a suite of tools developed by ESRI. These included ArcGIS Field Maps, ArcGIS Online, and ArcGIS StoryMaps. ArcGIS Field Maps is a mobile technology app that is used for gathering georeferenced data (see https://www.esri.com/en-us/arcgis/products/arcgis-field-maps/overview). ArcGIS Online is a dynamic mapping application that utilizes Web and cloud-based services for viewing, editing, and analyzing collected data along with other available georeferenced data (see https://www.esri.com/en-us/arcgis/products/arcgis-online/overview). An ArcGIS StoryMap is a web-based application that allows a user to share their maps in the context of narrative text and other multimedia content (see https://www.esri.com/en-us/arcgis/products/arcgis-storymaps/overview).

In this related paper set, we present three different cases of the SESI curriculum-linked PD approach that was designed to support secondary teachers' development and implementation of SESI investigations and projects in three different high schools located in different geographic locations in the USA. These included Ft. Worth, Texas, Tri-Cities, Washington, and the Philadelphia, Pennsylvania, and Wilmington, Delaware areas. Each SESI investigation and project was collaboratively designed and developed between classroom teachers and science teacher educators, social studies teacher educators, and faculty with expertise in learning technologies. Each case illustrates the effectiveness of the curriculum-linked PD approach in providing teachers with professional growth experiences that enabled them to implement SESI investigations and projects in their classrooms with diverse high school students.

Figure 1:
Key components of the geospatial curriculum approach



Geospatial Science Technological Pedagogical Content Knowledge	**Earth and Environmental Science Content**	**Social Studies Content**
• Interactions between geospatial technology and pedagogical content knowledge to produce effective environmental science teaching and student learning. • Modeling geospatial data exploration and analysis techniques. • Scaffolding students' geospatial thinking and analysis skills.	• Human-Environment Interactions: Know and apply geographic information about relationships between nature and society. • Physical Geography: Know and apply geographic information about processes shaping the structure of the Earth's surface, physical landscapes, natural hazards, weather, climate, and atmospheric processes.	• Human-Environment Interaction: Place, Regions, and Culture • Human Population: Spatial Patterns and Movements

Geospatial Science and Analysis Skills

- Use GIS to manage, display, query, and analyze geospatial data.
- Use geospatial analysis to process geospatial data for the purpose of making calculations and inferences about space, geospatial patterns, and geospatial relationships.
- Use geospatial data analysis in which geospatial relationships such as distance, direction, and topologic relationships (e.g., adjacency, connectivity, and overlap) are particularly relevant.
- Use inductive and deductive reasoning to analyze, synthesize, compare, and interpret information.
- Use logic and reasoning to identify strengths and weaknesses of alternative solutions, conclusions, or approaches to problems.

Paper One: River Water Quality in Texas

The Texas site includes two high schools in a large urban school district and a project team of two professors and one doctoral student. School A, built in 1957, is a typical high school with a student population of 2,301, while School B, renovated in 2019, is a STEM Academy with a student population of 600. The teaching assignments include psychology, history, computer science, robotics, environmental science, biology, and ethnic studies. This case study focuses on the journey of one science teacher in a STEM-focused school. Tara was a second career educator with a Ph.D. in biochemistry and prior experience working in cancer research. Even with her own experience working in a research lab, she indicated that her campus was limited with their science lab equipment, technology support, and chemistry lab supplies. Because her campus focused on instructional technologies required for blended and virtual learning rather than scientific data collection and analysis, the adoption of geospatial technologies with data collection capabilities was new to her. Even with these campus-level limitations, she was still interested in using ArcGIS Online and mobile data collection to enrich a water quality unit in her chemistry course by making it place-based and related to current environmental issues. Although Tara was new to using geospatial technology, working with students to use iPads to collect field data, and integrating geospatial thinking and reasoning within her science content, she wanted to enhance her students' experience using technology to collect water quality data in the field.

During the first year of PD sessions with the university, Tara learned the basics of ArcGIS Online and the overall capabilities and embedded tools of this dynamic mapping platform. She was introduced to curriculum materials curated by ESRI (e.g., GeoInquiries and StoryMaps) and mobile applications for collecting geo-referenced data (e.g., Survey123 and Field Maps app). The intent of the PD was to provide experiences with ArcGIS Online allowing teachers to interact with geospatial inquiry in a way similar to their students. Tara also reviewed basic cartography elements such as boundaries, points and lines, distance, geometric shapes, density, and patterns. Because in-service teachers have likely not had previous exposure to geospatial reasoning (Bourke & Lidstone, 2015), it was important for the PD to demonstrate the importance of geography and geospatial thinking in order to appreciate GIS as a learning tool (Bednarz & van der Schee, 2006). Tara was able to view existing maps, see how the map layer features worked, and add her own MapNotes to a map. This led to an activity where she collected her own data using ArcGIS Field Maps, and she manipulated her data within ArcGIS Online. During the first year of PD, there was no requirement for her to implement geospatial technologies into her curriculum, only that she would increase her confidence with ArcGIS Online and consider possible applications for geospatial thinking in her chemistry course.

Field Trip

The university team provided technology and curriculum support for Tara as part of the NSF funding for the collaborative research grant project. In addition to monthly PD meetings, the university team was available to meet individually with teachers to assist with instructional planning and technology integration as needed during the school year. Early in the school year, Tara emailed the university team to discuss her plans to revise the existing water quality curriculum for her chemistry course and integrate the geospatial concepts and technologies she had learned in the PD. Although she was confident with her science content and pedagogy, she was apprehensive about incorporating technology into a field trip for water quality field testing. During several planning meetings, Tara expressed her concerns about the field trip and being able to facilitate her students using geospatial technology, collecting geo-referenced data with iPads, and analyzing water samples for chemical elements.

The university team assisted her with the logistics of the field trip, including collecting permission forms, accessing the river site near the school, reviewing safety protocols for students, and having students use the grant-funded iPads for the first time. The technology demands included creating student accounts for ArcGIS Online, writing a survey to collect chemical water quality data, and adding a map for students to access on their iPads while at the river sampling location. Students also needed to log in to the iPads while on the school's WiFi account to download the map that would later be used to view the map at the river site. Tara decided that using water quality test strips purchased by another teacher on her campus would be the easiest and most efficient way for her students to quickly test water samples. Learning this, the university team advised her on the methods and equipment for collecting water samples, limitations of using chemical test strips with the water samples, considerations for safe handling of samples, and alignment of chemistry content with state curriculum standards.

As a result of the collaborative planning with the university team, Tara finalized plans for the field trip and even arranged for an industry expert from the local water district to enrich the field trip experience. On the morning of the field trip, the industry expert met Tara, her students, and the university team on the riverbank. After the expert described his own career pathway in STEM and explained how to properly collect, label, and transport water samples, Tara distributed the water sampling equipment to her students. Students worked in pairs to carefully dip collection jars into the river and marked their GPS location for their sample site using the ArcGIS Field Maps app, which was loaded on the iPads. Students also labeled their jars with their names, date, and time the water was collected.

When the group returned to their classroom and the iPads were back on the school's WiFi network, the students used chemical test strips to measure the properties of their water samples. The test strips Tara purchased were difficult for students to read because they measured multiple water quality parameters, and students were unfamiliar with how to read these strips. Adding to the complexity, the text fields in the ArcGIS Field Maps app did not exactly match the elements on the chemical test strips, so students had to search the app for the correct place to input their data. Students worked in pairs to make estimates of the readings for each chemical parameter before entering the data into the ArcGIS Field Maps app, which then connected their data to the GPS location where they collected the sample. As often happens with a field trip experience, students did not have enough time to enter their information into the iPads and analyze their data in ArcGIS Online before the bell rang to dismiss students to their next class period. Students abruptly left their water samples, test strips, and iPads before Tara was able to debrief the students about geospatial trends and patterns in their data and what this means for water quality at the river site. Due to school schedules and time constraints, Tara was not able to follow up with the students about how the water data and corresponding map locations provided insight into river conditions.

Reflection

After the field trip, Tara initiated a meeting with the university team to discuss the field trip and, specifically, using the iPads and test strips. Although she had been apprehensive about taking the students to the nearby river, she was comfortable with how they behaved and their general learning experience. She found that integrating geospatial technologies into the field trip was easier than she anticipated, and the field trip added rigor to the water quality unit because students participated in authentic fieldwork similar to the industry expert. Although she expressed concerns about the accuracy of the student collected data, she sought ideas for ways her students could view the data in ArcGIS Online and ways for students to analyze the data. The university team realized the post-field trip experience did not provide the students with opportunities for geospatial reasoning, even though students had used technology in the field and collected their own authentic data.

Tara began thinking about how she could use geospatial technologies to expand her unit to include water samples from the students' homes and other city locations. The data collected from the field trip was limited because of student measurement errors with the test strips and the fact that all of the samples were collected from a 15-meter stretch of the riverbank. Expanding the geographic area of samples would provide students opportunities to use geospatial reasoning to compare patterns and trends in water quality data from multiple locations using a dynamic map of the city using ArcGIS Online. The GIS map used by students also had data layers that identified storage towers, pump stations, treatment plants, and reservoirs, which could be used to show the interconnected nature of the water supply system in their city. In future iterations of this activity, students could use these visualizations to increase their spatial understanding of where their water originates and the many steps it takes before it comes out of their tap. Tara also inquired about the possibility of purchasing probes as a way to increase the accuracy of the data collection and to give students the opportunity to use other STEM technology tools. She thinks the revised water quality unit will allow her to integrate geospatial thinking and technology applications that will make the content more relevant to her students' lives.

Paper Two: Campus Trash in Washington State

At the Washington State site, the project team consisted of three faculty members, a doctoral student, a program coordinator, and eight teachers from two local high schools. The high schools are a small project-based alternative school and a large comprehensive school—one of the largest in the state and serving large numbers of Latinx and low-income students. The teachers participating in the Washington State project included science, mathematics, environmental science, earth science, agriculture, and special education instructors. In this section, we describe how the high school special education teacher in the project, Denise, gained an understanding of ArcGIS Online during the summer PD experiences, planned and implemented an activity with her 12th-grade students, and reflected on her use of technology with her special needs students. Denise teaches in a large comprehensive high school; her students are children with intellectual and learning disabilities who have limited experience using technology in the classroom. Denise stated that she wanted to expose the students to authentic experiences using technology and expand their awareness of their capabilities in using technology to solve problems. She also had a goal of connecting her students to the school to increase their feeling of belonging.

Prior to the implementation of this activity, the teachers involved in this project met at the university campus during the summer to learn about designing and implementing SESI investigations to be integrated into their curriculum during the upcoming academic year. The focus of this PD was to introduce teachers to using ArcGIS Online through experiences as students themselves, followed by planning time where, partnering with faculty, they designed SESI activities and investigations that could be embedded into their existing curriculum. Teachers were also encouraged to pilot their lessons with the whole group during the final day of the PD. The expertise of faculty on geospatial activities and the teachers' knowledge about their curriculum and students provided a strong collaboration on which to develop the SESI investigations.

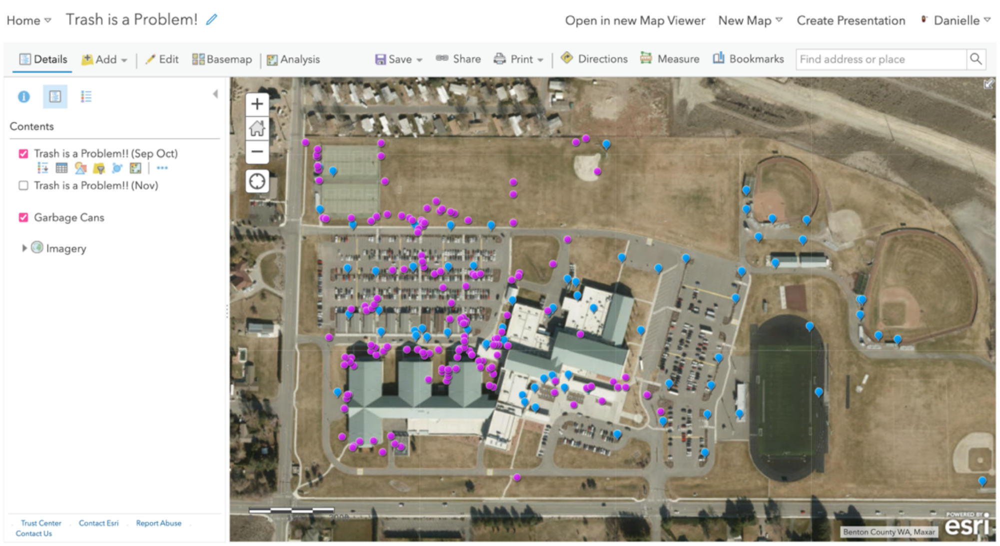
Denise had no prior experience using the geospatial tools introduced in the PD and spent time during the sessions planning for lessons where she would introduce her students to navigating and accessing data within various layers on a map. For example, as a sample activity in the PD, Denise created a lesson that involved students navigating a map of the contiguous United States that included one data layer of over three hundred civil war battles and another layer color-coding the states' allegiance. Denise also spent time with the other teachers learning how to manipulate maps in ArcGIS Online, collecting data with the ArcGIS Field Maps app, and designing an ArcGIS StoryMap. From her summer experiences, Denise gained the knowledge and confidence to start a project with her students when the school year began. She stated that she wanted to engage her students in a problem involving authentic data collection using a data collector app that would connect the students to their local environment and school context.

Trash is a Problem

Denise started the new school year with a plan to engage her students in an authentic project that involved mapping and data collection. She drew on everything that she had learned over the summer and applied it to her preparation for the new school year. Her class included eight 12th-grade students, two with intellectual disabilities, three with learning disabilities, and three with health impairments. Denise initiated the project by asking students to identify issues within the school that they believed could be investigated. The students talked about various issues, but many of them shared experiences about how they regularly see an excessive amount of garbage on the school grounds; Denise viewed this as a topic that could be used for data collection and mapping in ArcGIS Online. Engaging the students in an authentic problem and pushing them to propose solutions were part of her stated goals.

Using ArcGIS Online, Denise created a feature layer that would allow the students to collect data regarding the trash on campus using Esri's ArcGIS Field Maps app. To do this, Denise used an ArcGIS StoryMap created by the University team members that guided them in creating feature layers using ArcGIS Online. The students were able to use their mobile devices to download the app and record data on the trash they found around campus (e.g., type of trash) and include a photo. Denise created a second feature layer that allowed students to collect data on the school grounds' garbage cans. Students mapped where the garbage cans were located and the cleanliness of the container. Students only collected data outside on the school's grounds, and they did not collect data from inside garbage sites. The class used the map to discuss where garbage was located, the type of garbage found, and its proximity to garbage cans (see Figure 2). Students were genuinely surprised to see how much garbage there was on school grounds when they viewed a map depicting locations where trash had been spotted. One student said, "we were shocked when we saw all the garbage on the map," and "it made me disgusted to see all that garbage." The students came to some conclusions about why garbage was located in specific locations (e.g., where students ate lunches) and why some garbage cans were not used (e.g., "they were disgusting"). Using the data they had collected themselves to make inferences and draw conclusions is a critical piece of this lesson. Students were highly engaged because they had direct experience with the data used to draw conclusions.

Figure 2
Trash is a Problem map



Note: Map displays two data layers (a) trash data collected before Trash Awareness Week (purple), and (b) garbage cans on campus (blue)

Their data provided entry into a whole class brainstorming sessions, discussing the various ways to reduce trash around the school. For example, students proposed different sites for garbage cans, suggested cleaner garbage cans, and suggested creating a plan to bring awareness of the trash problem through "Trash Awareness Week." During this week, the students designed posters and displayed them in the school cafeteria (Figure 3), wrote notices about trash on school grounds, read the student-created announcements over the intercom during the school's daily announcements, and created coupons for HERO points (i.e., school incentive points) to hand out to students they saw disposing of trash in the proper locations. All of these activities were envisioned by students as they brainstormed ways to inform the entire school that trash on school grounds is a significant problem. When students were asked about their participation in the Trash Awareness Week activities, they said they loved making posters and telling the story, and they hoped it made people see that trash is a concern on campus. Through observations and discussions with the students involved, they expressed a sense of ownership over this project and the intervention strategies they implemented. Participation in these activities provided a sense of purpose for students who may not always feel a strong connection to their school. They saw their posters in the cafeteria and heard their announcements over the intercom. One student commented about being too shy to make the public, all-school announcement, but the student talked about it proudly after doing it.

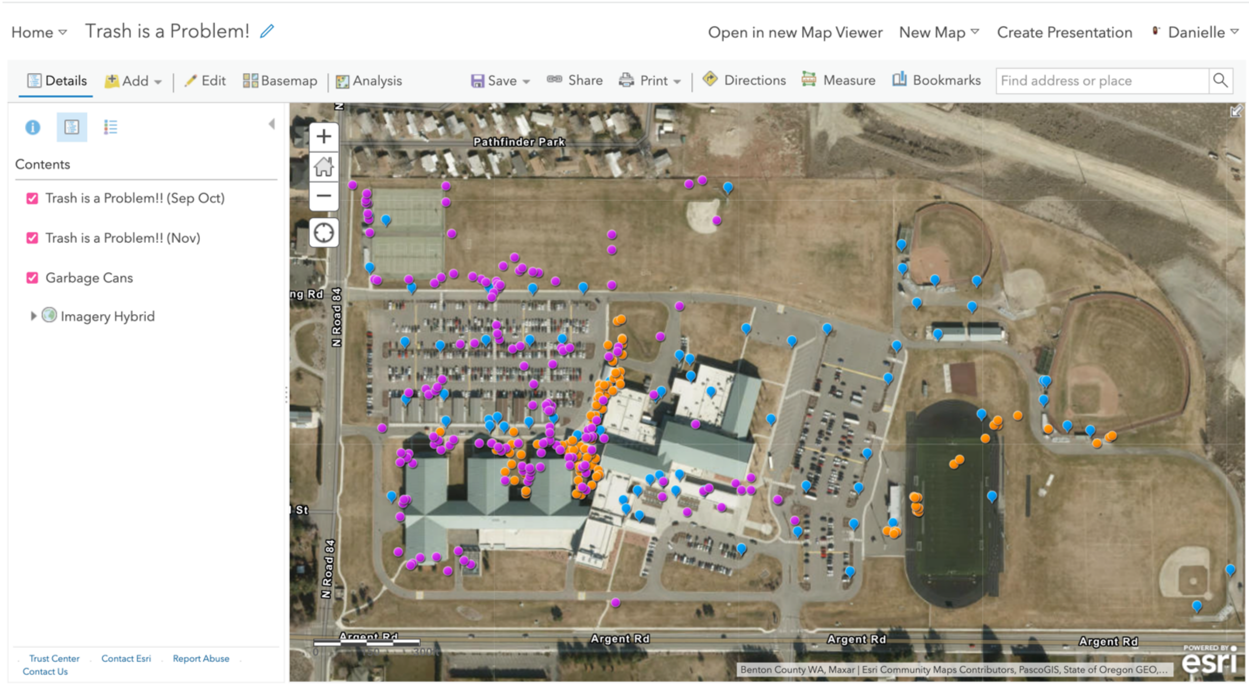
Figure 3
Student-created posters displayed in the school's cafeteria during Trash Awareness Week

Data on garbage location and type were again collected after the whole school Trash Awareness Week to determine if there were any changes in the amount of trash on campus (see Figure 4). Students looked at maps and compared data collected before and after the awareness interventions during Trash Awareness Week. The students concluded that there was less trash in some areas of the school that seemed to be problem areas (e.g., right outside of the cafeteria). However, the students also noted the change in weather, suggesting that the cold weather impacted the trash because more students were eating indoors. Esri's ArcGIS Online and the ArcGIS Field Maps app allowed the students in Denise's class to collect data and use geospatial technologies to identify areas that amassed the most trash. They discussed student body movement on the campus grounds and how this affected the accumulation of trash. These conclusions may not have been easily identifiable without using the geospatial technologies used in this project.

Reflection

As Denise reflected on her integration of geospatial technology into her special education classroom and the impact this project had on her students, she stated that the gains her students made in conducting authentic data collection and then using the data to make inferences, draw conclusions, and propose changes were of the utmost importance to her. She said that her students certainly gained experiences in using the geospatial technology but having this use embedded in a real-world, local context problem was most important. The students Denise worked with experienced seeing the data they collected on the map of the whole campus and then used those data points to make inferences about the main campus trash issue. These skills are essential in many discipline-based curriculum contexts but may not often be available to the students in a special education classroom. Denise created a project that strengthened students' technology skills, improved their connections with their campus environment, and increased their confidence in communicating with other students and administrators.

Figure 4.
Trash is a Problem map



Note: there are three data layers: trash collected before intervention (purple), trash collected after intervention (orange), and garbage cans on campus (blue*)*

Paper Three: Ecosystem Restoration in Delaware

At the Philadelphia, Pennsylvania and Wilmington, Delaware area sites, the University team is working with six teachers from two schools: a Philadelphia, PA environmental science magnet high school and a Wilmington, DE comprehensive high school. The teachers (including a special education teacher) teach a variety of science and social studies classes, comprised of 9th through 12th grade students. One of the teachers is in his first year of teaching, while others are more experienced. Two teachers have worked with GIS technology in the past, with the remaining four being new to the practice. The hybrid, curriculum-linked PD began with the teachers during the summer of 2020. Due to the COVID pandemic, all of the work with teachers and their students was virtual through the summer and the 2020-21 academic year.

Because of the shift to online instruction, the university team elected to focus on supporting teachers as much as they could, making their work as easy as possible under the trying circumstances. One adaptation was to reduce the frequency of outdoor data collection by students and instead emphasize exploring online maps in the context of their curriculum. In year two, with the return of students to the physical classroom–albeit with continued COVID restrictions–students were able to engage more fully in SESI investigations. In data collection, students download ArcGIS maps created by the teachers and researchers to the freely available Esri Field Maps app on either their mobile phone or a classroom GPS-enabled iPad. Then, students go outdoors to collect georeferenced data points on their maps, which then can be viewed by the class as a whole. This outdoor data collection step is essential to the SESI process of place-based education as students gather data about real world objects in their environment, which often includes a photo. The students are then able to analyze data they themselves have gathered. The focus of this case study is Sean, a trained and experienced Biology teacher, who also teaches Environmental

Science and Earth & Space Science courses. Because of his experience and characteristics, Sean was the first teacher in our group to implement a SESI project with his students.

Classroom investigations to set the scene

Sean was a participating teacher in our precursor National Science Foundation grant in a different high school, so he entered the project with more experience with our hybrid, curriculum-linked PD model and using ArcGIS Online and the related apps, such as ArcGIS Field Maps and Survey123, in the classroom (Carrigan et al, 2019; Hammond et al, 2018; Hammond et al, 2019). In fact, Sean has reached the point where he often creates SESI investigations and lessons for his students on his own, with little assistance needed from our research and development team. He is a teacher who is unafraid of trying new things in support of his curriculum and has the creative control to take his curriculum in new directions.

In the second year of the grant-funded project, Sean implemented a variety of ArcGIS-based investigations in his Environmental Science classes. Some of these activities were adaptations from the precursor grant, such as the Built Environment Scavenger Hunt, Trees & Ecological Services, and Urban Heat Islands (UHI). In the Built Environment Scavenger Hunt, students explore their school grounds for examples of human infrastructure (Figure 5) and code examples by service provided (see https://eli.lehigh.edu/sesi/instructional-sequence/built-environment-scavenger-hunt). For the Trees and Ecological Services investigation, students explore their school property in order to locate, measure and identify trees and examine their impacts on the community (Carrigan et al., 2019). Lastly, in the Urban Heat Island investigation, students measure the temperature of a variety of outdoor surfaces (e.g., asphalt, concrete, grass) in sun and shade at different times of the day. Students learn that human-made surfaces often absorb and retain a large amount of heat from the sun, resulting in urban areas often being hotter than surrounding suburban and rural communities, which usually have more shade trees and natural areas (https://eli.lehigh.edu/sesi/instructional-sequence/urban-heat-islands). Other SESI investigations were new creations from the current grant, such as an investigation of community waste management and sustainable growth and development. In addition to the geospatial SESI investigations, Sean also included instruction on habitat fragmentation, animal migration, native and invasive plants, pollinators, and human impact on the natural environment. This sequence of instruction culminated in an Ecosystem Restoration project.

Ecosystem Restoration Project

A SESI project is different from a SESI investigation in that students are expected to draw data from previous lessons, synthesize a solution to a problem, and demonstrate geospatial thinking and reasoning skills. For the Ecosystem Restoration project, students were charged with developing a proposal suggesting three changes to the school property that would enhance its natural ecosystem, with the potential of school district funding for the most highly rated proposal(s). For each of the three proposed changes, students were to identify the environmental issue(s) and how their change would address the issue(s). In addition, they were instructed to rank order their changes and select the best two for potential funding. They used the data they had gathered in the prior SESI investigations to support their proposals. Students' proposed changes included consolidating athletic practice fields to allow for surrounding forest recovery, planting native plants and creating a pond in a central courtyard to draw pollinators, and installing bird houses and feeders on school grounds in order to attract native species and educate other students about them. To illustrate and support their proposals, students developed maps in ArcGIS Online to show where their changes would take place and also created either a slide presentation or an ArcGIS StoryMap to explain their intended solutions and anticipated impacts. Using these materials, they gave an oral presentation to make their case. Completed student presentation files were also distributed to school administrators. This project will be done with new students in year three of the program, with school administration being invited to the presentations.

Figure 5
Sample Built Environment Scavenger Hunt data

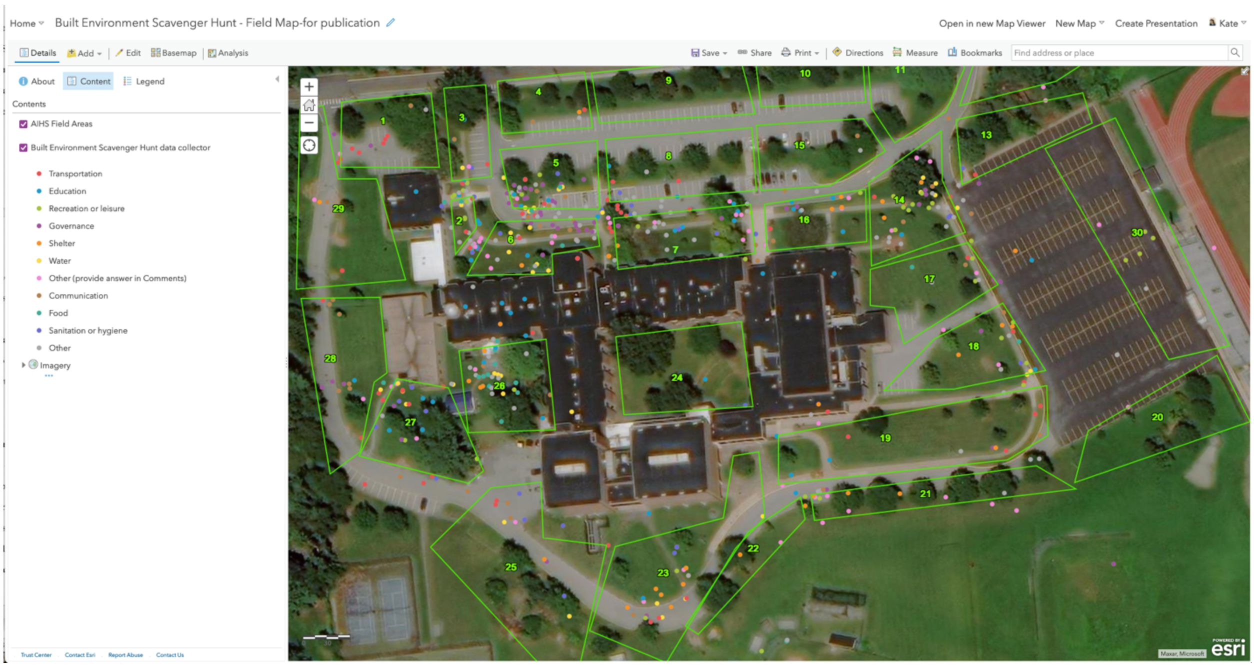


Figure 6 shows a sample student map, which the student then embedded into a StoryMap. As directed, this student suggests three potential areas to address by planting native flowers, shrubs, and trees. Then, in the related StoryMap (https://storymaps.arcgis.com/stories/5d074af7a38a49dfb38022744378083c), the student discussed why he ultimately chose only two of the areas (southeast play field and immediately west of the school) for restoration, as the area directly southeast of the school has too much student foot traffic to and from the bus loading area.

An important feature of SESI projects is the ability of the teacher to assess students' geospatial thinking and reasoning skills. In our precursor grant, we developed a reliable and valid rubric for that purpose, which we adapted for the Ecosystem Restoration project evaluation. Table 1 shows the components used to assess each student's geospatial analysis and geospatial reasoning skills. In this first implementation of a SESI project in our current work, we worked closely with Sean to refine the rubric to accurately assess students' geospatial thinking and reasoning skills. As we enter year three of our four-year grant, we expect all of our teachers to implement at least one SESI project in their classes. We will then be able to use the refined rubric to ascertain what geospatial thinking and reasoning skills students are able to demonstrate.

Figure 6
Sample student map for the Ecosystem Restoration project, showing areas of proposed changes

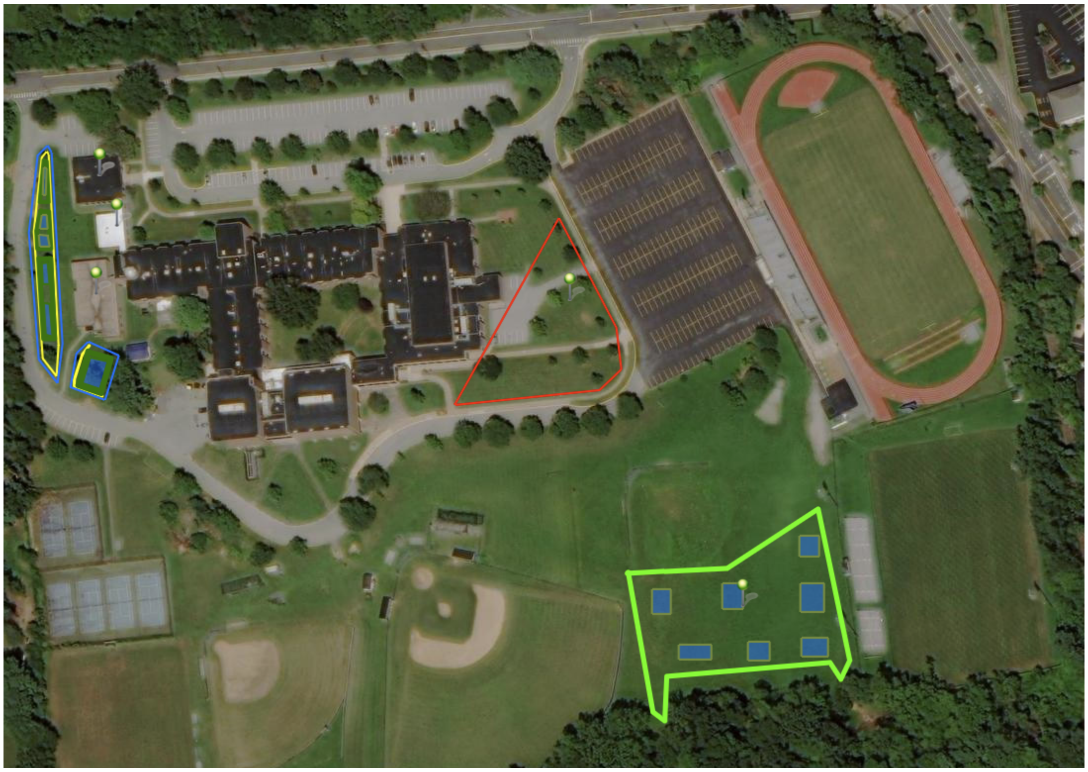


Table 1
Skills assessed in SESI projects

Category	Skill
Geospatial Analysis	• Use GIS to manage, display, query, and analyze geospatial data. • Use geospatial analysis to process geospatial data for the purpose of making calculations, and inferences about space, geospatial patterns, and geospatial relationships. • Use geospatial data analysis in which geospatial relationships such as distance, direction, and topologic relationships (for example, adjacency, connectivity, and overlap) are particularly relevant.
Geospatial Reasoning	• Use inductive and deductive reasoning to analyze, synthesize, compare, and interpret information. • Use logic and reasoning to identify relative strengths and weaknesses of conclusions, or approaches to problems.

Reflection

The SESI projects allow students to synthesize the data they have gathered throughout the school year in order to make a case to have an effect on their school community. This can be an impactful experience for students. High school students can often feel powerless in their school community and their community at large as they progress to young adulthood. Presenting their ideas about making changes in their environment, with the potential for their ideas to be implemented, can be a very powerful learning experience. In our previous work at another high school, students completed a SESI project where they presented their proposals to plant trees on school property. With support from the school and city, the winning proposal was implemented, with the student author and classmates participating in planting the trees in front of the school. These projects can help students be seen as true members of the community and can empower them to continue in such work

Implications and Recommendations

From the work with teachers at three different geographic sites, each with unique school cultures, it is evident that the SESI curriculum approach on which they based their PD helped high school teachers develop practical teaching strategies that integrated a variety of geospatial digital technologies into their teaching and learning activities. The technologies used in the three cases presented in this paper set provided the teachers with the ability to help students engage with authentic content and collect authentic data in the field. The geospatial tools highlighted in the chapter included iPads with embedded GPS without a data plan, ArcGIS Field Maps for data collection, and ArcGIS online for data analysis. These tools were selected specifically for their ability to engage learners with outdoor data collection either around their school grounds or in locations in students' communities. The collected data was then analyzed to examine geospatial relationships and patterns in the collected data. Using the SESI curriculum approach, the three cases illustrate how geospatial thinking and reasoning skills were promoted. Further, each case dealt with an authentic socio-environmental issue that was inherent to the students' immediate environment. The River Project is an example of a first step into SESI, whereas the Campus Trash Project is further along a continuum toward project implementation. The Ecosystem Restoration Project is an example of a SESI project. The Ecosystem Restoration Project and the Campus Trash Project enabled students to engage in authentic decision-making to make recommendations to enhance their school environment. These place-based learning activities made the SESI investigations and projects meaningful and relevant to the learners.

Implementing SESI investigations and projects requires preparation and planning. There are no costs involved for schools to use ArcGIS Field Maps and ArcGIS Online. To use ArcGIS Field Maps for data collection, either a cell phone with a telecommunication plan is needed or an iPad with a built-in GPS without a telecommunication plan. As part of the grant, we funded the purchase of a classroom set of iPads for each school, along with durable cases and a charging cart. These will remain in the schools after the grant is completed. During the CoVID-19 pandemic, we found that almost all the high school students had access to a cell phone that could be used for data collection. While ArcGIS Online is also freely available to schools, it involves setting up an organizational account for a school. At the classroom level, individual student logins and passwords need to be set up and managed. Quite often, some students forget their login passwords, and it is important that teachers keep a good organizational record system to access student passwords when this occurs. We have provided that support for teachers in the first two years of the grant, but are now scaffolding teachers to promote sustainability of this work.

As teachers consider using SESI-style investigations and projects with students, we recommend coordinating set-up with a school or school district's technology support staff. Such support staff may serve as invaluable resources for installing applications on school computers and iPads, ensuring network connectivity on the devices, and maintaining software and hardware updates on school equipment. Over time, applications such as ArcGIS Field Maps may become updated or even overhauled completely, and ArcGIS Online may undergo interface changes and updated analysis tools. School technology staff can serve as helpful resources to work with teachers to become familiar with these changes when software and Web application updates occur.

There are many resources available to help teachers get started with their own geospatial investigations. Examples of SESI investigations and projects that have been implemented in high school classrooms are available at https://eli.lehigh.edu/sesi. For teachers who are not yet ready for outdoor data collection with their students, Esri maintains a library of GeoInquiries at https://www.esri.com/en-us/industries/k-12-education/geoinquiries. GeoInquiries are short, structured, and guided data-based learning activities that use dynamic maps to investigate geospatial patterns and relationships among specific data. In addition, Esri also provides ArcGIS StoryMaps (https://storymaps.arcgis.com/stories), which enable students and teachers to select from a suite of templates to craft a digital story with maps and text. In the Ecosystem Restoration Project case, the classroom teacher had each student develop a StoryMap to highlight their recommendations for enhancing the ecosystem on the school property.

The three cases presented in this paper set highlight how teachers used SESI investigations with their students. The cases demonstrate how place-based, socio-environmental investigations using geospatial technologies actively engage learners with authentic data collection and analysis to explore geospatial patterns and relationships. The students were involved with geospatial thinking and reasoning skills. In two of the cases, students were involved in making recommendations to enhance their local environment. The hybrid form of PD was effective for promoting enhanced geospatial pedagogical knowledge of the teachers resulting in powerful learning activities for the students.

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