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Geospatial Technology Integration With Professional Development: A STEM Teacher's Use of ArcGIS, Robotics, and Drones

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Teachers in the fields of science, technology, engineering, and mathematics (STEM) need professional learning opportunities to understand how to integrate geospatial technologies like ArcGIS into classroom experiences. Few studies have examined how teachers engage in professional development and then apply new technology knowledge to school environments. Improving the pipeline into STEM career pathways requires alignment between K-12 STEM teaching and learning with STEM careers; thus, research is needed to explore ways K-12 educators can infuse their classroom practices with STEM industry applications like geospatial technologies. This descriptive case study explored one STEM teacher's 3-year journey in a geospatial technology professional development program led by a university. Over 2 years, the teacher gained expertise in ArcGIS and eventually created an independent robotics exercise incorporating the technology. The study highlights how teachers' technology integration pathways vary based on individual experiences, school settings, and teaching assignments. Understanding teachers' experiences with professional development and classroom implementation provides insight into the challenges STEM educators face when transitioning from training to real-world application. Successful geospatial technology integrations require an intricate balance of teachers' instructional decisions about content with student engagement and technology capabilities. STEM teacher educators should consider the intentional placement of geospatial technologies into courses that have curricular flexibility with content, instruction, and assessment to increase the success of teacher technology integration.

Industries related to geospatial technologies are essential to the economy and are projected to add significant numbers of new jobs or affect the growth of other industries in the coming years (National Geospatial Advisory Committee, 2012). Geospatial thinking and reasoning (GTR) are vital for jobs in which there is a heavy reliance on cognitive thinking skills that include knowledge about geospatial data and their relationships (Goodchild & Janelle, 2010; National Research Council, 2006). School experiences that mirror industry by engaging students in collecting and analyzing data and solving problems can help develop vital skills that prepare students for career opportunities and lifelong learning (National Research Council, 2011). However, existing STEM curricula may not prepare students to use the analytic practices that are necessary for success in STEM-based occupations (Schulze, 2020; Tan & Chen, 2015). Few school-based curricula utilize geospatial technologies from industry, and the integration of GIS into K-12 schools has been challenging (Bernhäuserová et al., 2022; Fischer et al., 2020).

The educational opportunities students receive have been shown to be an important factor in determining their interest and efficacy in STEM fields (Nguyen, 2025); however, teachers may not be prepared to support students in the challenges that are associated with STEM learning (Morrison et al., 2021). Alarming, the supply of STEM teachers has dropped significantly over the past 10 years, despite the increased demand for STEM careers (White & Shakibnia, 2019).

Professional development (PD) is a crucial factor in both training STEM teachers and retaining them for long-term careers in the education field (Rehman et al., 2025). PD in STEM teaching is a particularly complex problem due to this rapidly shifting field and the project-based nature of STEM education (Joseph & Uzundu, 2024). If the goal is to prepare students to be successful in the workforce after graduation, then educators must bridge the gap between industry technologies and school-based technologies (Fischer et al., 2020).

STEM teachers need PD to understand how geospatial technologies are utilized in industry and to design lessons that incorporate the technologies and skills into their curriculum for students. The problem is that few studies have examined how teachers engage in PD and then apply newly acquired technology knowledge to their school environments. Exploring the teacher's PD experiences and analyzing the use of the PD within the classroom provides an opportunity for STEM teacher educators to consider the challenges a classroom teacher encounters when making the leap from brainstorming, collaborating, and designing innovative instruction during PD to the teacher's actual classroom implementation of PD. Improving the pipeline into STEM career pathways requires alignment between K-12 STEM teaching and learning with STEM careers. Thus, research is needed to explore ways K-12 educators can infuse their classroom practices with STEM industry applications like geospatial technologies. Understanding STEM teachers' experiences with targeted teacher PD in technology integration is relevant for STEM teacher educators who design PD experiences and support STEM teachers in the classroom.

This descriptive case study explored one STEM teacher's 3-year journey in geospatial technology integration and highlights how one teacher's

technology integration varied because of the teacher's personal experiences, the school setting, and the teaching assignment. This research fills a void in STEM teacher education that bridges scholarly research in STEM with teachers' experiences with PD and classroom implementation of geospatial technologies. Understanding STEM teacher perspectives is a crucial component in improving STEM education and STEM pipelines from K-12 into postsecondary education and ultimately industry careers.

Literature Review

Geospatial Technologies in K-12 Schools

Langran and Baker (2016) defined *geospatial technologies* as the software and tools, which require human "critical thinking skills to locate, display, and analyze geographic information and make sense of the increasing amount of emerging place-based data" (p. 373). Geographic Information Systems (GIS) software provides users visualizations of map layers with additional information specific to a geographic location (Malone et al., 2024). ArcGIS Online, a GIS cloud-based software owned by Esri, allows users to view and analyze multiple layers of map data at different levels of scale (Moorman et al., 2021). Because Esri provides free ArcGIS accounts to schools, teachers, and students, the software has the potential to integrate geospatial technology into school curriculum to foster students' spatial thinking and problem-solving (Malone et al., 2024).

GIS technologies are important to integrate into K-12 education because they lend themselves to learning opportunities that simulate some of the ubiquitous real-world applications of geospatial technologies, like solving transportation and shipping logistics (De Miguel Gonzales & De Lazaro Torres, 2020). Online GIS programs have also become more user friendly for educators to explore online geospatial databases and software, which might give teachers more time to incorporate GIS in their instruction and assessment (Langran & Baker, 2016; Oda et al., 2019). Unfortunately, there is little research into how teachers effectively integrate geospatial technologies into their instruction (Oda et al., 2019), and large-scale research on implementations of GIS in K-12 settings have been limited, leading to a gap between research and practice (Baker et al., 2015).

Professional Development With Technology

PD has the potential to change teachers' knowledge, beliefs, and instructional practices (Borko, 2004; Hochberg & Desimone, 2010), and PD can support teachers in integrating technology, pedagogy, and content when they design instruction (Chai, 2019). Although PD can take many forms, research has suggested that the most effective PD is ongoing, supportive, collaborative, and instructionally focused (Perry, 2022; Sims & Fletcher-Wood, 2021). After a PD experience, teachers return to their classrooms and independently implement ideas, lessons, and strategies from PD.

Adopting and adapting curriculum and instructional materials after a PD experience may be easier and take less time for teachers than creating

innovative lessons and experiences for students (Charles & Kolvoord, 2004). Documenting the effectiveness of PD is difficult for several reasons: (a) teachers have varying PD experiences, (b) measuring changes in teachers' classrooms after PD is challenging, (c) PD providers may not offer a full explanation of the PD intervention, and (d) outcomes for successful PD may not be clearly defined (Penuel et al., 2007).

Few studies have analyzed the ways STEM teachers participate in PD and use new technology knowledge and skills when they plan instruction (Chai, 2019; Rubino-Hare et al., 2016). The amount of time spent in formal PD experiences could explain why some teachers adopt new technologies and curriculum more successfully than others, and there may be interactions between the delivery of the PD experiences and duration of time spent in PD (Bodzin et al., 2014; Penuel et al., 2007). Targeted teacher PD may be necessary for spatial thinking and geospatial technologies to be successfully taught to secondary students (Hammond et al., 2018). As teachers attempt to replicate authentic STEM experiences in their classrooms, they need PD opportunities to learn the tools professionals use, such as geospatial technologies (Malone et al., 2024; Whitworth et al., 2022).

PD focused on curriculum and instruction reforms may be more successful if teachers participate in the design of the curricular materials and experience PD to foster their understanding of technological, pedagogical, and content knowledge (TPACK; Børte et al., 2023; Hammond et al., 2018). If teachers are expected to integrate emerging technologies into their instruction, then teacher PD needs are an important consideration that may impact the effectiveness of teachers using the technologies with students (Baker et al., 2015; Hammond et al., 2018; Rubino-Hare et al., 2016).

Classroom Technology Integration

More research is needed to assess how teachers implement what they learn from PD into their classrooms and how PD leads to improved student outcomes (Gale et al., 2022; Whitworth et al., 2022). Although teachers may need educational opportunities to use innovative technologies and to incorporate emerging digital technologies into their content and pedagogy, research has shown that teachers who participate in technology PD may not continue using the technologies with their students in the long term (Collins & Mitchell, 2019; Niess et al., 2010). After learning how to use a novel technology during PD, there should be a concern as to how teachers will adopt and actually use the technology in their classroom with students (Leary et al., 2021). The goal for teachers should be to infuse the technology into their content and pedagogy, rather than using the technology as a tool to present the same information and content (Lei et al., 2020).

The purpose of the research was to investigate the intersection of technology PD with teacher implementation in an authentic STEM classroom. Specifically, our research question was as follows: How does a STEM teacher who participates in targeted PD in geospatial technology integration implement the new technology knowledge and skills into their STEM curriculum and instruction?

Methods

To evaluate the impact of teacher PD in geospatial technologies, we selected a descriptive case study design focused on one STEM teacher's experiences with PD and her implementation of newly learned skills and strategies in her classroom. Because STEM teacher PD is a complex social phenomenon and different teachers may have their own unique perspectives, a descriptive case study is ideal for explaining the STEM PD intervention, the STEM teacher's experiences, and the real-world context in which the teacher implemented the STEM PD (Yin, 2018). For the case study, various data were collected from a single classroom teacher, including interviews, personal communications, and online meeting transcripts (as recommended in Rubino-Hare et al., 2016).

Context

To address the need to understand STEM teacher outcomes following PD, three universities located in the US states of Pennsylvania, Texas, and Washington used an integrated PD and curriculum approach described by Hammond et al. (2018) to foster high school teachers' use of geospatial skills and collaborate with teachers to integrate geospatial technologies into their curriculum. The goal of this university and school research partnership was to expand the number of schools and individuals with the geospatial and technology skills needed to design and implement local geospatial inquiry activities in high school classrooms.

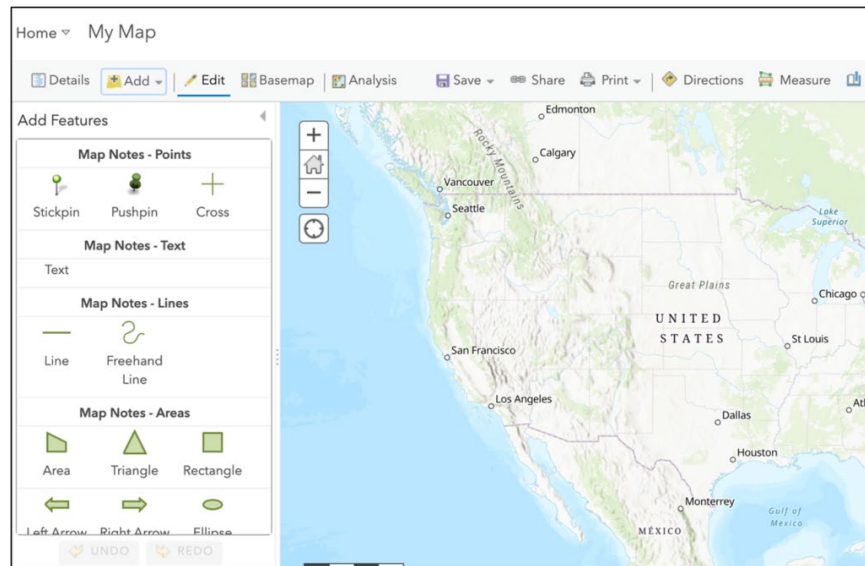
This multiyear program utilized a PD model developed specifically for GTR (Bodzin et al., 2016; Hammond et al., 2019), in which teachers simultaneously learned how to implement the Socio-Environmental Science Investigations (SESI) framework alongside a suite of geospatial technologies and codeveloped classroom activities with the support of the researchers. The PD was intended to help teachers learn *about* using GIS as teachers while learning *with* GIS as a learner (Baker et al., 2015). A general overview of the PD activities and sequence for the teachers who were part of the research group in Texas is described next.

STEM PD Intervention

The PD cycle began in August with monthly PD meetings followed by intensive summer PD with us, the researchers. The goal of the PD sessions during the 1st year was to introduce the geospatial mapping technology, ArcGIS. Each meeting included an icebreaker to foster collaboration among the group, direct instruction, and guided practice in the geospatial technology ArcGIS, opportunities for questions, and independent practice to be completed prior to the following meeting. To foster the teachers' implementation of geospatial thinking into their existing classroom curriculum, the teachers were provided a sandbox account within ArcGIS, which provided teachers the opportunity to experience geospatial inquiry as students. During the PD sessions, teachers learned the basics of ArcGIS, which included accessing and logging into the PD and school ArcGIS accounts.

We oriented the teachers to the overall capabilities within the ArcGIS platform, which included curriculum materials curated by Esri (e.g., GeoInquiries and StoryMaps) and applications for collecting geospatial data (e.g., Survey123 and Esri Field Maps app). After this initial introduction to ArcGIS, teachers reviewed basic cartography elements, such as boundaries, points and lines, distance, geometric shapes, density, and patterns (Figure 1).

Figure 1
Adding Points, Text, Lines, and Areas in ArcGIS

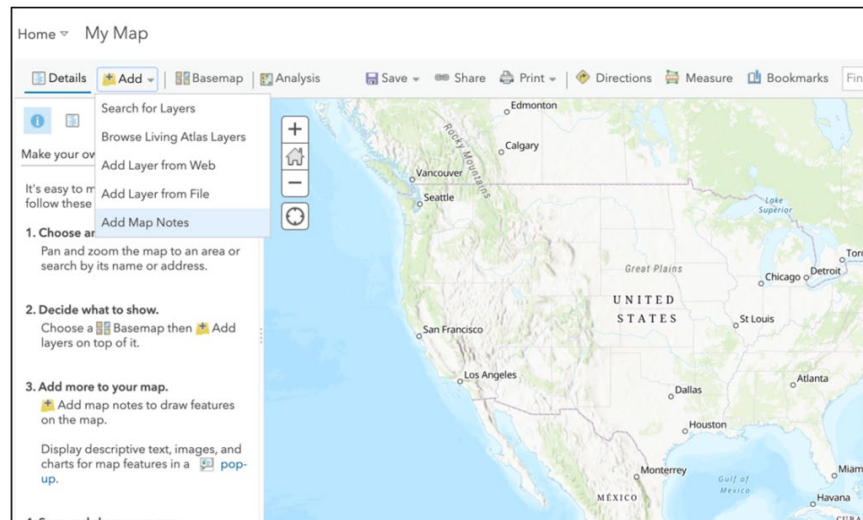


Teachers viewed existing maps, saw how the map layer features worked, and added their own MapNotes™ (i.e., annotations in the form of comments and symbols) to a map (Figure 2).

During the 2nd year, teachers collected their own data in FieldMaps™ and explored how the data could be manipulated within the map data file. During the summer PD sessions, teachers collected geospatial data, practiced analyzing geospatial data, brainstormed curriculum integration with geospatial technologies, and virtually collaborated on the Zoom videoconferencing application across Delaware, Pennsylvania, Texas, and Washington with other teachers participating in the research project.

At the beginning of the research project, there was no expectation for teachers to immediately implement this new technology into their lessons, only that they would increase their confidence with ArcGIS technology and consider possible applications for spatial thinking in their content area. Teachers were able to choose how and when they implemented the geospatial technologies in their classrooms. Because the research and PD began during the 2020-2021 school year, there were adjustments made to the original plans for PD, due to constraints from the COVID-19 pandemic. For example, the PD meetings were held virtually during the first school year and in-person for Years 2 and 3 of the research project.

Figure 2
Adding Map Notes in ArcGIS



There was also no in-person PD during the summer after Year 1 because the teachers were not available at the same time to schedule 5 days of in-person PD. After Years 2 and 3, we planned 3 days of summer PD for the teachers. After 3 years of the project, there were five teachers in the Texas group who had participated in the project continuously, and all of them attempted to do at least one project that integrated the ArcGIS technology within their curriculum and instruction.

Participant

The STEM teacher, referred to with the pseudonym Helen, was an engineering teacher who was part of a high school STEM department that was volunteered by the school's principal to participate in the STEM PD project with a local university in North Texas. Helen was informed of the potential risks of participating in human subjects' research and consented to participate in the research project with the university. The STEM PD project began after Helen finished her 1st year of teaching robotics and engineering at a public magnet high school for arts and STEM. Prior to entering the teaching profession, Helen applied her degree in mechanical engineering to design a mobile gaming app, consult for a business startup in China, and design a robotics and engineering program for an area Girl Scouts organization (personal communication, October 2024).

Helen was selected for this case study because of her unique experiences prior to becoming a STEM teacher, her STEM teaching assignment in robotics and engineering, and perhaps most importantly, her willingness to implement new technologies from the STEM PD sessions into her instruction. As compared to the other four teachers who participated in the STEM PD and university research project over a 4-year time period, Helen was present at most PD sessions, showed an eagerness to implement ideas from the PD into her curriculum, and sought out the

university research team for support when she had ideas for using ArcGIS with her students.

Although Helen had the least amount of teaching experience in the group, she was confident in her content knowledge and ability to teach robotics and engineering courses. Other teachers were less enthusiastic about integrating ArcGIS into their curriculum, especially teachers who taught core science courses (e.g., biology, chemistry, and physics). Helen participated in 20 hours of PD in Year 1, 31 hours during Year 2, and 8 hours in the fall of Year 3, for a total of 59 hours of PD before she decided to integrate ArcGIS into a classroom experience for students.

Data Collection and Analysis

The qualitative data were triangulated to document the teacher's experiences with and implementation of the STEM PD through interviews with the teacher, records from the PD meetings, and researchers' field notes and observations from the PD sessions over 3 years (Yin, 2018). At the end of each year of the research project, teachers engaged in individual online semistructured interviews with us. The questions were designed to probe teachers' understanding about teaching practices, participating in the STEM PD, and the support they received from their campus administration and teaching peers.

Helen also agreed to record an online planning meeting with us to brainstorm using ArcGIS with her engineering students during the 2nd year of the research project. Finally, observations, field notes, meeting agendas, and attendance records from PD meetings provided additional qualitative data to illuminate Helen's participation in the STEM PD and her interactions with us outside of the PD meetings.

Our team of three researchers independently conducted *incident by incident* coding of the qualitative data collected from Helen across all sources previously described (as recommended in Charmaz, 2006). At the conclusion of the initial coding phase, in vivo codes reflected Helen's words and terms that situated the research in a specific time and place. We then met and employed simple group consensus to synthesize individual codes into larger themes about participating in STEM PD, supporting students in learning geospatial technologies, and Helen's planning and implementation of classroom activities (as recommended by Saldana, 2016).

Results

Helen's STEM PD Experience

Helen was introduced to a suite of tools she could incorporate into her STEM courses (e.g., Esri ArcGIS Online, ArcGIS StoryMaps, and Survey 123). She learned ArcGIS account management, map authoring, and strategies for utilizing these tools in learning activities. Each activity was situated in the local environment (place-based) that required data collection similar to methods students would use.

Year 1

Due to district COVID precautions at the time, the monthly PD sessions during the first academic year were held remotely on Zoom after school. Because ArcGIS is an online cloud-based application, Helen could access the software from her classroom or home. The PD sessions reviewed what Helen learned over the summer and introduced new skills in ArcGIS and StoryMaps. Discussions over using personal phones and district-issued tablets for data collection helped Helen plan instruction using ArcGIS. She was introduced to ready-to-use ArcGIS learning activities from Esri (GeoInquiries™) to become familiar with the platform and to observe the versatility of the technology. She collected data points near her home and school for fieldwork and learned to manipulate the GIS data in Survey 123 and in ArcGIS maps.

Each PD session showed Helen how to use various components within ArcGIS and allowed time for her to collaborate with other teachers and brainstorm classroom applications of ArcGIS and geospatial thinking. Helen was provided time during the PD to understand, design, and reflect on innovative curriculum changes, as a PD experience may be more effective in generating change in instructional practices when they are long-term (Penuel et al., 2007).

During the PD sessions Helen collaborated with teachers from various disciplines to design learning activities because she was the only robotics and engineering teacher in the group. Helen was encouraged to use SESI activities in her instruction whenever she felt prepared to successfully implement the newly learned geospatial technology and skills; however, she was not required to use ArcGIS during the research project.

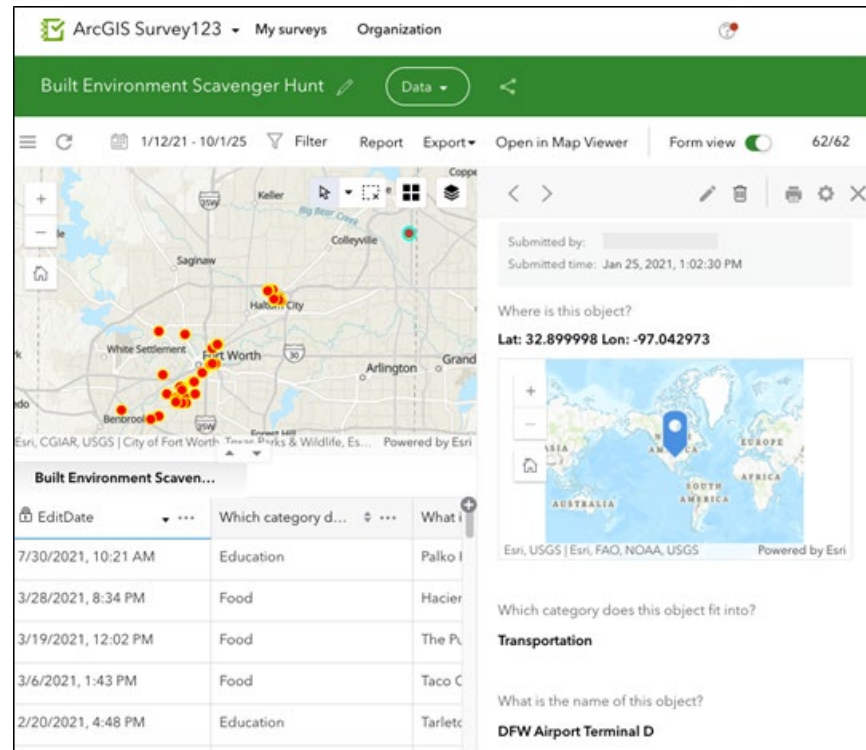
Helen was also given a choice about when the summer PD would occur and what topics should be covered (as suggested in Osman & Warner, 2020). She and the other teachers selected to meet in person for 3 days at the university and to collaborate virtually on Zoom with other teachers participating in the research project in Washington, Delaware, and Pennsylvania. We wanted to provide teachers with opportunities to collect their own geospatial data on the university campus and have time to analyze the data. Helen participated in a scavenger hunt to collect data for specific locations on the university campus (Figure 3), then worked individually and later with a group to analyze data in ArcGIS.

Modeling data collection and data analysis strategies with the teachers was purposefully designed to encourage the teachers to incorporate student-collected field data and ArcGIS in their courses. Other ArcGIS logistical issues with high school students were discussed, such as setting up and managing student accounts, changing passwords for accounts, and creating class groups and assignments in ArcGIS.

Finally, teachers from similar disciplines across the four states collaborated over Zoom, shared ideas for SESI activities, and discussed ideas for incorporating the ArcGIS technology into their courses. During these summer PD sessions, Helen continued to develop her own familiarity and skills with the ArcGIS suite of tools. While expanding her confidence, the summer gave her space and time to reflect on her

curriculum for places to infuse ArcGIS into her courses. The goal was to further develop skills and confidence in using the technologies so she could use them with students.

Figure 3
Built Environment Scavenger Hunt PD Activity



Years 2 and 3

The 2nd and 3rd years followed the same PD format, with the goal of helping Helen continue to incorporate ArcGIS into her existing curriculum. Teachers were encouraged to incorporate student GIS data collection into their teaching, and we modeled ways to analyze geospatial data on map layers in ArcGIS. Each PD session provided time for teachers to collaborate and share ideas for integrating ArcGIS into their upcoming curriculum units. In addition, we offered time, expertise, and assistance with codeveloping lessons and activities with teachers in between the monthly PD sessions during the school year. Checking in with teachers monthly provided them the opportunity to share their use of ArcGIS activities that they planned and completed between the group PD sessions.

During the fall of the third academic year, Helen attended monthly in-person PD sessions, during which teachers shared what they were doing in their classrooms, acknowledged problems, and brainstormed ideas for classroom activities. She continued to explore ways to naturally incorporate the ArcGIS technology into her robotics curriculum. Listening

to lessons learned from other teachers participating in the PD helped Helen see some of the benefits and challenges of using ArcGIS with students. This additional time allowed her to become more familiar with the robotics course curriculum.

PD Implementation: Using ArcGIS With Students

Helen needed time to build her confidence in using the technologies, and then she independently planned an innovative way to introduce the technologies to her students. Her journey implementing new technologies and ideas from the PD with students did not follow Charles and Kolvoord's (2004) model for anticipating teachers' integration of technology. Rather than following an entry-adopt-adapt-innovate progression, Helen skipped to adapting in the 2nd year and then innovating in Year 3 with ArcGIS in her curriculum.

One way for STEM teachers to connect content to authentic STEM learning is through real-world and socially relevant problems that are informed by science and include an ethical decision-making component (Sadler et al., 2007), such as human impact on the environment, climate change, and disease. A framework for designing school activities that expose students to important STEM workforce skills is SESI. The investigations provide opportunities for students to collaborate, seek evidence, problem-solve, master technology applications, develop geospatial technology skills, and practice professional communication, all of which are essential in the STEM workplace (Malone et al., 2024). In addition, students engage in decision-making grounded in the analysis of geospatial data, examination of germane social science content, and reflection of social equity implications. SESI lessons may also require students to present to the campus, community, or other external audience and develop advocacy plans to address one or more socioscientific issues in their community.

Helen requested support in her first attempt to integrate ArcGIS technologies into classroom activities for students in the spring semester of Year 2. We demonstrated one of the GeoInquiries™ with Helen during an online planning meeting and assisted her with using the activity as an assignment within a STEM course. Helen adapted a lesson on wind turbines and wind speed to align with some of the mathematics content in her engineering curriculum. Using GeoInquiries™ allowed Helen and students to establish a level of comfort with both the technical side of using ArcGIS and integrating the technology into classroom instruction. As Year 2 continued, she received support in incorporating the technology tools and geospatial thinking into existing curriculum and in designing SESIs for students, but she did not engage students in additional ArcGIS activities.

Finding time to plan and experiment with new technology applications can be a barrier for implementing new ideas and skills into a course (Malone et al., 2024; Whitworth et al., 2020). Before the beginning of the 3rd year, Helen expressed concerns that she had four different courses to teach, was sponsoring three clubs, and trying to add new geospatial technologies and activities might require more time than she had to give. At the end of the fall semester of the 3rd year, however, Helen was ready to build on her use

of the GeoInquiries™ the previous year and independently innovate a learning activity for high school robotics students. Her challenge was deciding where ArcGIS could be incorporated into the robotics course and how to expand her current curriculum.

She decided to use her knowledge and skills learned during PD with her robotics students, using drones in a way that would connect them to workforce applications. Because Helen had prior training in creating project-based learning units, she knew it was important to get students engaged with local, real-world STEM applications of robotics. She wanted students to feel confident with the ArcGIS online software platform and to have fun using a new technology in the robotics course.

Her first step was to use one class period to introduce the basics of ArcGIS, including logging into the online platform and adding points to an existing ArcGIS map. Students added a location they planned to visit or wished to visit over the winter break to a map, serving as a formative assessment of their newly acquired ArcGIS skills. Helen described the activity as “kind of a Yelp review of things to do over the break” (interview, February 2023). Students were engaged by using their cell phones to mark a point on a map in the ArcGIS Field Maps app, upload a picture of the location, and explain to peers why this place would be a fun location to visit over a school holiday.

The option to select actual versus ideal locations was designed by Helen to protect students who might not have the opportunity to travel for the winter break. The scaffolding activity ensured students would be able to log in to ArcGIS, add points, pictures, and information to a map, and view multiple locations on a single map at one time. Helen said students liked sharing pictures and locations with their peers, and the activity “got them excited to use ArcGIS and do other projects with it” (interview, February 2023).

Helen’s second step was to design a lesson to use ArcGIS with students. She began researching ways companies currently use drones and robotics and found several recent articles about the use of drone technologies for delivering products, such as small items like medicine, in hard-to-reach areas outside of the United States. Her interest in drones stemmed from class “discussions on robotics and drones and kinds of drone technologies, keeping up with those current events” (interview, February 2023). She found several informational videos from Amazon® about their plans to use drones for certain types of deliveries in the future. Building a unit around Amazon as the delivery company seemed appropriate because there were several distribution centers near the school, and they had piloted residential drone delivery to two cities within the state in the last year. Framing this activity as providing help to Amazon with their drone delivery research was the perfect SESI hook for student engagement and provided an authentic reason for students to integrate their knowledge about robotics and drones with ArcGIS maps (Malone et al., 2024). Helen wanted students “to be familiar with what their prototyping looks like right now in those other areas” (interview, February 2023), so she modified the engineering design process for her students to plan their investigation into drone delivery.

Engineering Design Process

Many students in the robotics course participated in robotics and drone competitions outside of school. Therefore, the project design and timeline reflected the competition's time limits and use of real-world simulations within the engineering design process (define the problem, do background research, specify requirements, develop a solution, test the solution, and make adjustments). In both the robotics competitions and the engineering course, Helen described the engineering design process:

That's an iterative process where they have to identify the problem. Do some research to see what existing solutions may already exist, or research to see what other attempts there have been to solve the problem. Then they have to brainstorm, come up a plan, create tests, and repeat whatever steps they have to go back to. (interview, February 2023)

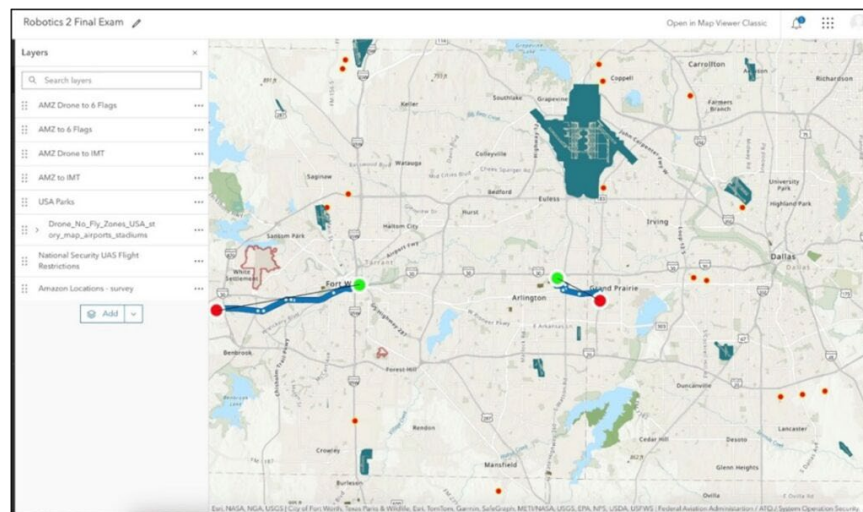
Helen provided videos, articles, and websites for the students' background research so the learning activity could be completed during one extended three-hour class period (see <https://arcg.is/1uXojG1>). Helen explained, "The first hour was a review of what we had already looked over in ArcGIS ... just reminding them some of the tools we had already learned" (interview, February 2023). To launch the learning activity, Helen showed students a promotional video from Amazon, which explained how Amazon planned to use drones for residential deliveries from distribution centers. She provided the students with information about where to find articles and geospatial data, as follows:

1. Amazon Staff. (2022, June 13) Amazon Prim Air prepares for drone deliveries. Amazon. <https://www.aboutamazon.com/news/transportation/amazon-prime-air-prepares-for-drone-deliveries>
2. Amazon Staff. (2022, July 12). Amazon's drone delivery is coming to Texas. Amazon <https://www.aboutamazon.com/news/transportation/amazon-prime-air-prepares-for-drone-deliveries>
3. Amazon Staff. (2022, November 10). Amazon reveals the new design for Prime Air's delivery drone-here's your first look. Amazon <https://www.aboutamazon.com/news/transportation/amazon-prime-air-delivery-drone-reveal-photos>
4. Amazon Staff. (2022, August 16). How Amazon is building its drone delivery system. Amazon. <https://www.aboutamazon.com/news/transportation/how-amazon-is-building-its-drone-delivery-system>

Students were required to identify the design problem within the topic of drone delivery. They used the format of "[who] needs [what] because [why]" as they decided what needed to be delivered. In this case, the problem was how to use drones to deliver packages to specific locations. Each student group selected a different location for delivery. They were provided with resources and materials to further research and explore their specific design problem. Students worked with a partner to research

Federal Aviation Administration (FAA) regulations for drones in airspace and other no-fly zones in the area, such as airports, military bases, and federal parks. Helen provided students with some curated map layers because she “wanted them to at least have these [ArcGIS map] layers where they could find them” (interview, February 2023). Students were instructed to use their new technology skills to create a map of North Texas and to add the following map layers: (a) Amazon warehouse locations, (b) National Security Unmanned Aircraft System (UAS) flight restrictions, (c) US airports, (d) Drone “No Fly Zones,” and (e) USA parks. Figure 4 shows the Dallas-Fort Worth (DFW) Airport (dark blue/green), Amazon distribution centers (red dots), and no-fly zones (squares).

Figure 4
Screenshot of Ground Route and Drone Route



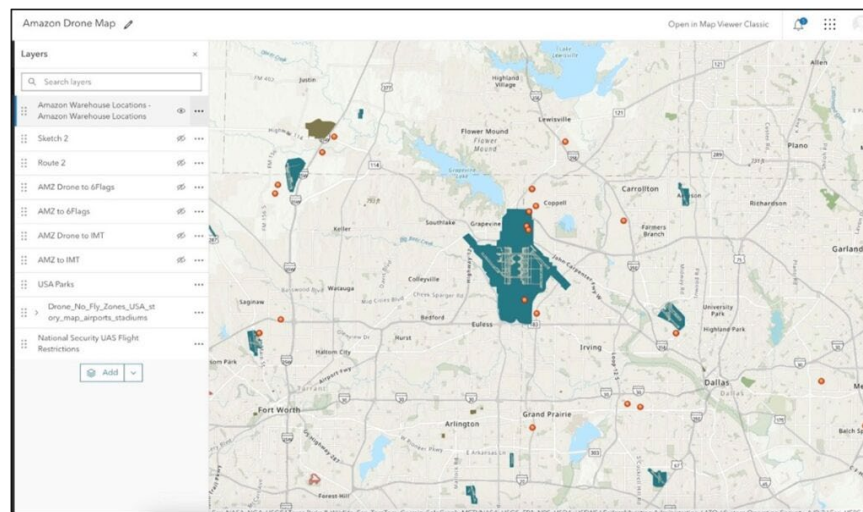
Real World Application

Through the resources provided, students learned specifics about flying drones in metropolitan areas. For example, there are limits for the distances drones can fly without recharging, and there are maximum amounts of weight the drones can carry. Helen acknowledged that students did not actually test a design for this activity; rather, students researched, explored, and investigated options for deliveries with some assumptions. Helen addressed her thoughts behind the design assumptions:

We’d have to have more information as to what other restrictions that we’re assuming ... one example is to calculate for the time, or the amount of fuel, or the height of the drone would need to take. We just assumed a lateral distance chance. There were some other assumptions made; we didn’t look at weather or wind patterns. (interview, February 2023)

They assumed the Amazon drones have a maximum speed of 50 miles per hour at 400 feet altitude. Students used the formula, $D = RT$, to create the route layer, which Helen described as an “application of math and science and physics. ... It’s a formula. ... they had to reverse some of the variables and solve different parts of the equation that they had” (interview, February 2023). Students investigated ways to solve the design problem by applying GTR with ArcGIS to visualize where Amazon distribution centers were located. After each student group selected a drone delivery location that would meet requirements for fly zones, distance, and so forth, the ground and aerial routes were mapped from the distribution center to the delivery location (Figure 5).

Figure 5
Example of a Map and the Student Worksheet



Students investigated the Amazon distribution center closest to the delivery location, then calculated the distance, weight of load, and amount of fuel that would be required for the delivery. For example, one group decided that their problem was that they were at the Six Flags Over Texas amusement park and needed sunglasses. They predicted that a drone could fly to Six Flags from a nearby distribution center, deliver the sunglasses, and return to the distribution center. Students created StoryMaps to submit as a final product, illustrating their design problem, maps, calculations, justifications, and recommendations for Amazon drone deliveries.

Teacher’s Perspective on PD and Implementation

Helen was satisfied with the students’ work on map layers, analysis of data, and solutions they generated for the real-world problem, saying, “I think the students really did enjoy this study of how we could use the maps for the drones” (interview, February 2023). Although Amazon did not use drones at this time in this region of Texas, students determined that some drone delivery in the future was feasible. Helen was able to integrate both

ArcGIS and GRT into her robotics course as a summative assignment. This end-of-semester activity required students to synthesize their knowledge about drones, local geospatial data, ArcGIS, and basic geometry and apply it to a potential real-life problem.

Even though students had flown drones both indoors and outdoors, this activity required students only to use their personal computers and to access ArcGIS. These factors reduced any concerns for students' physical safety during the learning activity. The activity was also designed to be completed during an extended class period during the semester exam week, so Helen was mindful of the amount of time students would need to complete the activity's background research, access the maps and layers on ArcGIS, draw lines and calculate distances on the maps, and justify their solutions to the proposed drone problem.

Helen was often humble about her work with students, both in her engineering classes and her outside work with students in robotics competitions. Her willingness to try new geospatial technologies with her students made her unique among the other STEM PD participants. She described her comfortability with technology:

I was pretty open to using technology ... maybe a little too open. There's a lot of hiccups, so the trainings are very helpful. I feel that it's very good to have the technology in the classroom, just because that's very much what they're going to be using in the workplace. So, not working with technology is not a realistic environmental practice. (interview, April 2024)

Helen wanted students to have access to technologies they would experience in a STEM workplace, even if implementing new technologies in the classroom can be unpredictable at times. Those "hiccups" could be losing instructional time to reset account passwords and assisting with students logging into technologies, troubleshooting errors when students search for map layers online, or finding real-world applications that students find engaging. Participating in the long-term PD project also challenged Helen's ideas about teaching and learning. She explained,

It challenged me in a way. I did have some predetermined ways I would approach my content, but it challenged me to think even more outside the box than I might normally, and it was a good experience. There are other ways that ArcGIS can be incorporated in robotics, and specifically, my subject. It was challenging, but a good kind of challenge. (interview, May 2024)

As a teacher who is open to using technology, Helen was willing to try a new technology application, ArcGIS, with her students after the long-term STEM PD intervention. Helen enjoys learning, saying,

I like learning technology. But sometimes when people say technology, you can get a very wide range of something that's very low and very low barrier, too simple even where it's not a good use of time, but because this was very new and unfamiliar to me, I felt my time was used appropriately, that I was able to learn new content. (interview, May 2024)

Helen's comfort with technology made it easier for her to try using it with students in her robotics class. She said, "Being able to have you come out ... when it comes to doing the activity ... you've already offered" (interview, May 2022), demonstrating that Helen was aware that we would come into her classroom to help on-site when she wanted to use ArcGIS with students.

Teacher's Decision-Making Post-PD

The long-term duration of the PD provided Helen time to internalize her learning and recognize an entry point that best suited her content and pedagogy for her robotics course. Her adoption was not apparent during the first and second years, as it included only the ready-to-use GeoInquiries created by ESRI. Helen admitted to struggling with finding time to plan and implement a new technology into her existing course, so she attempted to use ArcGIS with drones in her afterschool robotics club as a starting point. During the 3rd year, evidence emerged that the PD was working behind the scenes. Helen learned about a free online technology tool, developed skills in using the tool, and reflected on how to use the tool constructively with students to strengthen the school-to-work emphasis of the robotics course.

Without any outside support, Helen researched a real-world robotics problem, designed an activity for her students to complete, and implemented the lesson as a final exam assessment. As a classroom teacher, Helen did not plan the instruction and assessment with data collection in mind; instead, she was focused on incorporating the geospatial technology as part of the students' final exam. She did not invite us to observe when she integrated the geospatial technology into her curriculum, and she did not share the activity with us until she had successfully completed the lesson with students. In Helen's case, the long-term PD intervention resulted in positive outcomes as she gained confidence utilizing a new technology application within a robotics curriculum, and students learned new technologies and utilized socioscientific decision-making.

Discussion

Factors Influencing Teachers' Integration of Geospatial Technologies

Throughout the 3-year PD project, both Helen and we learned not only about the geospatial technology and pedagogical strategies but also about the complex interplay of factors in the current educational ecosystem that will allow innovation to launch. There are numerous potential barriers preventing teachers from implementing geospatial technologies in their classrooms, such as using technology, the time required to implement new technology, and aligning technology with the existing curriculum (Baker et al., 2015; Baker & Bednarz, 2003). Incorporating a geospatial technology, such as ArcGIS, into a teacher's instruction can be hindered by the teacher's ability to use the technology, the teacher's personal experiences and attitudes toward technology, and the ways the teacher is

provided support and training to implement the new technology (Koehler & Mishra, 2009).

After STEM teacher educators provide PD for teachers, it is important to identify how to support teachers who are eager and teachers who are reluctant to learn new technologies. Teachers must not only learn how to use geospatial technologies, but they must also integrate geospatial technology skills into their content and pedagogy if they want their students to use geospatial technologies in their course (Baker et al., 2015; Trautmann & MaKinster, 2010).

Research documenting how teachers implement PD, adapt it to their own curriculum, and integrate geospatial technologies is limited (Baker et al., 2015). Teachers attend PD during the summer or at other times outside the regular school day and may or may not decide to implement new technologies, curriculum materials, or learning activities into their instruction. Ultimately, STEM teacher educators have little control over how and when teachers implement new knowledge from PD into their instruction, possibly explaining why researchers have difficulty documenting the effectiveness of STEM PD interventions after teachers return to their classrooms (Baker et al., 2015; Rubino-Hare et al., 2016).

While working with a STEM teacher as part of a university-school partnership, researchers may not have the opportunity to witness how teachers incorporate new content and pedagogy, even if it was part of the original research design. In this case, the teacher did not invite us to observe the activity, so there was no documentation of the nuances of the classroom instruction. Observing teachers after PD is one of the many difficulties when university researchers conduct research in public school classrooms, especially post-COVID. STEM teacher educators need to better understand how teachers learn and change their behaviors following PD so that teachers are ultimately able to improve student outcomes in STEM learning.

Supporting Teachers' Classroom Integration of Geospatial Technologies

Researchers can provide teachers and students with pedagogical support and just-in-time technology assistance, such as password resets, user login names, and accessing the online software platform (Baker et al., 2015). STEM teacher educators may also assist with lesson planning, ideas for curriculum integration, and best practices for using the technology as a problem-solving tool with students. However, from the teacher's perspective, researchers may be considered experts, who might inadvertently judge the teacher's performance and execution with a new technology. What if the activity is unsuccessful and the students are not able to perform the technology tasks the teacher designed? What if the teacher's timeline for the activity is too short or too long, and the lesson plans had to be modified on the fly? For these reasons and a myriad of other concerns, teachers may feel more comfortable trying out innovative lessons with students without observers or an external audience.

The findings are consistent with Niess et al. (2010) and Rubino-Hare et al. (2016), who found that in-service teachers need educational opportunities

to develop innovative technology skills, like using components within ArcGIS, and to incorporate emerging digital technologies, like GIS mapping, into their content and pedagogy. For STEM teachers to successfully implement geospatial technologies in their classrooms, they must seamlessly weave their instructional content, technology knowledge, and pedagogical strategies together (Baker et al., 2015).

Other teachers may be more reluctant to learn about new technologies and also to risk the hiccups that may occur when trying to teach students how to use new technologies. Even though teachers were not required to begin using geospatial activities in their instruction, some teachers were eager to adopt some geospatial thinking components into their curriculum and piloted geospatial technologies with their students during the 1st year. Other teachers struggled to find ways to seamlessly incorporate GIS into their required curriculum and waited until the 2nd or 3rd year of the research project to use ArcGIS in their instruction. In this PD experience, some of the teachers were hesitant to invite the researchers to observe when they were attempting to use a new technology tool with their students for the first time.

Limitations

This case study was limited to a single teacher who participated in a long-term PD project with university researchers, and these findings are not generalizable to other contexts. Furthermore, the focus of this research is on the teacher's perspective of integrating geospatial technologies into her classroom instruction after PD; therefore, data collection focused on the qualitative teacher interview data and artifacts from the ArcGIS activity and do not include student outcome data. Although this research presents a single teacher's perspective, there is the potential to gain insight from the experience that may be useful for other researchers who design STEM teacher PD relating to geospatial technologies and classroom technology integration.

Conclusions

It has been well-documented that teachers potentially face numerous challenges when implementing new technologies into their repertoire, even with intensive PD supports (Baker et al., 2015; Baker & Bednarz, 2003; Hammond et al., 2018; Trautmann & MaKinster, 2010). As STEM teachers integrate geospatial technologies into their teaching, they must weigh the pros and cons of these tools as they relate to the demands of a mandated curriculum and the classroom environment (Hammond et al., 2018; Rubino-Hare et al., 2016). Learning new technology skills and appreciating how students could benefit from learning to use them do not always lead to teachers adding these tools and skills into their curriculum. Rubino-Hare et al. identified factors that increased teachers' likelihood of using a geospatial technology after PD, including the alignment between the technology and the content, flexibility in teaching strategies and assessments, and support from the school environment.

For example, teachers who have high-stakes testing as part of their courses may find it difficult to incorporate geospatial technologies into existing curriculum standards and assessments (Malone et al., 2024). Teachers

who taught subjects with mandated state testing or university dual enrollment syllabi may have more challenges in incorporating geospatial technologies into an already crowded curriculum. In this case study, a STEM teacher who taught an elective course appeared to have more curricular flexibility to let students explore new technologies and add projects into their scope and sequence of instruction. Therefore, STEM teacher educators should consider the intentional placement of geospatial technologies into courses that have curricular flexibility with content, instruction, and assessment to increase the success of teacher technology integration. Trying to force geospatial technologies into courses with strict requirements for curriculum, instruction, and assessment, or weak alignment to geospatial concepts is an unlikely recipe for successful technology integration, even if teachers have a positive experience with PD.

Providing targeted PD and support as part of a professional learning community and allowing flexibility for the teachers in their post-PD expectations was recommended by Trautmann and MaKinster (2010). We worked cooperatively with teachers in the STEM PD project and introduced new tools and strategies to infuse geospatial technologies into the STEM curriculum, giving teachers both time and space to let their ideas germinate and grow naturally. While this approach prioritized teacher autonomy and independence to implement new knowledge and ideas, collecting classroom data was challenging because researchers were rarely informed before teachers attempted to use new technologies with students. Although teacher implementation after PD was unpredictable, collecting some data was possible after the classroom implementation to describe how the teachers enacted the PD (as in Marton & Pang, 2006).

Unfortunately, collecting student products to evaluate student outcomes proved limiting because of the campus culture post-COVID and the design of the classroom implementation. Designing research projects with high-quality student data collection should be a priority because research documenting K-12 student experiences with geospatial technologies is limited (Baker et al., 2015; Hammond et al., 2018). However, balancing STEM teacher needs with research data collection from K-12 schools continues to be a challenge for STEM teacher educators working with in-service STEM teachers.

This case study illustrated that successful geospatial technology integrations require an intricate balance of teachers' instructional decisions and content requirements with student engagement and technology capabilities. Teachers may need ongoing support with technology that allows the teachers and their students to actively engage with technology and collaborate together (Børte et al., 2023). Technology PD should also be differentiated to meet teachers' needs for learning and implementing technology into their specific content and curriculum (Rubino-Hare et al., 2016).

Helen's unpredictable implementation of geospatial technology PD may be more common among teachers, which could camouflage PD effectiveness in the classroom if researchers anticipate a progressive PD adoption. Because Helen had more advanced technology skills, she was able to overcome challenges with using ArcGIS online that may have prevented other teachers from trying the technology with students

(Rubino-Hare et al., 2016). Examining how teachers acquire and implement technology knowledge and skills from PD can inform STEM teacher educators how to design PD and learning to improve technology integration for teachers and increase the use of authentic technologies in STEM education.

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