

TITLE: Teacher Preparation and Student Participation in a GIS-Focused Computer Science Unit Impact Students' Geospatial Thinking

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ABSTRACT: Experience with geographic information systems (GIS) can improve students' spatial skills and provide a foundation for success in STEM (Jant et al., 2019). Researchers and educators co-designed a GIS unit in which high school students learned to use ArcGIS software by exploring geospatial patterns in their local communities. Across three teachers, 134 students participated in the unit and completed a geospatial problem-solving assessment. Students' performance on the assessment significantly increased from pre- to post-test. Students whose teachers had more GIS experience and completed graded GIS assessments scored higher on geospatial assessments and used more spatial language than students whose teachers had less GIS experience and graded on participation. Students' expectancy, value, and cost of computer science varied across teachers, and may be linked to students' ability to devote time to map-building and their engagement with a GIS careers guide. We discuss the impacts of teacher training and lesson implementation on students' geospatial thinking.

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I. OBJECTIVE

Geographic information systems (GIS) comprise a variety of software used in a wide range of fields, including business, government, environmental science, and social science (Kerski, 2021). GIS allows users to generate and analyze spatial data on a digital map and explore how data varies by location. Students who learn GIS have doors opened to numerous academic and career opportunities. But GIS also helps students develop more general skills, such as spatial thinking (Cortes et al, 2022; NRC, 2006). Spatial thinking—the cognitive ability to visualize, understand, and draw inferences from spatial information—is foundational for achievement across science, technology, engineering, and mathematics (STEM) domains (Stieff & Uttal, 2015; Uttal et al., 2013). Importantly, research has demonstrated that spatial skills can improve substantially through training (Uttal et al., 2013).

In this paper, we examine how a GIS unit can improve high school students' spatial thinking skills. Our study builds upon the successful Geospatial Semester (GSS) developed by faculty at James Madison University in Virginia. Students in GSS learn to use GIS and apply their skills to address problems in their communities (Kolvoord et al., 2019), and studies have shown that GSS leads to improved spatial thinking (Jant et al., 2019). In this project, we adapt GSS for implementation in a variety of Chicago Public Schools (CPS) courses. Instead of offering a yearlong GIS course, we integrate GIS lessons into existing course curricula. This study focuses on a GIS data analysis unit, collaboratively developed by GIS educators and CPS teachers, and implemented in the *Exploring Computer Science* (ECS) course.

We examined two research questions. First, does participation in a GIS-focused computer science unit relate to students' spatial problem-solving and expectancy, value, and cost of computer science? Second, how do teachers' GIS training experiences and lesson implementation strategies impact students' spatial problem-solving and expectancy, value, and cost of computer science?

II. THEORETICAL FRAMEWORK

The three teachers implementing the GIS-focused ECS unit provided an intriguing natural experiment, as the three teachers had very different levels of experience with GIS and different histories of participation in our GIS professional development (PD) sessions, ranging from one PD workshop to four years of GIS training. Desimone's (2009) Professional Development Model proposes that the features of PD can impact teachers' knowledge, skills, and attitudes on a topic. In turn, teachers' skills and attitudes affect their instruction approaches, which ultimately affects students' learning. Building upon this model, we predicted that teachers' GIS preparation would relate to their lesson implementation approaches and their students' spatial thinking.

In addition to assessing students' spatial thinking, we examined students' expectations that they can be successful in computer science (expectancy), their value of computer science (value), and their perception that success in computer science requires burdensome effort (cost) before and after the GIS unit. For students to persist in STEM fields, they not only need to build STEM skills and knowledge, they need to feel that STEM is important and accessible. Indeed, students' expectancy, value, and cost of STEM domains are predictive of STEM-related achievement (Eccles, 2009; Wang & Degol, 2013). Using a validated survey (Hulleman &

Harackiewicz, 2021; Kosovich et. al., 2015) built upon Eccles's (2009) expectancy-value-cost framework, we considered whether the GIS unit may affect students' expectancy, value, and cost of computer science, as well as whether there were differences across teachers.

III. METHODS

Three teachers implemented the GIS unit in their ECS courses. To prepare for implementation, all three teachers participated in a one-day PD workshop in Spring 2023 that focused on training GIS skills in the context of the ECS lessons. Throughout the course of this multi-year project, we have engaged in a design-based research process to identify GIS PD opportunities that best support teachers' GIS skill development and confidence (James et al., 2020). The biggest change has been shifting from multi-day workshops focused on teaching broad GIS skills to shorter workshops (a few hours) focused on teaching specific GIS skills relevant to the designed GIS lessons. Teachers were introduced to ArcGIS Online software and practiced the skills expected of the students. We also added opportunities for teachers to rehearse lessons and get feedback from our team during the PD workshops. After the PD, we shared the GIS lesson guide and resources (e.g., slideshows, activity worksheets) with the teachers.

The GIS unit is designed for 15 days of instruction. Building on insights gained in the first few years of the project, the GIS unit is designed to promote student-driven inquiry, cultural relevance, spatial thinking, and connections to disciplinary content (James et al., 2020, 2021). The first three days involve providing students with a foundational understanding of spatial data and how GIS can be used to address community problems. Days 4-11 center on helping students develop GIS skills, such as creating maps, displaying and filtering data, and mapping relationships. Lastly, days 12-15 are designated for students to create and present a personally relevant GIS project. Because this is typically the last unit in the ECS course, teachers may not complete all lessons or have time for students to complete the final projects.

In an effort to highlight the cultural relevance of GIS, during the 2022-2023 school year, we developed a GIS Careers Guide for students. The guide highlights the careers of eight GIS experts working in Chicago. Their careers center on environmental sustainability, wildlife conservation, and urban planning throughout Chicagoland. Teachers were provided with physical and digital copies of the guide to use in their classes. Teachers were given freedom to decide when to introduce the guide during the GIS unit and how to use it with their students.

Using ethnographic methods, a researcher observed each of the three teachers as they implemented at least one lesson, noting the teachers' instructional approaches, the technologies and resources used with their students, and the activities completed during the class. After the unit, the researcher interviewed each teacher about their GIS training, their prior teaching experience, their lesson implementation strategies, and the challenges they encountered in the unit. As shown in Table 1, Teacher A had several years of experience using GIS and had taught GIS in multiple classes before 2023. Teacher B participated in two PD workshops and taught the GIS unit once before. Teacher C participated in one PD workshop and it was their first year implementing the GIS unit.

Table 1. Teacher Experience and Confidence

Teacher	Number of ECS Classes in Spring 2023	Class Composition	Number of Times Teaching the ECS GIS Unit	GIS Training Experience	Reported Confidence (Scale of 1-10)
A	5	Mostly Sophomores	1 + Experience teaching GIS in other classes	Annual PD Workshops from 2019-2023	10
B	2	Mostly Freshmen and Sophomores	1	2 PD Workshops (2022, 2023)	7
C	2	Mostly Sophomores and Juniors	0	1 PD Workshop (2023)	7

Across the three teachers, 134 students completed both the pre- and post-assessments at the start and end of the GIS unit. Teacher A's classes included 86 students. Because of a survey error, students in Teacher A's classes did not report demographic information. However, Teacher A's school reported that in 2023 their student body consisted of 51% black, 23% Hispanic, 23% white, 1% Asian, and 2% other race/ethnicity students. Teacher B's classes included 25 students—ten male (40%), eight female (32%), and seven (28%) transgender/non-binary; 17 who identified as Hispanic/Latine (68%), one Asian (4%), four who identified as more than one (16%), and three who did not report (12%). Teacher C's classes included 23 students—sixteen male (69%), five female (22%), and two (9%) who identified transgender/non-binary; 21 who identified as Hispanic/Latine (91%) and two as more than one race/ethnicity (9%).

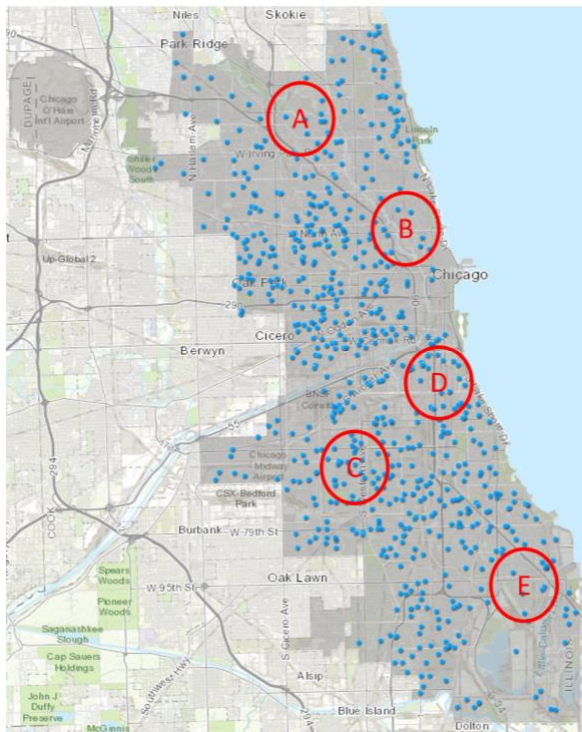
IV. MATERIALS

Before and after the GIS unit, students completed a geospatial problem-solving assessment, which asked them to use spatial data on maps to solve two problems (Stone, 2021). The first question focused on identifying where to add resources to in an area, based on a current lack of resources. For example, “Based on the locations of existing free pre-kindergarten programs shown on this map, which of these five locations would be the best place for a new free pre-kindergarten?” The second question focused on identifying areas to target to maximize the impact of a service or experience, based on prevalence of existing locations in the area. For example, “Based on the locations of polling places shown on this map of Chicago, which of these five areas should a polling monitor visit to see as many as possible?”

Figure 1.
Geospatial Assessment: Add Resource Question

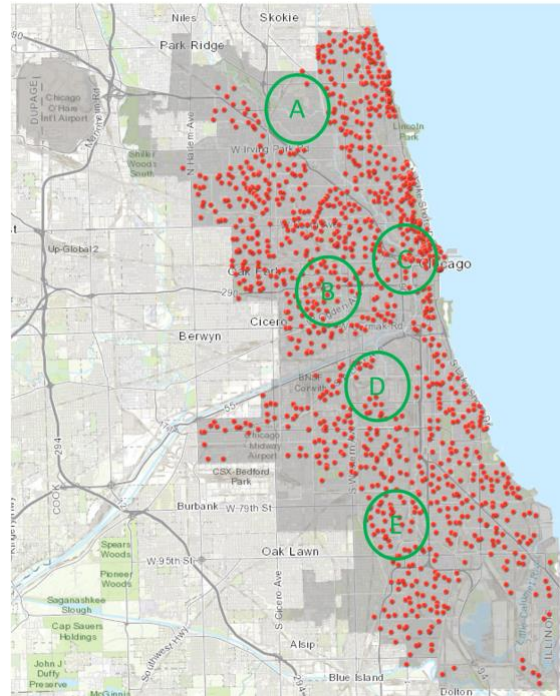
Figure 2.
Geospatial Assessment: Maximize Impact Question

Free Pre-K Programs in Chicago



Polling Places in Chicago

This map shows the locations of polling places in Chicago. Examine the map then answer the questions on the next page.



In answering these questions, students were asked to choose a location on a map, describe their reasoning for their selection, and identify whether additional data might be needed to make a better decision. We scored students' responses to the multiple-choice portion on a scale of 0-2, with 2 representing the best choice. Students' explanations for their choices were further coded for their use of spatial language (e.g., above, between, clustered, edge, nearby, region, spread). At post-test, we also asked students how they would specifically use GIS to solve the maximizing impact problem, and responses were coded for whether or not students used GIS approaches in their responses (e.g., referring to layers, attributes, boundaries, data).

Students' pre- and post-assessments also included a survey which asked students ten questions about their feelings of expectancy, value, and cost in computer science (Kosovich et al., 2015). For each question, students read a statement and were asked whether they strongly agreed (6), agreed (5), slightly agreed (4), slightly disagreed (3), disagreed (2), or strongly disagreed (1).

V. RESULTS

Among students in Teacher B's and Teacher C's classes who reported demographic information, analyses of variance (ANOVA) demonstrated no gender or racial/ethnic differences in students' reported expectancy, value, or cost of computer science at pretest or post-test. Moreover, we found no gender or racial/ethnic differences for students' pre- and post-test scores on the geospatial assessment, nor for students' use of spatial and GIS-related language. Because there were no differences by gender or race/ethnicity, and because we were missing demographic data for one class, we did not include gender or race/ethnicity in our main analyses.

A. Geospatial Problem-Solving

We next conducted a series of repeated measures ANOVAs to explore how students' geospatial assessment scores, spatial language use, and expectancy, value, and cost increased from pretest to post-test. The ANOVAs included teacher as a between-subjects factor. For students' scores on the "Add Resource" question of the geospatial assessment, there was a significant increase from pretest to post-test, $F(1, 125) = 6.03, p = .015$, as well as a significant main effect of teacher, $F(1, 125) = 3.79, p = .025$ (see Figures 3 and 4). For students' scores on the "Maximize Impact" question of the geospatial assessment, we similarly found a significant increase from pretest to post-test, $F(1, 124) = 11.41, p < .001$, but there was not a main effect of teacher, $F(1, 124) = 1.45, p = .238$.

Figure 3.
Students' Geospatial Assessment Scores Pre-Post

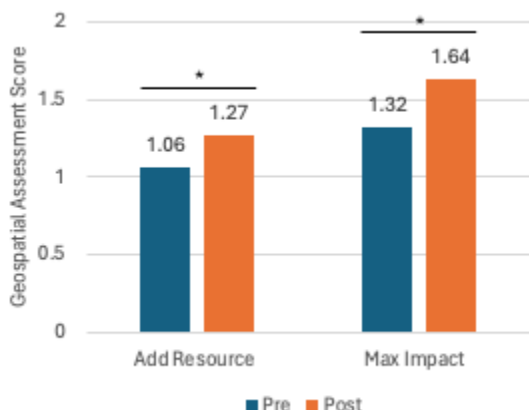
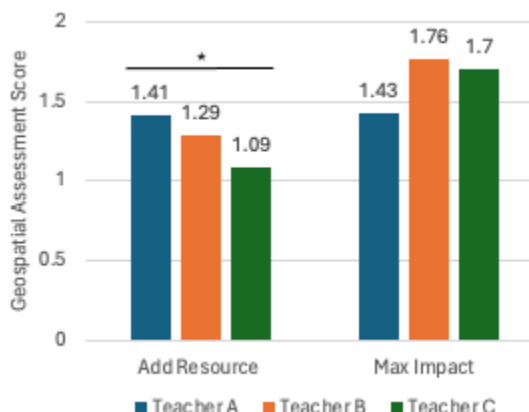


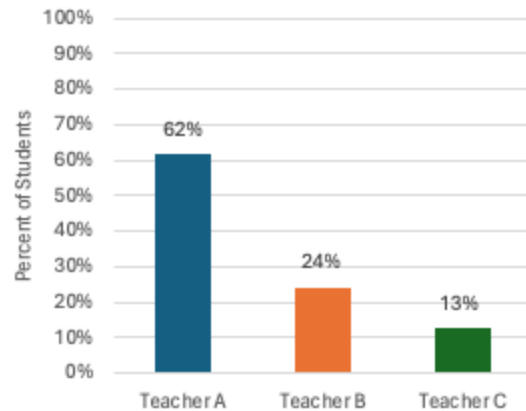
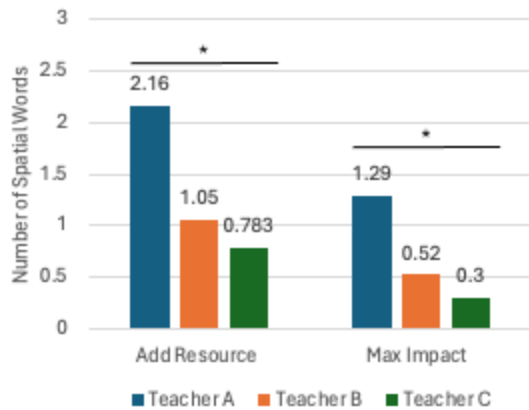
Figure 4.
Students' Geospatial Assessment Scores by Teacher



For students' spatial language use on the "Add Resource" question, there was not a significant increase from pretest to post-test, $F(1, 131) = .002, p = .966$, but there was a main effect of teacher, $F(1, 131) = 11.57, p < .001$ (see Figure 5). Likewise, there was not a significant increase from pretest to post-test for students' spatial language use on the "Maximize Impact" question, $F(1, 131) = .402, p = .527$, but there was a main effect of teacher, $F(1, 131) = 12.26, p < .001$. Students' use of GIS language was only measured for the "Maximize Impact" question at post-test, but we found a significant effect of teacher, $X^2(2, N = 134) = 23.36, p < .001$ (see Figure 6).

Figure 5.
Students' Spatial Language Use by Teacher

Figure 6.
Students' Use of GIS Approaches by Teacher



For the geospatial problem-solving assessment, compared to Teacher C's students, Teacher A's student's scored significantly higher on the "Add Resource" question, they used significantly more spatial language in their responses for both the "Add Resource" and "Maximize Impact" questions, and they were more likely to report using GIS techniques to solve the problems. As shown in Table 1, Teacher A had been teaching GIS for multiple years, both in ECS and in other classes. Moreover, they had been attending annual professional development sessions on GIS for four years and developed broad GIS skills. By comparison, this was Teacher C's first year teaching the GIS unit in ECS, and their only preparation had been one professional development session. As a result, teacher A rated their confidence in implementing the unit a 10 on a scale of 1-10, whereas Teacher C rated their confidence a 7. The two teachers also differed in their approaches to assessing students' learning. Both teachers used Google classroom and asked students to upload their daily journal entries and screenshots of their ArcGIS maps. However, Teacher C graded students on participation, whereas Teacher A graded students on the content of their journal entries and the quality of their ArcGIS maps. Teacher A also administered a final exam in which students were asked to recreate a map in ArcGIS and explain their process.

Teacher C: *"They had a place to upload their screenshots...and probably the journals. [Grading was based on] participation."*

Teacher A: *"They submit their maps to me and then submit their questions to me to do the journal entries. I look at their journal entries and grade that and I look at the match [of the maps]...The whole idea is that...I want you to show me that you're able to go to ArcGIS Online, add a layer, and do a basic analysis. If you could do that, we're good...Also with the final exam, I asked them to create a buffer...95% was able to do it."*

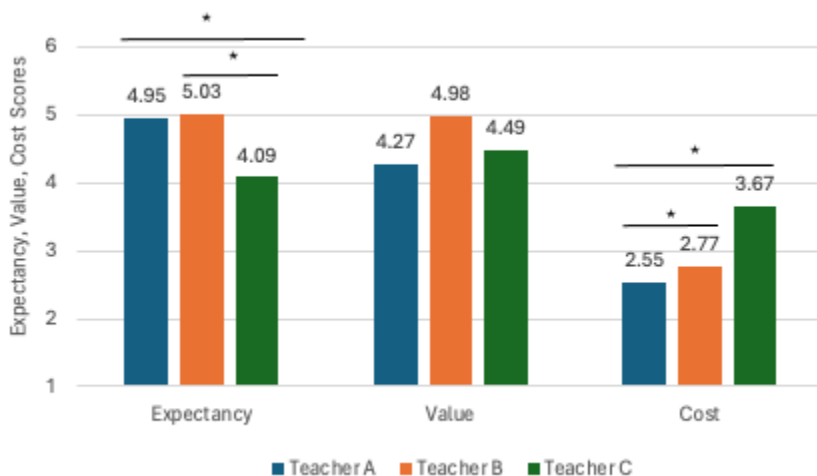
B. Expectancy, Value, and Cost of Computer Science

For students' expectancy of success in computer science, there was not a change from pretest to post-test, $F(1, 123) = .143, p = .706$, but there was a significant effect of teacher, $F(1, 123) = 9.45, p < .001$ (see Figure 7). For students' value of computer science, there was not a change from pretest to post-test, $F(1, 118) = .059, p = .809$, but there was a trending effect of teacher, $F(1, 118) = 3.06, p = .051$. Finally, for students' perceived cost of computer science, there was not a change from pretest to post-test, $F(1, 121) = 1.65, p = .201$. However, there was a

significant main effect of teacher, $F(1, 121) = 6.29, p = .003$, and a significant interaction between teacher and pretest/post-test, $F(1, 121) = 6.46, p = .002$.

Figure 7.

Students' Expectancy, Value, and Cost of Computer Science by Teacher



Students in Teacher A's and B's classes had significantly higher reports of expectancy for success in computer science and reported that computer science was significantly less costly than Teacher C's students. As shown in Table 1, both Teacher A and Teacher B had longer histories of teaching GIS and attending GIS professional development sessions than Teacher C. But Teachers A and B may have had better conditions for their students to make progress on their maps in ArcGIS Online. Teacher A elected to have ArcGIS Online accounts made for their students, so that students could save their work and continue working on the same map across multiple 50-minute class periods. Teacher B did not use accounts, but their students had 90-minute block class periods and could spend more time working on their maps each day. Teacher C, however, had only 45-minute class periods, and their students did not have ArcGIS Online accounts. This meant that students had to make new maps each class period.

Teacher C: *"The struggle was getting them to reset every time we came back to class, making the same map over. And then that was the whole period."*

The GIS Careers Guide was shared with teachers as a supplement to the GIS unit, and teachers used the guide in different ways and at different points throughout the unit. Teacher B introduced the guide on the first day of the unit and asked students to create reports on the eight GIS experts in the guide to share with the rest of the class. Teacher A used the guide as substitute work in the middle of the unit, requiring students to write a journal entry on which GIS career they identify with most. Teacher C handed out the guide to students at the end of the unit, but did not design an activity or assignment around the guide.

Teacher B: *"So we started...with the brochure...And I was like...this is like a great reading opportunity for the kids...I give the students the information and then each table is in charge of explaining a part of the lesson to the other teams."*

And you know, one thing that a couple of my students mentioned...was that...this is so cool, this is in Chicago!"

Teacher A: *"I did it as sub work because I was out... this is a journal entry and they're able to click on the brochure [and write about] what GIS expert's career you mostly identify with and why. And then the second [question] they had to do was why are GIS skills important."*

Teacher C: *"We handed them out...when we were kind of wrapping up...so that they could see...where this tool is used...It's not just like something we do in computer science..It's something that's used in multiple different kinds of careers."*

VI. SIGNIFICANCE

We found that students' performance on a geospatial problem-solving question increased from pretest to post-test, demonstrating the effectiveness of the GIS unit for improving students' spatial thinking. We also found that students' geospatial problem-solving scores and their use of spatial language and GIS approaches when explaining their problem-solving process differed across the three teachers included in our study. Finally, students' expectancy, value, and cost of computer science differed across the three teachers in our study.

Because this project is design-based research and implemented in real classrooms, a constellation of factors may have contributed to the differences across teachers. All teachers demonstrated how to use ArcGIS tools in each class, after which they let students complete hands-on ArcGIS activities. But from classroom observations, we noticed that teachers with more GIS experience relied less on their notes and lesson guides. Teachers who had implemented the GIS unit before 2023 personalized the unit, integrating relevant examples, engaging students in discussion, and encouraging exploration beyond the lesson. It is promising that teachers who participated in more GIS PD workshops report greater confidence when teaching the GIS unit, and that they adapt and personalize the lessons each year. Another factor which may have impacted students' geospatial problem-solving and spatial language use was teachers' assessment style. Two teachers (B and C) in our study graded students on participation-whether or not students completed journal entries and uploaded the ArcGIS Online maps to Google Classroom. But our most experienced teacher (Teacher A) graded students on the content of their journal entries and the quality of their ArcGIS maps, focusing on the extent to which students' maps included certain criteria. Teacher A also administered a final exam in which students were asked to search for layers, analyze data, and create buffers. This teacher articulated clear goals for students to master basic GIS skills, and students may have been motivated to learn the skills in order to perform well on assessments.

We also observed differences across teachers in students' expectancy, value, and cost of computer science. Students reported greater expectancy for success and felt that computer science was less costly if they were in classes with teachers who were more experienced with GIS. But beyond teacher experience, time for map-building and use of the GIS Careers Guide may have affected students' feelings of expectancy and cost. Teacher A used ArcGIS Online accounts so their students could save their work and build on the same map across class periods. Teacher B had 90-minute block classes, so students had more time to make progress on their

maps. Teacher C had the shortest class periods (45-minutes) and students did not have ArcGIS Online accounts, so they had to remake their maps in each class session. The teacher reported that this was taxing for the students and it was hard for them to make progress, which may be why students' reports of expectancy were lower and reports of cost were higher than those of students working with Teachers A and B. Additionally, teachers used the GIS Careers Guide in different ways. Teachers A and B intentionally designed lessons around the guide and introduced the guide early on in the unit, whereas Teacher C distributed the guide at the end of the unit and did not design activities around the guide. The GIS Careers Guide may be useful for emphasizing the importance of GIS in students' local communities, making them feel that the effort to learn GIS is worthwhile, and that succeeding in learning GIS can have major benefits.

Based on these findings, we are continuing to adjust our PD opportunities and GIS lessons to better serve teachers and students. In addition to offering lesson-focused PD, we are also designing GIS skill-building videos so that teachers can gain broader GIS experience and feel more confident when teaching. We are making GIS assessments and Google Classroom resources available to all teachers implementing the GIS-focused ECS unit. We are working with district administration to gain permission to create ArcGIS Online accounts for all ECS students. Finally, we plan to emphasize the value of offering activities based on the GIS Careers Guide early in the GIS unit's implementation.

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