Integrating Geographic Information Systems (GIS) into History and Computer Science Curricula: Approaches and Student Outcomes

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ABSTRACT

Learning to use Geographic Information Systems (GIS) can improve students' spatial thinking skills and provide a foundation for success in STEM (Jant et al., 2019). We worked with two teachers to incorporate GIS into their high school courses. With one teacher, we co-designed GIS lessons for AP United States History (APUSH), and with another teacher, we collaboratively modified a GIS unit for Exploring Computer Science (ECS). 145 students completed assessments of spatial problem-solving before and after the GIS lessons and responded to surveys about expectancy and value in STEM and their teachers' instructional approaches. Overall, students' spatial problem-solving significantly increased from pre- to post-test. Students in APUSH saw greater gains in using claims, evidence, and reasoning, whereas students in ECS saw greater gains in spatial thinking and GIS problem-solving. Students' perceptions that their teachers promoted meaningful learning were associated with their expectancy for success in STEM.

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I. OBJECTIVE

Spatial thinking skills, such as navigation and mental rotation, are foundational for success across science, technology, engineering, and mathematics (STEM) fields (Stieff & Uttal, 2015; Uttal et al., 2013). Moreover, many STEM disciplines rely on spatial visual representations like maps, graphs, and diagrams to communicate information (Uttal & Doherty, 2008), so it is crucial that students develop spatial thinking skills that will support their abilities to interpret and create spatial data visualizations. Geographic Information Systems (GIS) are used to generate and analyze spatial data visualizations (i.e., maps), and learning to use GIS software has been linked to improvements in students' spatial thinking skills (NRC, 2006). GIS has gained traction across a range of disciplines, including business, government, environmental science, and social science (Kerski, 2021), so learning GIS can bolster students' academic and career prospects.

Our work adapts the successful Geospatial Semester (GSS) curriculum for implementation in a large, urban public school district. The year-long GSS was developed by faculty at James Madison University in Virginia nearly twenty years ago, and students who participate in the course show growth in their spatial thinking abilities (Jant et al., 2019). In the VA GSS program, high school students spend the year learning to use ArcGIS software, and the class culminates in a final project in which students use GIS to examine and address problems in their local communities (Kolvoord et al., 2019).

In our efforts to spread and scale GSS to the Chicago Public Schools, we do not ask schools to add a new course to their curriculum. Rather, we seek to "spatialize" existing curriculum (Newcombe, 2017) by integrating GIS lessons and units into a range of courses. During the 2023-2024 school year, we worked with two teachers to incorporate GIS into their courses. We worked with one teacher to co-design GIS lessons that would supplement the eight different time periods in his Advanced Placement United States History (APUSH) course. With another teacher, we collaborated over the course of several years to develop a GIS unit for the Exploring Computer Science (ECS) course (Margolis et al., 2012).

We examine three research questions. First, do students who participate in GIS lessons show improvements in spatial reasoning and problem-solving skills? Second, are there differences in spatial reasoning and problem-solving skills between students who learned GIS through periodic lessons throughout the year and students who learned GIS through a standalone, designated GIS unit? Finally, what features of teacher instruction are linked to students' spatial reasoning and problem-solving skills, as well as their feelings of expectancy and value in STEM?

II. THEORETICAL FRAMEWORK

Numerous studies have demonstrated links between spatial skills and STEM achievement (Atit et al., 2020; Wai et al., 2009). Spatial Encoding Strategy Theory posits that spatial skills are essential for STEM thinking because they provide "generalizable strategies for encoding…non-verbal information" (Margulieux, 2019, pp. 7). The Heuristic Framework of Spatial Ability similarly proposes that spatial skills offer learners generalized strategies for processing visual information before they develop domain-specific STEM understandings (Buckley et al., 2018). Building on these theories, we see learning GIS as an opportunity to build a valuable STEM skill, but also as a potential pathway to developing general, transferable spatial abilities.

However, building STEM-related skills and knowledge is not enough for students to persist in STEM fields. Expectancy-value framework (Eccles, 2009) emphasizes that students' STEM

achievement is dependent on their feelings that they can succeed in STEM (expectancy) and their feelings that STEM is valuable for their future (value). Indeed, students' reports of expectancy and value are predictive of their later STEM-related achievement and career aspirations (Wang & Degol, 2013). Therefore, in addition to examining students' spatial problem-solving, we also considered students' expectancy and value of STEM before and after their GIS lessons.

Our final research question asks how teachers' instructional approaches relate to students' spatial problem-solving and expectancy and value of STEM. The Tripod 7C Framework identifies seven key components of teaching that are predictive of student engagement, motivation, and learning (Ferguson & Danielson, 2014). These components fall into the categories of personal support (care, confer), curricular support (captivate, clarify, consolidate, and academic rigor (challenge, classroom management). We surveyed students about the extent to which their teachers adopted these strategies in their class (McGee et al., 2018). Building on Vekiri's (2013) constructs and Situated Cognition Theory (Brown et al., 1989), our survey also asked students about whether their teacher prioritized collaboration amongst students, promoted active learning through discussion, and made learning meaningful by connecting GIS to real-world issues. Situated Cognition Theory further proposes that learning is highly contextual, influenced by factors like culture, social interactions, and activity (Brown et al., 1989). Our study examines how the context in which students learn GIS, including the course subject, contextual nature of the lessons, and the timing of GIS activities, relate to students' learning.

III. METHODS

During Summer 2023, we worked with two high school teachers to co-design GIS lessons for their classes. The two teachers worked at the same school, had similar levels of teaching experience, and both have attended our team's GIS professional development opportunities since the start of the project in 2019. Each lesson co-design working group consisted of a member of the research team, the teacher, and a GIS teacher-expert from GSS in Virginia.

One teacher wanted to work with our team to develop GIS-focused lessons for his Advanced Placement United States History (APUSH) course. The GIS teacher-expert in this working group had experience teaching GIS in history and social studies classes, so the two worked together to adapt existing GIS lessons for APUSH. Together, the working group developed eight GIS-focused APUSH lessons, which aligned with eight of the nine United States history time periods specified by the College Board. The lessons aimed to illustrate historical events through spatial data on maps, introduce students to a variety of tools in ArcGIS, and promote inquiry-based exploration. These eight lessons were implemented approximately monthly as the school year progressed.

The second teacher worked with our team to update a GIS unit designed for Exploring Computer Science (ECS) (James et al., 2020; Pagano et al., 2024). The ECS teachers and the GIS teacher-expert in this working group had contributed to the initial development of the GIS unit, and the two worked together to refine the unit materials to be more accessible to GIS novices and to align with software updates to ArcGIS Online. The unit consists of 15 lessons, which are designed to be implemented consecutively over the span of three weeks at the end of the school year. The unit is offered as an alternate unit for the ECS "Computing and Data Analysis" unit, and therefore targets the development of concrete GIS problem-solving skills. Throughout the unit, students apply their skills by exploring locally relevant issues using GIS.

Because the unit was implemented near the end of the school year, the ECS teacher shared that his classes completed seven of the 15 lessons.

Overall, 145 students from the school completed the lessons and associated assessments. 50 students participated in GIS lessons in the APUSH class, and 95 students participated in the GIS unit in ECS. Across the classes, 53% of students self-reported as male, 43% self-reported as female, and 4% self-reported as transgender/non-binary. For students' ethnicity, 47% identified as Black, 26% as White, 3% as American Indian, 2% as Native Hawaiian/Pacific, 11% as mixed/more than one, and 11% preferred not to say. Moreover, 69% of students marked that they were not Hispanic/Latine, 27% marked that they were Hispanic/Latine, and 4% preferred not to say.

IV. MATERIALS

Before and after the GIS unit in ECS and at the beginning of the school year and end of semester 1 in the APUSH class, students completed a spatial reasoning and problem-solving assessment, which asked them to use spatial data on maps to solve problems. One type of question focused on identifying where to "Add Resources" in an area, based on a current lack of resources. For example,"Based on the locations of existing free pre-kindergarten programs, where would the best location for a new free pre-kindergarten program be?" The second type of question focused on identifying areas to target to "Maximize the Impact" of a service, based on prevalence of existing locations in the area. For example, "If you were an election monitor hoping to visit as many polling locations as possible, which area would you target?" In answering these questions, students were asked to choose a location on a map and describe their reasoning for their selection. We scored students' responses to the multiple-choice portion on a scale of 0-2, with 2 representing the best choice.

For the "Add Resources" questions, students were also asked to respond to short answer questions about why their selected location was best. We scored students' proficiency in claim-evidence-reasoning argumentation in their short answer responses on a scale of 0-2. For claims, we considered whether they identified a specific location. For evidence, we assessed whether students provided data or spatial patterns from the maps to support their choices. For reasoning, we examined whether students provided further rationale or interpretation of the evidence. For the "Maximize the Impact" questions, students were asked to respond to short answer questions about how they made their decision, whether additional information would support their decision-making, and how they would use that information. These questions were scored based on a scale of 0-2 based on the extent to which students adopted a spatial approach in their thinking. This could include using spatial language (e.g., above, below, clustered, dense, far, near) or describing how spatial information would inform their choices. Students were also asked how they would specifically use ArcGIS to solve the problem, and we scored their description of GIS features, tools, or practices on a scale of 0-2.

Students' pre- and post-assessments also included a validated survey (Hulleman & Harackiewicz, 2021; Kosovich et. al., 2015) which asked students questions about their expectations that they can be successful in STEM (expectancy) and their value of STEM (value). For each question, students read a statement and were asked whether they strongly agreed, agreed, slightly agreed, slightly disagreed, disagreed, or strongly disagreed. The post-assessments included an additional twenty questions built upon a modified version of the Tripod 7C survey (Ferguson & Danielson, 2014; McGee et al., 2018). Questions focused on whether

students believed that their teacher valued students' ideas and views (confer), showed concern for students' emotional and academic well-being (care), made learning enjoyable and interesting (captivate), asked students to explain and persevere (challenge), fostered an orderly and respectful classroom (control), knew when the class understood concepts and explained content well (clarify) and provided useful comments (consolidate). The survey included questions based on additional constructs from Vekiri (2013), including whether there were opportunities to work with other students (collaboration), whether learning involved class discussions and explanations (active learning), and whether learning highlighted how GIS can solve everyday problems and be utilized across occupations (meaningful learning).

V. RESULTS

We first assessed students' performance of the multiple-choice section of the spatial reasoning and problem-solving assessment. A repeated measures ANOVA indicated that students' performance on the "Add Resources" question significantly increased from pretest (M = 1.01, SE = .09*)* to post-test (M = 1.31, SE = .09), $F(1, 100) = 9.54$, $p = .003$. Students' performance on the "Maximize Impact' question did not change from pretest to post-test, $F(1, 101) = 1.61$, $p = .21$. Students' reported expectancy ($F(1, 106) = .03$, $p = .86$) and value ($F(1, 102) = 3.23$, $p = .08$) also did not change from pretest to post-test. In each of these analyses, there were no significant between-subjects effects by course.

We used another repeated measures ANOVA to assess students' proficiency in using claim-evidence-reasoning argumentation in the short answer portion of the "Add Resources" question. We found a significant increase from pretest (M = 2.05, SE = 0.10) to post-test (M = 2.71, SE = 0.10), $F(1, 91) = 20.31$, $p < .001$. There was not a main effect of course, $F(1, 91) = 1.97$, $p = .16$, but there was a significant interaction between time and course, $F(1, 91) = 6.81$, $p = .01$. Students in APUSH demonstrated greater gains in claim-evidence-reasoning argumentation than students in ECS (see Table 1).

Table 1. Students' Pretest and Post-Test Scores for Claim-Evidence-Reasoning Argumentation

	Pretest		Post-Test	
	M	*SE*	*M*	*SE*
APUSH	2.01	0.15	2.83	0.14
ECS	2.09	0.13	2.31	0.13

We similarly conducted a repeated measures ANOVA to examine students' uses of spatial approaches to solving the "Maximize the Impact" question. We again found a significant increase from pretest (M = 1.56, SE = 0.17) to post-test (M = 2.02, SE = 0.19), $F(1, 92) = 14.6$, $p < .001$. This time, we also found a significant difference between courses, such that students in APUSH (M = 1.97, SE = 0.13) generally engaged in more spatial reasoning than students in ECS (M = 1.38, SE = 0.11), $F(1, 92) = 12.00$, $p < .001$. This finding was qualified by a significant interaction between course and time, $F(1, 92) = 20.2$, $p < .001$. As shown in Table 2, students in APUSH started with and maintained high spatial approach scores, but students in ECS saw notable gains in the use of spatial approaches.

Table 2. Students' Uses of Spatial Approaches at Pretest and Post-Test

	Pretest		Post-Test	
	M	*SE*	*M*	*SE*
APUSH	2.01	0.14	1.93	0.18
ECS	0.85	0.12	1.91	0.16

Finally, for the "Maximize the Impact" question, we analyzed the extent to which students described how they would use ArcGIS to solve the assessment problems. There was a significant increase in scores from pretest to post-test, $F(1, 92) = 72.3$, $p < .001$, as no students could describe how they would use ArcGIS at pretest ($M = 0.00$, $SE = 0.00$), but 55% described how they would use ArcGIS at post-test ($M = 0.53$, $SE = 0.08$). Here we saw a significant effect of course, $F(1, 92) = 11.1$, $p = .001$, with students in ECS receiving higher scores for how they would use ArcGIS ($M = 0.31$, $SE = 0.03$) than students in APUSH ($M = 0.13$, $SE = 0.04$). We again saw a significant time by course interaction, $F(1, 92) = 11.1$, $p = .001$, with students in ECS seeing greater gains in GIS problem-solving than students in APUSH (see Table 3).

Table 3. Students' GIS Problem-Solving Descriptions at Pretest and Post-Test

	Pretest		Post-Test	
	M	*SE*	*M*	*SE*
APUSH	0.00	0.00	0.27	0.08
ECS	0.00	0.00	0.61	0.07

Lastly, we next conducted a series of multiple regression analyses to explore how students' perceptions of teachers' implementation approaches predicted their geospatial assessment scores and expectancy and value of STEM at post-test (controlling for pretest scores). The final model for the multiple-choice portion of the "Add Resource" question was significant, $F(4, 92) = 5.01$, $p = .001$, $R^2 = 0.18$, but only pretest score was a significant predictor. The model for the multiple-choice portion of the "Maximize Impact" question was not significant, $F(22, 75) = .37$, $p = .37$. For students' claim-evidence-reasoning scores on the "Add Resources" question, the final regression model for teachers' instructional approaches was significant, $F(4, 84) = 5.47$, $p < .001$, $R^2 = 0.207$, but only pretest claim-evidence-reasoning score and course were significant predictors. The model for students' use of spatial approaches in the "Maximize the Impact" question was not significant, $F(22, 67) = 1.70$, $p = .05$, with no teacher instructional approaches predicting students' uses of spatial approaches. Similarly, the model for students' descriptions of GIS problem-solving approaches in the "Maximize the Impact" question was not significant, $F(21, 68) = 1.07$, $p = .40$.

Finally, the model for expectancy for success in STEM was significant, $F(4, 98) = 16.4$, $p < .001$, $R^2 = .400$, with teachers' description of how GIS is useful in real-world occupations ($\beta =$

0.38, $p < .001$) and teachers wanting students to explain their thinking ($\beta = 0.22$, $p = .017$) acting as significant predictors. Similarly, the model for value was significant, $F(3, 95) = 24.7$, $p < .001$, $R^2 = .438$, with teachers giving multiple explanations of concepts as a significant predictor, $\beta = 0.26$, $p = .003$.

VI. SIGNIFICANCE

We found that students' performance on a spatial reasoning and problem-solving assessment--including multiple choice questions, claim-evidence-reasoning argumentation, spatial approaches, and GIS problem-solving--increased from pretest to post-test. Intriguingly, students in APUSH saw greater gains in claim-evidence-reasoning argumentation, whereas students in ECS saw greater gains in the use of spatial approaches and GIS problem-solving. This finding suggests that various approaches to introducing students to GIS can support spatial thinking. But APUSH focuses on building students critical thinking skills, and the GIS lessons were offered approximately monthly and aligned with eight different historical time periods. In this way, GIS lessons helped students to use data to make historical claims. ECS, on the other hand, offered a GIS data analysis unit, so students became more proficient in spatial analysis and could better articulate ways to specifically use GIS to solve problems. Our investigation of teachers' implementation practices indicated that when teachers showed how GIS could be useful in real-world occupations or asked students to explain their thinking in class, students had higher feelings of expectancy for success in GIS-related STEM fields. Highlighting how GIS can be applied in a range of careers may help students to see that STEM skills like GIS are important and may help them succeed in the future. Based on our findings, we have developed a GIS lesson repository[1] so that teachers across disciplines can offer GIS lessons for their students, which will support development of a range of valuable competencies. Moreover, we have created a GIS Careers Guide[2], which teachers can use to highlight GIS careers available in the local community.

VII. REFERENCES

Atit, K., Uttal, D. H., & Stieff, M. (2020). Situating space: Using a discipline-focused lens to examine spatial thinking skills. C*ognitive Research: Principles and Implications, 5,* 19. https://doi.org/10.1186/s41235-020-00210-z

Buckley, J., Seery, N. & Canty, D. A. (2018). Heuristic framework of spatial ability: A review and synthesis of spatial factor literature to support its translation into STEM Education. *Educational Psychology Review, 30,* 947–972. https://doi.org/10.1007/s10648-018-9432-z

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher, 18(1), 32-42.

Eccles, J. S. (2009). Who Am I and What Am I Going to Do With My Life? Personal and Collective Identities as Motivators of Action. *Educational Psychologist, 44*(2), 78-89.

[1] https://geospatialexplorers.net/en

[2] https://futurumcareers.com/careers-in-gis

Ferguson, R. F., & Danielson, C. (2014). How Framework for Teaching and Tripod 7Cs Evidence Distinguish Key Components of Effective Teaching. In T. J. Kane, K. A.. Kerr, & R. C. Pianta (Eds.), Designing Teacher Evaluation Systems (pp. 98–143). John Wiley.

Hulleman, C. S., & Harackiewicz, J. M. (2021). The utility-value intervention. In: G. W. Walton & A. Crum (Eds.), *Handbook of Wise Interventions: How Social Psychology Can Help People Change* (pp. 100-125). Guilford Press: New York.

James, K., McGee, S., Uttal, D., and Kolvoord, B (2020, June 20-22). Design-based research in GIS-infused disciplinary courses: Toward a design framework [Paper presentation]. International Conference of the Learning Sciences 2020 Online Conference. https://www.jointhepartnership.net/publications/design-based-research-in-gis-infused-disciplinary-courses-toward-a-design-framework/

Jant, E. A., Uttal, D. H., Kolvoord, R., James, K., & Msall, C. (2019). Defining and measuring the influences of GIS-based instruction on students' STEM-relevant reasoning. *Journal of Geography*, *119*(1), 22-31.

Kerski, J. (2021). Top 10 Educational Benefits for Students Who Use GIS**.** *ArcWatch.* https://www.esri.com/about/newsroom/arcwatch/top-10-educational-benefits-for-students-who-use-gis.

Kolvoord, B., Keranen, K., & Rittenhouse, S. (2019). The geospatial semester: Concurrent enrollment in geospatial technologies. *Journal of Geography*, *118*(1), 3-10.

Kosovich, J. J., Hulleman, C. S., Barron, K. E., & Getty, S. (2015). A practical measure of student motivation: Establishing validity evidence for the expectancy-value-cost scale in middle school. *Journal of Early Adolescence, 35*(5-6), 790-816. https://doi.org/10.1177/0272431614556890

Margolis, J., Ryoo, J. J., Sandoval, C. D. M., Lee, C., Goode, J., & Chapman, G. (2012). Beyond access: broadening participation in high school computer science. *ACM Inroads, 3*(4), 72-78. doi:10.1145/2381083.2381102

Margulieux, L. E. (2020). Spatial encoding strategy theory: The relationship between spatial skill and STEM achievement. *ACM Inroads, 11*(1), 65-75. https://doi.org/10.1145/3381891

McGee, S., McGee-Tekula, R., Duck, J., McGee, C., Dettori, L., Greenberg, R.I., Snow, E., Rutstein, D., Reed, D., Wilkerson, B., Yanek, D., Rasmussen, A., & Brylow, D. (2018a, February). Equal Outcomes 4 All: A study of student learning in Exploring Computer Science. Proceedings of SIGCSE '18, Baltimore, MD, USA, 50-55.

National Research Council (2006). *Learning to Think Spatially.* The National Academies Press: Washington, DC.

Newcombe, N. (2017). Harnessing spatial thinking to support STEM learning. *OECD Education Working Papers, 161*. https://doi.org/10.1787/19939019

Pagano, L.C., Sotelo, J., McGee-Tekula, R., McGee, S., Kolvoord, R.A., & Uttal, D.H. (2024, April 11-14). Teacher Preparation and Student Participation in a GIS-Focused Computer Science Unit Impact Students' Geospatial Thinking [Rountable]. Annual Meeting of the American Educational Research Association. Philadelphia, PA. https://doi.org/10.51420/conf.2024.5

Stieff, M., & Uttal, D. (2015). How much can spatial training improve STEM achievement?. *Educational Psychology Review, 27*(4), 607-615.

Uttal, D.H., Doherty, K.O. (2008). Comprehending and learning from 'Visualizations': A developmental perspective. In Gilbert, J.K., Reiner, M., Nakhleh, M. (Eds.), *Visualization: Theory and practice in science education* (pp. 53-72). Springer. https://doi.org/10.1007/978-1-4020-5267-5_3

Uttal, D. H., Miller, D. I., & Newcombe, N. (2013). Exploring and enhancing spatial thinking: Links to achievement in science, technology, engineering, and mathematics? Current Directions in Psychological Science, 22(5), 367–373. https://doi.org/10.1177/0963721413484756

Vekiri, I. (2013). Information science instruction and changes in girls' and boys' expectancy and value beliefs: In search of gender-equitable pedagogical practices. Computers & Education, 64, 104-115. https://doi.org/10.1016/j.compedu.2013.01.011

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101*(4), 817.

Wang, M. T., & Degol, J. (2013). Motivational pathways to STEM career choices: Using expectancy–value perspective to understand individual and gender differences in STEM fields. *Developmental Review*, *33*(4), 304–340. https://doi.org/10.1016/j.dr.2013.08.001