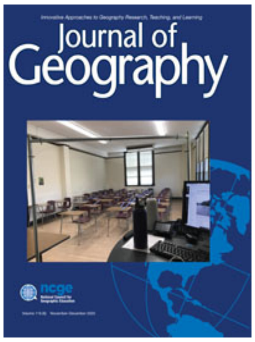

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High School Students' Experiences with Geographic Information Systems and Factors Predicting Enrollment in the Geospatial Semester

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ABSTRACT
The goal of the present study was to characterize high school students' (n = 338) exposure to geospatial technologies and investigate factors predicting enrollment in a GIS course. Students who reported using GIS were almost 10 times more likely to enroll than students without experience using GIS. Males were more than 3 times more likely to enroll than females. Spatial skills, but not beliefs about spatial ability, also predicted enrollment. These results underscore the importance of providing opportunities for students to use geospatial technologies as a pathway to students' future learning and training for GIS related careers.

KEYWORDS
GIS; high school; secondary education; sex differences; geographic education

Introduction

In the past decades, there has been a significant expansion of geospatial technologies, including geographic information systems (GIS), remote sensing (RS), and global positioning system (GPS). GIS provides a suite of tools for mapping spatial data to address questions in geography, and can support geography education by helping students develop spatial analysis skills and engaging students in real-world problem solving. Given the relative paucity of direct geography education in U.S. high schools, the introduction of GIS in other disciplines can help bolster geography awareness and analysis in high school students. The potential to apply GIS to important questions has created a demand for individuals prepared to use GIS technologies in their careers. The expansion of GIS-related careers, such as geoscience and cartography, is projected to increase at an average to above average rate between 2016 and 2026 (U.S. Department of Labor 2019), creating an unmet need for individuals skilled in GIS and related fields (AGI 2014). Given this unmet need, it is important to understand factors related to individuals' decisions to pursue training in geospatial technologies.

Therefore, the objectives of the present study were twofold: (1) to examine high school students' experience with GIS, and (2) to explore factors predicting students' enrollment in a high school GIS course. To address these objectives we collected survey data about students' GIS experiences, spatial habits of mind, and self-efficacy; assessed their spatial skills; and analyzed their high school transcripts. To examine the first objective, we characterized the types of exposure students have with GIS and how frequently students have prior experience using GIS outside of a standalone GIS course. In this study, we define GIS exposure as having knowledge or awareness about GIS (i.e., aware of a company or a family member/friend who uses GIS). Prior GIS use is defined as having first-hand experience using GIS, such as in a class. To address the second objective, we investigated factors predicting whether students enroll in a high school GIS course—the Geospatial Semester—that serves as an elective course applied toward high school graduation and provides students with college credit for an introductory GIS class (i.e., concurrent enrollment) (Kolvoord, Keranen, and Rittenhouse 2019).

This study makes two significant contributions to the extant literature. First, prior research on factors predicting GIS course enrollment have typically been undertaken in undergraduate and post-college settings. Understanding whether the same factors apply to students' choices to pursue a GIS course in high school is important given the role of exposure to GIS-related disciplines during adolescence on students' college and career trajectories (e.g., Adetunji et al. 2012). Second, in addition to examining demographic factors (e.g., gender, race/ethnicity) and GIS exposure and use, we investigated other factors such as spatial ability and beliefs about spatial and technological skills (Lee and Bednarz 2009; Vogt and Hodza 2013). Although spatial ability has not been examined as a factor predicting enrollment in GIS courses, spatial skills are related to success in GIS and can improve as a result of taking GIS courses (Lee and Bednarz 2009).

Factors predicting engagement with GIS and related fields

Individuals' reasons for entering GIS, geography, and related fields such as geoscience (comprising a combination of

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disciplines such as physical geography, Earth science, and geology) are related to a number of factors, including students' experiences in these fields, the makeup of disciplines that commonly employ GIS technologies, and the relative perception of GIS within education. Three major factors are particularly relevant. First, opportunities to learn about and use GIS are often limited in K-12 education and instruction in GIS is often left to the discretion of individual teachers or treated as an elective course (Hoisch and Bowie 2010; Lay, Chen, and Chi 2013; Kolvoord, Keranen, and Rittenhouse 2019). That is, students often have to seek out classes that incorporate GIS technologies, if those experiences are available at all. Second, disciplines that use GIS (e.g., geography, geoscience, earth and environmental science) tend to have low rates of women and underrepresented minorities in the field (Kaplan and Mapes 2016; Lunn 2016; National Science Board 2018). Third, GIS technology is perceived as potentially challenging to learn (Vogt and Hodza 2013), while the disciplines that use GIS are perceived by students as less rigorous and prestigious than other disciplines (Stokes, Levine, and Flessa 2015).

Students' exposure to and use of GIS technologies

Initial exposure to GIS is often happenstance, and students have limited opportunities to use GIS in K-12 education (Kerski 2003; Levine et al. 2007). In 2003, GIS had been adopted by less than 2% of high schools in the United States (Kerski 2003). A decade later, GIS was still not a part of the required geography curricula in the U.S.—including Virginia, the location of the present study—although it has been recommended by National Geography Standards, and GIS curricula have been adopted by other countries, including China, Finland, and India (Kerski, Demirci, and Milson 2013). GIS is central to geography education and to geoscience education more broadly. In the U.S., many states include Earth Science concepts in middle school and high school (NESTA 2019). However, Earth Science typically covers a wide array of topics, including geology, meteorology, and astronomy, with GIS typically regarded as an optional component—an option that is rarely chosen. As such, students' exposure to the subject often takes the form of extracurricular experiences such as field trips, summer camps or having a parent who supports a related hobby (Levine et al. 2007).

Programs designed to provide opportunities for students to gain knowledge of geoscience and GIS further underscore the importance of exposure to students' decisions about courses and careers. For example, Project GAP, The Geosciences Awareness Program at Ohio State and Columbus State Community College introduced high school and college students and teachers to geoscience through outreach seminars (Adetunji et al. 2012). The students participating in Project GAP reported more interest and desire to pursue geoscience after participating. More in-depth exposure through summer camps for high school students have also demonstrated a positive impact on students' perceptions of geoscience (Miller et al. 2007).

Opportunities to use GIS technologies are often limited in K-12 education (Kerski 2003; Kerski, Demirci, and Milson 2013). Of undergraduate students enrolled in a geography course in Canada, only 11% had used GIS and 26% had used Google Earth in their mandatory high-school geography classes (Leydon, McLaughlin, and Wilson 2017). The lack of exposure to GIS in secondary school is important to consider, given that it has been found to impact students' decisions to take college GIS courses (Vogt and Hodza 2013). By introducing GIS as a required course early on for students majoring in geography and Earth Science, Vogt and Hodza (2013) reported that many students felt encouraged to pursue geospatial science. While changing college curricula is one way to increase college student interest in GIS, increasing awareness of GIS at many levels, including high school and community college, can bolster student interest in GIS science programs & careers (Yu, Huynh, and McGehee 2011).

Women and under-represented minorities in GIS and related fields

Geography has historically been a field with more men than women (Kaplan and Mapes 2016; Lunn 2016). Despite trends of increasing participation among women, men remain over-represented in professional geography associations, geography awards, undergraduate and graduate degrees in geography, and as educators at the K-12 and undergraduate levels (Brysch 2014; Kaplan and Mapes 2016; Lunn 2016). Among high school students, geography course participation is relatively equal between male and female students (Lunn 2016), yet, male students tend to outperform their female peers on standardized tests of geography at the K-12 level (Brysch 2014).

Similar to geography, geoscience has been identified as having lower rates of women and underrepresented minorities relative to other STEM disciplines (National Science Board 2018). For instance, in 2015, women were awarded only 20.8% of bachelor's degrees in geology and earth science, compared to 53.3% of bachelor's degrees in biological and medical science (National Science Board 2018). Recent efforts to increase the number of women and underrepresented minorities in geoscience have been widely supported and have included efforts to highlight existing diversity in geoscience and introduce geoscience to students before high school (Baber et al. 2010; Miller et al. 2007). Programs such as the Geoscience Awareness Program decreased students' perceptions that the geoscience is "mostly men" (Adetunji et al. 2012, p. 238). Yet, such efforts are not widespread, and there is evidence that women and under-represented minority students perceive a lack of fit in geoscience and GIS. For instance, even among geoscience majors, women see a disconnect between themselves and the image of geoscientists (Stokes, Levine, and Flessa 2015). This lack of fit in the culture of geoscience may be particularly salient for nonwhite women who do not see themselves represented in the field (Stokes, Levine, and Flessa 2015).

Perceived difficulty and prestige of geoscience and GIS

GIS technologies are perceived as a particularly challenging component of geography and related majors (Vogt and Hodza 2013). In a study of undergraduate geography and environmental science majors, Vogt and Hodza (2013) reported that students perceived GIS courses as intimidating. Similarly, teachers are less likely to pursue GIS training if they perceive that it is difficult to use (Baker, Palmer, and Kerski 2009; Lay, Chen, and Chi 2013). There is some evidence that spatial skills can support students' learning from GIS (Lee and Bednarz 2009).

In contrast, students perceive geoscience to be less difficult and less prestigious than other STEM disciplines (Hoisch and Bowie 2010). Perceptions of geoscience as lacking the difficulty and rigor of other sciences were noted by individuals in geoscience careers as a perceived hindrance to studying geoscience (Levine et al. 2007). Individuals remarked that the perceived lack of difficulty of geoscience courses resulted in peer pressure against majoring in geoscience (Levine et al. 2007; Stokes, Levine, and Flessa 2015). For instance, one individual described high school geoscience courses as "something that dummies do" (Levine et al. 2007, p. 463). The perceived lack of prestige may serve as a further deterrent for nonwhite students (Stokes, Levine, and Flessa 2015). In interviews, Hispanic geoscience majors reported pressure from their families to pursue more prestigious majors (e.g., medicine, law). Therefore, while students' perceptions of their ability in geoscience in general may not serve as a valuable indicator of GIS course enrollment, students' abilities in skills relevant to GIS—such as technological and spatial skills—may be important to consider.

The current study

In the current study, we characterized high-school students experiences with GIS, and investigated factors that predicted whether students would enroll in an elective GIS course. This study was part of a larger project examining the impact of taking a GIS course on students' spatial reasoning. We examined the following research questions:

1. What types of exposure to and prior use of GIS do high school students have outside of a stand-alone GIS course?
2. To what degree do high school students' (a) prior exposure to and use of GIS, (b) demographic factors, (c) academic background, and (d) spatial and technological abilities predict their enrollment in a GIS course?

We surveyed whether students knew about GIS or had first-hand experience using GIS prior to taking the Geospatial Semester, and examined patterns in response. Students also completed measures of spatial habits of mind, self-efficacy, and spatial skills, and high school transcripts were collected for analysis. Then, we used logistic regression analysis to examine which factors predicted whether students enrolled in the Geospatial Semester. Based on prior research we hypothesized that students would be more likely to enroll in a GIS course if they were more represented in the GIS field (i.e., male, white), had prior GIS experience, took a less rigorous academic program of coursework, and had greater spatial skills and beliefs about their own spatial and technological ability.

Method

Participants

Participants ($N = 338$) in the present study attended five public high schools in Virginia during the 2015–2016 and 2016–2017 academic years. The schools were predominately located in suburban areas, with one school located in an urban area. Average demographic data for public schools in the two counties indicate that slightly fewer than 50% of students are White and approximately 15–30% qualify for free or reduced price lunch. Students were recruited in the spring and early fall and transcripts were examined to determine whether or not the students enrolled in the GIS course. Students were recruited predominantly during study hall or classes that were common among high school juniors (e.g., US history, mathematics). In order to recruit a sufficient sample of students taking the GIS course, we oversampled enrolled students. For the comparison group, most schools allowed recruitment of either (a) all junior and senior study hall sessions or (b) specific classes that were mostly populated by students in the spring of their junior year (e.g., U.S. History; trigonometry). In the final sample, there were 90 students enrolled in the GIS course and 248 students enrolled in alternative courses.

GIS course context: The Geospatial Semester

We examined participants in the Geospatial Semester (GSS) (Kolvoord, Keranen, and Rittenhouse 2019), which is a yearlong course that teaches students to use GIS by solving problems relevant to their local communities. GSS is a concurrent enrollment course taught at students' high schools by high-school teachers who receive training and ongoing support in GIS from college faculty at James Madison University. Students receive both high school and college credit for an introductory GIS class upon satisfactory completion of the course. Students begin the course by learning to use GIS tools and techniques through structured, teacher-guided problems. The final quarter of the course is devoted to students' self-selected capstone projects, in which students present to college faculty as the culminating activity in the course. GSS is a flexible curriculum. As such, teachers adapt the content of the problems to fit their students' interests. Although GSS is typically taken in the senior/fourth year of high school, some students take the course in their junior/third year. Of the students participating in this study, 90 (26.63%) enrolled in GSS, and the remaining students took other elective courses. Additional details about the GSS curriculum can be found in Kolvoord, Keranen, and Rittenhouse (2019) and at www.isat.jmu.edu/geospatialsemester.

Measures

Prior experience with GIS

Students' prior use and exposure to GIS technologies were measured with three questions reported prior to students' enrollment in GSS. Prior GIS use was measured by students' self-report of whether or not they had used GIS themselves in any of their classes. Prior GIS exposure was measured with two questions in which students reported whether or not they (a) had parents, relatives, neighbors, or family friends who use GIS, or (b) could name a company that use(s) GIS. Participants who responded yes to any of the questions were prompted to provide a written explanation for each question. Students who responded yes to at least one of these two questions (i.e., knowing someone or a company that uses GIS) were coded as having prior GIS exposure. Data were missing from 1 participant for GIS use and GIS exposure, and from 1 participant for GIS exposure.

Demographic factors

Self-reported demographic factors were collected using a survey. Dichotomous indicator variables were created for gender and race/ethnicity. Gender was coded as male or female (no students reported other gender identities) and race/ethnicity was coded as white or nonwhite. Nonwhite included students who selected at least one of the following options: Hispanic, Black, Asian, American Indian/Pacific Islander, or Other. Participating students were 59.47% female and 37.87% nonwhite.

Academic background

Information about students' academic background was retrieved from the school transcripts and records as a measure of overall academic rigor. Specifically, we counted the number of Advanced Placement (AP) and International Baccalaureate (IB) courses taken prior to enrolling in GSS or other elective courses, and recorded students' overall GPA. Given that this was a measure of overall academic rigor, we included both STEM courses (e.g., AP Biology; AP Calculus) and non-STEM courses (e.g., AP English; AP U.S. History).

Spatial and technological abilities

Measures of spatial skills and beliefs included a paper folding test, the Spatial Habits of Mind Inventory (SHOMI), and an assessment of self-efficacy for using maps. Technological beliefs were measured using an assessment of self-efficacy for computer use.

Spatial skills were measured using the 20-item paper folding subscale of the VZ-2 (Ekstrom et al. 1976). Each item depicts a sequence of 2–4 steps where a piece of paper is folded and punched. Dotted lines are used to represent where the paper has been folded and small circles are used to represent the holes punched through the paper. Participants are asked to determine where the punches will be located when the paper is unfolded by selecting the correct response from five choices. Performance on this measure is time-limited (max: 6 minutes). Total scores were calculated by adding the total number of correct responses with a 0.2 point deduction for incorrect responses. Possible scores ranged from 0 to 20 and test reliability was high (α=.79). Paper folding, similar to measures such as mental rotation, assess dynamic mental manipulation (Uttal et al. 2013). These measures are predictive of achievement across a wide range of STEM disciplines (Wai, Lubinski, and Benbow 2009) as well as for geographic thinking (Metoyer and Bednarz 2017). Given that participants in this study were part of a larger follow-up study, paper folding was selected because it has been shown to be correlated to measures that were to be given as assessments in the follow-up study (e.g., Mental Rotation Test; Blazhenkova and Kozhevnikov 2010; Hegarty and Waller 2004). This enabled the use of paper-folding as a covariate in the follow-up study, while eliminating re-test effects. Additionally, in contrast to other measures of spatial thinking that require computerized administration or require extended time to complete, paper folding could be completed by participants without a computer in the time available for testing within a school setting.

Developed by Kim and Bednarz (2013) and further tested with high school students (Holzer 2016), the SHOMI is a 28-item self-report questionnaire about students' tendencies to engage in spatial thinking. For each item participants were asked to rate their agreement on a 5-point Likert scale from *strongly disagree* to *strongly agree*. The SHOMI includes five subscales (see sample items in parentheses; all items available from Kim and Bednarz 2013):

- spatial pattern recognition (6 items, "When I use maps to find a route, I tend to notice overall patterns in the road network")
- spatial description (5 items, "I tend to use spatial terms such as location, pattern, or diffusion to describe phenomena")
- visualization (8 items, "I find that graphs, charts, or maps help me learn new concepts")
- spatial concept use (4 items, "When trying to solve some types of problems, I tend to consider location and other spatial factors")
- spatial tool use (5 items, "like to use spatial tools such as maps, Google Earth, or GPS")

Reliability of the SHOMI in the present study was high ($\alpha = 0.88$).

Students rated their self-efficacy for using maps (2 items) on a 5-point Likert scale from *not at all skilled* to *very skilled*. The following activities were assessed: using paper/printed maps and using online/digital maps on a computer or mobile device. This measure was modified from the Survey for Spatial Representation and Activities (SSRA; Terlecki and Newcombe 2005) for use in the present study in order to assess whether map-specific ability beliefs was related to course enrollment. Scale reliability was modest ($\alpha = 0.53$). Although low reliability is not unexpected for scales with a limited number of items, it also suggests that students may have different perceptions of their ability to read printed compared to digital maps.

Self-efficacy for using computers (2 items) was rated on a 5-point Likert scale from *not at all skilled* to *very skilled*. The following activities were assessed: using computers and learning how to use new software/computer programs. The self-efficacy for computers measure was modified for use in the present study based on the SSRA (Terlecki and Newcombe 2005), and was included given that it has previously been associated with spatial skills (Terlecki and Newcombe 2005). Reliability was high ($\alpha = 0.85$).

Procedure

Students who received parental consent to participate completed all of the measures in a single sitting. First, participants were given the paper folding test. The 20 items were divided into two sections of 10 items each. Participants had three minutes to complete each section. Then, participants completed the remainder of the questionnaires and a demographics survey at their own pace. School records and transcripts were obtained from each participant's school. All analyses were conducted using the statistical analysis program Stata 15.

Results

Descriptive statistics

Mean differences in predictor variables (e.g., prior GIS exposure; demographics) for students who did and did not enroll in the GSS course are presented in Table 1, and bivariate correlations among the predictors are presented in Table 2. The patterns of correlations suggest that having a stronger academic background (i.e., took more AP/IB courses and had a higher GPA) was related to GIS exposure. There was also a significant relation between having been exposed to GIS, spatial habits of mind, and self-efficacy for using maps. There were additional notable gender patterns. While being female was related to better academic performance, being male was related to spatial ability, spatial habits of mind, and self-efficacy for using maps and computers.

Students' GIS exposure and GIS use prior to taking the Geospatial Semester

More than one-quarter of participants (n = 90; 26.63%) had at least one form of experience with GIS. This included 12.46% (n = 42) who reported using GIS themselves, and 19.64% (n = 66) who were exposed to GIS. Students who were exposed to GIS included 16.37% (n = 55) of students who reported having a relative, neighbor, or family friend who used GIS and 12.46% (n = 42) who reported being able to name a company that uses GIS. GIS use and GIS exposure were not mutually exclusive. Rather, there was a modest correlation between students' prior exposure to GIS and their prior experience using GIS ($r = 0.27$, $p < .001$). We note that the types of exposure students had with GIS varied by school (see Figure 1). At some schools, students were more than twice as likely to have experience using GIS compared to students at other schools.

Most of the students who reported using GIS themselves (n = 42) reported doing so in a science or geography class in high school. Students cited courses such as IB Environmental Systems (n = 18), Earth Science (n = 5), AP Human Geography (n = 5), and Biology (n = 2). It is worth noting that in several of the schools included in this study, the teachers who teach the Geospatial Semester course also teach some sections of Earth Science and IB Environmental Systems. Other students reported using it for course projects or reported using GIS but did not list a specific situation in which they used it. No students specifically identified using GIS in contexts or situations outside of school, although it is possible that some of the students had done so, despite not reporting that use.

Students who knew relatives or family friends using GIS named 25 unique governmental, nonprofit, and corporate agencies. Of students who named a specific individual in their response, they reported 21 parents (17 fathers, 3 mothers, 1 non-specified), 7 family friends and neighbors, 3 siblings (2 brothers, 1 sister), 2 uncles, 2 grandfathers, and 1 scoutmaster. With the proximity of the schools to the center of federal government and related contractors, students reported knowing people using GIS in federal agencies such as the Department of Defense (n = 2) and NASA (n = 2). They also named corporations and foundations such as Northrop Grumman (n = 2), the World Wildlife Foundation (n = 2), and Orbital ATK (n = 2). Some students reported knowing someone who uses GIS, but they were not able to name the company or type of work completed by the individual. When asked to name a company that uses GIS, students reported 30 unique organizations, including many of the same companies where their relatives and family friends

Table 1. Student characteristics by course enrollment.

	Students not enrolled in GSS N = 248		Students enrolled in GSS N = 90	
	mean	*sd*	*mean*	*sd*
Prior exposure to GIS	0.18		0.26	
Prior experience using GIS	0.06		0.31	
Male	0.35		0.57	
Nonwhite	0.39		0.36	
Number of AP/IB courses taken	4.43	2.78	4.33	3.09
Overall GPA	3.52	0.45	3.54	0.46
Paper Folding	11.21	4.35	10.65	3.84
SHOMI	101.42	13.00	102.64	11.06
Self-efficacy for maps	6.85	1.41	7.01	1.22
Self-efficacy for computers	7.36	1.64	7.66	1.55

Note: Exposure to GIS, experience using GIS, gender, and race/ethnicity are presented as proportions

Table 2. Bivariate correlation matrix of predictor variables.

	1	2	3	4	5	6	7	8	9
1. Experience using GIS (yes = 1)	1.00								
2. Exposure to GIS (yes = 1)	0.27*** (<.01)	1.00							
3. Gender (male = 1)	−0.04 (0.51)	−0.04 (0.48)	1.00						
4. Race/Ethnicity (Nonwhite = 1)	−0.02 (0.78)	−0.09 (0.10)	−0.01 (0.84)	1.00					
5. Number of AP/IB courses	0.17** (<.01)	0.19*** (<.01)	−0.11* (0.04)	−0.06 (0.29)	1.00				
6. Overall GPA	0.13* (0.02)	0.11* (0.05)	−0.14* (0.01)	−0.16** (<.01)	0.42*** (<.01)	1.00			
7. Paper Folding	0.02 (0.69)	0.11 (0.05)	0.12* (0.03)	−0.14* (0.01)	0.10 (0.08)	0.24*** (<.01)	1.00		
8. Spatial Habits of Mind Inventory	0.06 (0.29)	0.14* (0.01)	0.14* (0.01)	−0.11* (0.04)	0.08 (0.15)	0.12* (0.03)	0.21*** (<.01)	1.00	
9. Self-efficacy for maps	0.08 (0.15)	0.23*** (<.01)	0.22*** (<.01)	−0.06 (0.29)	0.11* (0.04)	0.07 (0.18)	0.12* (0.02)	0.57*** (<.01)	1.00
10. Self-efficacy for computers	−0.01 (0.90)	0.07 (0.21)	0.20*** (<.01)	0.12* (0.03)	0.00 (0.96)	−0.07 (0.22)	−0.01 (0.81)	0.22*** (<.01)	0.38*** (<.01)

Note: *p*-values in parentheses.
$^{*}p < 0.05$,
$^{**}p < 0.01$,
$^{***}p < 0.001$.

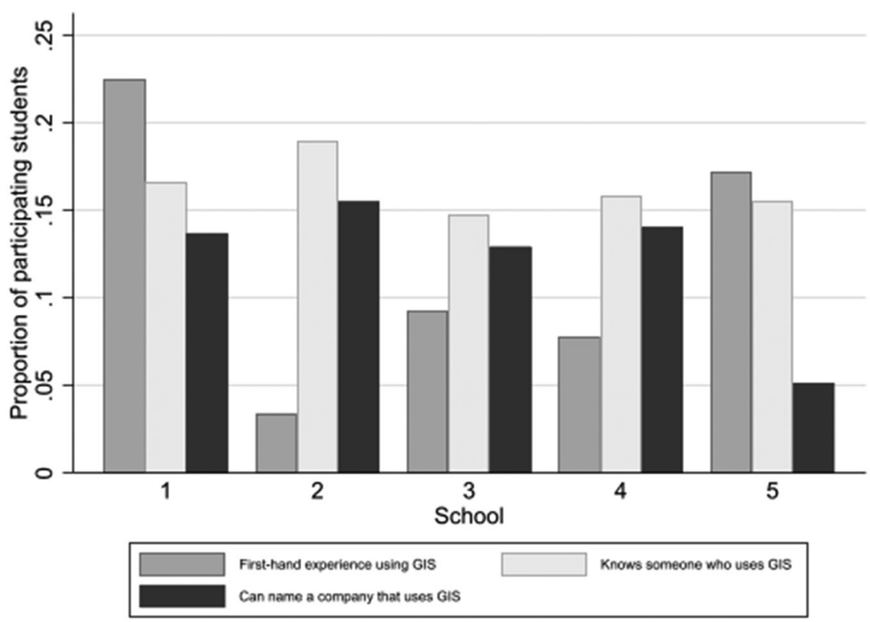

Figure 1. Proportion of Students' Prior GIS Experience by School.

worked. The most common organizations included CIA (n = 4), Lockheed Martin (n = 3), National Geospatial Intelligence Agency (n = 3), Airbus (n = 2), Northrop Grumman (n = 2), ESRI (n = 2), and FBI (n = 2). Participants also named local organizations (e.g., Dominion - a Virginia Power company, and a local water-proofing company) and national corporations (e.g., Microsoft, UPS). A complete list of organizations reported by students is included in the Appendix.

Factors predicting students' enrollment in the Geospatial Semester

To assess the factors predicting whether students enrolled in the Geospatial Semester, we conducted logistic regression analysis with enrollment in the GSS course as the dependent variable (enrolled in GSS = 1). Given that students were nested within schools, we accounted for the hierarchical nature of the data by using clustered standard errors. The independent variables were entered in 4 steps corresponding to Research Questions 2a–2d. Step 1 included whether students had prior exposure to or use of GIS (yes = 1). Step 2 included demographic variables, including gender (1 = male) and race/ethnicity (1 = nonwhite). In Step 3, number of advanced placement (AP) or International Baccalaureate (IB) classes taken and overall GPA were entered as measures of students' academic background. Finally, in Step 4, we entered spatial and technological skills, including performance on a test of spatial ability and questionnaires assessing spatial habits of mind and self-efficacy for using maps and computers. In each step the variables were entered as blocks.

Table 3. Logistic regression models predicting enrollment in the geospatial semester.

	Model 1	Model 2	Model 3	Model 4
Prior GIS use (yes = 1)	7.582***	9.129**	9.517**	9.690**
	(4.41)	(6.52)	(6.60)	(7.22)
Exposure to GIS (yes = 1)	1.010	1.033	1.121	1.234
	(0.21)	(0.23)	(0.25)	(0.35)
Gender (male = 1)		3.029**	2.820*	3.136*
		(1.14)	(1.28)	(1.43)
Race/Ethnicity (Nonwhite = 1)		0.889	0.843	0.793
		(0.39)	(0.39)	(0.33)
Number of AP/IB courses			0.921	0.922
			(0.06)	(0.05)
Overall GPA			1.220	1.403
			(0.41)	(0.60)
Paper Folding				0.936*
				(0.03)
Spatial Habits of Mind Inventory				1.007
				(0.02)
Self-efficacy for maps				0.891
				(0.10)
Self-efficacy for computers				1.082
				(0.08)
Constant	0.263**	0.160***	0.118	0.0865
	(0.12)	(0.08)	(0.17)	(0.13)
Pseudo R^2	0.09	0.13	0.14	0.15
Log likelihood	−176.62	−168.16	−164.51	−161.04
df	2.00	3.00	3.00	3.00
AIC	359.23	344.32	337.03	330.08
BIC	370.68	359.57	352.19	345.19
N	335	335	327	323

Note: Odds ratios presented with clustered standard errors in parentheses.
*$p < 0.05$,
**$p < 0.01$,
***$p < 0.001$.

Results from all four logistic regression models are presented in Table 3. Given the improved model fit for Model 4 based on the lower AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) values, results from Model 4 are summarized. In terms of overall model prediction, McFadden's pseudo R^2 suggests that 15% of the variance in GIS course enrollment was accounted for by the predictors included in Model 4 (pseudo R^2 estimates for Model 4 ranged from .15—McFadden's R^2 to .23—Cragg & Uhler's R^2 & McKelvey & Zavoina's R^2). Results revealed that prior exposure to GIS significantly predicted student enrollment in GSS, even after including all of the other variables in the model. The odds of a student enrolling in GSS if they had previously used GIS were almost 10 times greater than the odds of a student who had never used GIS (*odds ratio* = 9.69, *SE* = 7.22, p = 0.002, 95%*CI*: 2.25–41.73). However, whether students had been exposed to GIS through family connections or companies, did not predict enrollment. That is, exposure to GIS did not influence whether students enrolled in a GIS course, but their prior experience using GIS did.

Student gender, but not race/ethnicity, also significantly predicted whether students enrolled in GSS, even after accounting for exposure to GIS and all other variables in the model. The odds of males enrolling in GSS were more than 3 times greater than females (*odds ratio* = 3.14, *SE* = 1.43, *p* = 0.01, 95%*CI*: 1.27–7.69). Students' race/ethnicity did not predict enrollment.

Measures of academic background, including GPA and number of AP/IB courses taken were not significant predictors of course enrollment. Finally, spatial skills measured by the paper folding task was a significant predictor of course enrollment. Students with higher paper folding scores were more likely to enroll (*odds ratio* = 0.937, *SE* = 0.03, *p* = .04, 95%*CI:* 0.88–1.00). Beliefs about one's ability to use maps and computers, and spatial habits of mind were not significant predictors of whether students would enroll in GSS.

Discussion

The Geospatial Semester is unique as a high school course because it engages students in solving problems relevant to their local communities and teaches GIS as a tool for investigation and analysis. Over the year-long course, students learn a variety of GIS techniques, and perhaps more critically, they learn to think about problems in a spatial way (Kolvoord, Keranen, and Rittenhouse 2019). In the Virginia public schools where GSS is offered, students have many possible courses that they can select in order to fulfill graduation requirements. This includes multiple concurrent enrollment courses that, like GSS, provide college credit for course completion. Among the options available to students, GSS is novel in both content as well as pedagogical approach. Unlike many other college-level courses in high school (e.g., AP courses), GSS utilizes project-based and collaborative assessments rather than exams to measure student achievement.

The present study investigated student characteristics that predict whether high-school students enroll in GSS. The findings suggest that students' first-hand experience using GIS prior to the course, student gender, and spatial skills predicted enrollment; factors such as student's exposure to

GIS, academic background, and beliefs about spatial and technological abilities were not predictive. When considering how to encourage a more diverse GIS-trained workforce, these factors have implications for how schools and other educational organizations can support students to engage in GIS coursework before college. However, it is important to note that only 15% of the variance in GIS course enrollment was explained from these predictors, indicating that there are other factors involved that were not assessed in the present study.

Due to the high concentration of governmental organizations and intelligence agencies in the greater Washington, D.C. region where participating students lived, it is not surprising that more than one-quarter of the students knew about GIS. Despite this exposure, only the opportunity to use GIS first-hand, not being able to name a GIS organization, profoundly impacted whether students enrolled in GSS. In fact, 31% of participating students enrolled in the GSS course had prior experience using GIS compared to only 6% of students enrolled in other courses. This experience, however, varied by school, even among students enrolled in GSS. For instance, in School 1, 77.27% of participating students enrolled in GSS had previously used GIS. In contrast, prior GIS use among GSS students at other schools ranged from 0% (School 2) to 25% (School 5). Understanding why this variation occurred across schools is an important area for future research.

Students reported that they had opportunities to use GIS in other high-school classes. There are a few teachers in the participating school districts who have used GIS in middle school or earlier high school courses. Some of the exposure to GIS likely comes from being in classes with these teachers or interacting with peers who have been introduced to GIS. While these classes did not necessarily include GIS as a substantial component, it is possible that some did. Although many students did not write about the extent to which their prior courses incorporated GIS, some students specified brief experiences. For instance, one participant noted, "In human geography we used ArcGIS once to see how it works." In the present study, students reported prior experiences only in school contexts. Whereas previous studies suggested that out-of-school hobbies and experiences (e.g., scouting) are an important avenue to pursue geoscience interests, students may be limited in out-of-school opportunities to use GIS. If we want to encourage students to pursue GIS, these finding suggest that the most important factor is giving them first-hand opportunities to use GIS; an awareness of GIS without concomitant first-hand experience is not sufficient. Future research should examine whether the amount of previous experience using GIS is a factor in GIS course enrollment. Additionally, the GIS course in the present study was interdisciplinary, spanning geography and geoscience. Future research should examine whether the subject of the GIS course matters, both in terms of factors predicting course enrollment and students' learning of GIS.

Gender, but not race/ethnicity predicted whether students enrolled in GSS. This finding was consistent with representative statistics that show women are less inclined toward STEM (National Science Board 2018). Although it was not a research question in the present study, we note that the gender make-up of the GSS course varied by school. Among participating students, the percentage of females enrolled in GSS ranged from lows of 18.18% (School 2) and 21.41% (School 3) to a high of 59.38% (School 5). If we want more females to consider taking GIS courses, there are multiple possible factors to consider, and future research should investigate factors that explain why some schools had greater gender parity in GIS course enrollment. Anecdotally, some students reported a perception of the course as something boys do. This comment was more prevalent among students in schools where fewer girls enrolled in the course. Students' reports also reflected the perception that GIS is male-dominated; students reported knowing more male family members who use GIS than female family members. Students listed only 3 mothers who use GIS compared to 17 fathers, and listed uncles and grandfathers, but no aunts or grandmothers. While we would encourage those involved in students' course selections to help to change the stereotype that GIS classes are for boys, we acknowledge that this stereotype is grounded in gender differences in current STEM career participation (National Science Board 2018). It may also be useful to consider whether first-hand opportunities to use GIS may be particularly beneficial for encouraging girls, even in schools where GIS courses are male-dominated.

For high school students, prior measures of academic achievement and academic rigor did not predict whether students enrolled in GSS even after controlling for GIS use and student demographics. Additionally, pair-wise correlations indicated that prior use of GIS and exposure to GIS were positively and modestly correlated with academic background, including the number of AP/IB courses students had completed (rs: 0.17–19, $p\text{s} < 0.01$) and overall GPA (rs: 0.11-.13, $p\text{s} < 0.05$). The students with higher spatial ability were more likely to pursue GIS coursework. However, other measures of spatial skills should be examined in future studies, given that paper folding assesses only one type of spatial thinking. Further, it is worth noting that beliefs about one's spatial and technological skills did not predict enrollment in the GSS course even though spatial skills did. Future research should examine whether these factors also predict success in GIS courses.

This study was conducted with students across schools in two counties representing different suburbs of Washington, D.C. Findings, therefore, need to be contextualized within the geographic location of this study, given that students at these schools may have had more opportunities to become familiar with GIS. Whether the findings replicate in other regions that have less GIS access is an open question. Additionally, in the present study, race/ethnicity was not a significant predictor of course enrollment, a finding that contrasts with prior research. This should not be interpreted to mean that race/ethnicity disparities do not exist in the GIS field, only that they were not found in the present study.

In terms of students' coursework decisions, it was not possible to determine specific reasons why students did not enroll in GSS. For instance, students who did not enroll in

GSS may have been unaware of the course or they may have chosen to pursue another course instead. Future research should consider whether students who take alternative elective courses actively avoid GIS courses, are more enticed by other course options, or do not know that a GIS course is an option. This is important given that the strategies to encourage enrollment may differ based on these reasons. Another limitation of the present study was that we did not have data to indicate whether students had previously taken a course with the GSS teacher. It is possible that students used GIS in another class with the GSS teacher and they signed up for GSS because they liked the teacher, rather than because they had used GIS. This factor should also be taken into account in future studies.

Conclusion

Given the gap between available careers in geospatial science and individuals qualified for those positions, it is important to identify pathways to increasing GIS enrollment. This includes understanding factors impacting students' decisions to enroll in a GIS course when it is available in high school. In addition to meeting workforce demands, there is evidence that taking a GIS course improves students' spatial thinking, a skill that is broadly useful for STEM (Kim and Bednarz 2013; Wilkerson et al. 2012). In light of prior research that identified a large number of possible factors that might influence students' GIS course decisions, the findings from the current study indicate that three factors—first-hand experience using GIS, gender, and spatial skills—may be particularly important for students at the high-school level. Additionally, in the fifteen years of the Geospatial Semester, we have seen a variety of techniques for encouraging student participation. Teacher recommendation and support has been a mainstay as GSS teachers identify and encourage students who would benefit from the experience. This has been very powerful for female students and may provide some explanation as to why the percentage of females enrolled in the Geospatial Semester course varied by school. Parental influence is also powerful, as is the recommendation of guidance counselors and other adult influencers. Moreover, sharing the opportunity to pursue meaningful and current problems with students has been a draw for a number of students looking to work on problems that matter to them.

We acknowledge that providing stand-alone GIS courses in high school is a challenge for many schools, not to mention the challenge of incorporating GIS into classes outside of stand-alone courses. In the future, we hope that opportunities to use GIS are more broadly available to pre-college students. Results from this study suggest that researchers and educators who hope to encourage diverse participation in GIS should consider providing students with first-hand opportunities to use geospatial technologies.

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Appendix A: Alphabetized list of organizations students reported

Air National Guard, Air traffic control, Airbus, Arlington County Department of Technical Services, Arlington County Fire Department, Blue Raster Boeing, Booz Allen Hamilton, Caterpillar, CIA, Cisco, Court House, Department of Defense, Defense Intelligence Agency, Dominion Virginia Power, EPA, ESRI, FBI, General Dynamic, Geoeye/Digital Globe, Harris Teeter, IMF, JIEDDO, Leidos, Lockheed Martin, Metropolitan Council of Government, Microsoft, NASA, National Geospatial Intelligence Agency, National Rifle Association, National Science Foundation, Northrop Grumman, Orbital ATK, Prospect Water Proofing, Skyhigh Networks, UPS, US Air Force, US Coast Guard, Walmart, World Resources Institute, World Wildlife Fund

Appendix B: Self-efficacy measures

How proficient or skilled do you believe you are at the following activities?

	Not at all skilled	Below average skill	Average skill	Above average skill	Very skilled
Using paper/printed maps					
Using online/digital maps on a computer or mobile device					
Using computers					
Learning how to use new software/computer programs					