Computer Science and Programming Courses in Geography Departments in the United States

Forrest J. Bowlick, Daniel W. Goldberg, and Sarah Witham Bednarz
Texas A&M University

Geographic information systems (GIS) are fundamental information technologies. The capabilities and applications of GIS continue to rapidly expand, requiring practitioners to have new skills and competencies, especially in computer science. There is little research, however, about how best to prepare the next generation of GIScientists with adequate computer science skills. This article explores how U.S. geography departments are introducing and developing computer science and programming skills in their geography and GIS degree programs. We review the degree requirements in fifty-five geography departments and discover that forty-four of them offer some kind of GIS programming course. Of the 210 separate degree options identified, however, only 22 require one of these courses for a degree. There is little consistency or emphasis on computer science and programming skills in geography or GIS degrees, despite the immense importance of these components in geography and GIS careers. We propose future research along distinct investigative tracks to build a research-based understanding of the educational interactions among GIS, computer science, programming, and geography. **Key Words: computer science and programming, geography and GIS degree design, geography education, GIS education.**

地理信息系统 (GIS) 是基础的信息技术。GIS 的能力与应用，持续快速地扩张，并要求操作者具备新的技术及能力，特别是在计算机科学之中。但却少有研究探讨如何最佳地协助下一世代的 GIS 科学家具备适当的计算机科学技术。本文探讨美国的地理学系，如何在其地理学与 GIS 学位学程中引入并建立计算机科学与程式化技能。我们回顾五十五所地理学系的学位要求，并发现其中的四十四所提供若干 GIS 程式化课程。但在指认的两百一十个独立学位选项中，只有二十二个学位要求必修这些课程其中之一。儘管计算机科学与程式化是地理和 GIS 职业中相当重要的元素，但它们却鲜少具有一贯性或受到强调。我们随着特殊的探讨途径提出未来的研究，以对于GIS、计算机科学、程式化和地理学间的教育互动，建立以研究为基础的理解。**关键词: 计算机科学与程式化，地理学与 GIS 学位设计，地理教育，GIS 教育**。

Los sistemas de información geográfica (SIG) son tecnologías de información fundamentales. Las capacidades y aplicaciones de los SIG siguen expandiéndose rápidamente, demandando de sus practicantes la adquisición de nuevas habilidades y competencias, especialmente en ciencia de la computación. No obstante, es escasa la investigación existente sobre la mejor manera de preparar la siguiente generación de científicos SIG que estén adecuadamente dotados de habilidades en ciencia de la computación. En este artículo se explora la manera como los departamentos de geografía de los Estados Unidos están incorporando y desarrollando la ciencia de la computación y las habilidades de programación en sus programas de titulación en geografía y SIG. Revisamos los requisitos de título en cincuenta y cinco departamentos y hallamos que cuarenta y cuatro de ellos ofrecen algún tipo de curso sobre programación para SIG. Sin embargo, de las 210 opciones individuales de titulación identificadas solamente 22 requieren uno se esos cursos para conseguir un título. Existe poca consistencia o énfasis en ciencia de la computación y habilidades de programación en los programas conducentes a un título, a pesar de la inmensa importancia de estos componentes en las carreras de geografía y de SIG. Proponemos nuevos estudios a lo largo de ciertas avenidas conspicuas de investigación para construir un entendimiento que se fundamente en investigación sobre las interacciones educativas entre los SIG, la ciencia de la computación, la programación y la geografía. **Palabras clave: ciencia de la computación y programación, geografía y diseño para título en SIG, educación geográfica, educación en SIG.**

Geographic information systems (GIS) and GIScience are evolving rapidly. GIS is no longer locked to a desktop computer or confined to expensive computer labs (Kong, Zhang, and Stonebraker 2015). The affordances of advanced cyberinfrastructure, like distributed, high-performance computation, allow a greater flexibility, diversity, and scale of spatial investigation. Fundamental computer science and programming skills are expanding the capabilities of GIS and have become more prominently essential skills of proficient GIS practitioners (Dramowicz, Wightman, and Crant 1993; Johnson 2010; Liu et al. 2012). Data manipulation, analysis, and management, along with system implementation and design, are now core competencies in GIS (Schulze, Kanwischer, and Reudenbach 2013). With this growing emphasis of programming and computer science in the epoch of the Internet of things, big data, and Web-enabled society, determining how to best incorporate these topics in geography course work is an essential research effort (Muller and Kidd 2014).

Despite underpinning the fundamental technologies used in GIS and GIScience, the degree to which computer science and programming instruction are included

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in degree programs in these domains is unknown. What knowledge, skills, and practices will GIScientists need? What types of curricula, instruction, and learning experiences could develop the broad skill sets necessary for both competent and expert use of GIS? Before being able to answer such questions, we need to understand where we are right now in an educational sense. Very little is known about the curricula and requirements of degree programs in GIS and GIScience. There are a plethora of GIS degrees, certificates, and training venues to obtain such education and training, but no guidelines or structure to the integration of computer science or programming components. Constructing a descriptive analysis of the current state of degree requirements, recommended course work, and pathways to GIS competence is a useful and worthwhile starting point toward further understanding of how current formal competencies function. The status of computer science and programming instruction, whether outsourced to other academic departments or held within the geography degree–granting department, merits special consideration, particularly due to the changes just outlined. The growth of application of computer science and programming in GIS shows the abundance of ways GIS users, developers, and researchers can capitalize on fusing capabilities in computer science with programming knowledge to form new ways of engaging with spatial problems.

We provide an initial glimpse into the growing role and importance of computer science and programming instruction in current degrees by addressing several questions. First, are students acquiring computer science and programming knowledge and skills within their primary degree programs in geography or outside of them? There are many avenues by which to learn this knowledge and skills in the university environment and, much like GIS, programming does not belong to any individual entity. How students acquire this knowledge is of interest. Second, what factors influence the number of computer science or programming courses required for geography and GIS degrees? Further, do bachelor of science (BS) degrees require more computer science and programming instruction than bachelor of arts (BA) degrees? Given the diversity of research, applications, and programs in geography, identifying patterns related to the prevalence of computer science and programming course work in geography and GIS degrees could provide a useful basis for investigating further trends in this realm. Third, do GIS degrees or GIS-specific degree tracks or options require more computer science and programming courses than non-GIS degrees or tracks in the same department? Related to this question is the issue of sequencing: Where is computer science and programming course work typically positioned in the curriculum? Knowing whether there is a consistent sequence of courses or whether courses are merely optional rather than required could provide meaningful information about the general integration of computer science and programming in GIS programs. Keeping the variation in program instruction in mind, we intend to explore the disparate student preparation and provide insight into the relative importance of computer science and programming in different programs and degrees. It is our intent to construct a reference useful for departments or colleges considering revising degree plans and programs.

Overall, we seek to understand the position of computer science and programming instruction in GIS and geography programs; is this critical domain being taught in departments of geography, is it housed in traditional computer science departments, or is there a potential point of collaboration between GIScientists and computer scientists? To address these questions, we first explore the intersections among computer science, programming, geography, and GIS. Then, we discuss the selection of universities in our sample and our methodologies for extracting program requirements. After presenting the data discovered in our analysis, we discuss the findings as relevant to our research questions. We conclude by outlining extended implications of our work and outlining additional research lines for exploration on this topic.

Computer Science and Programming in Geography and GIS

Computer science and programming exist as independent ideas and concepts and manifest in different course work. Computer science courses teach fundamental skills and practices to develop perspectives on and understanding of how computers function (Kay et al. 2000). Programming courses, in contrast, focus on developing skill in the semantics and syntax of specific languages to analyze code and generate programs (Van Merrienboer and Krammer 1987). The ability to program, develop applications, and generally to be proficient in geospatial information technologies are core proficiencies required to enter the GIS workforce (DiBiase et al. 2010; Mirzoev et al. 2015). Thus, many career and postundergraduate tracks in geography require programming and computer science knowledge, even though geography students experience considerable anxiety when faced with such instruction (Muller and Kidd 2014; Rickles and Ellul 2015). Integrating GIS, computer science, and programming instruction remains difficult (Sinton 2009).

The GIS skills least developed during GIS courses are those related to programming and computer science (Şeremet and Chalkley 2015). Although typical GIS courses involve instruction across a broad range of concepts, the domain information in computer science is considered to be more complex in terms of fundamental knowledge and comprehension (Gasparinatou and Grigoriadou 2011). Learning in computer science is complex and fraught with known barriers, including conditions of negative reinforcement (Kinnunen and Simon 2012), impersonal interactions (Barker and Garvin-Doxas 2004), and detachment and demotivation (Babin, Tricot, and Mariné 2009). Students need support to overcome these barriers (Robins, Rountree, and

Rountree 2003). Effective support helps learners to develop domain-specific knowledge; to regulate their cognition, behavior, and motivation (Devolder, van Braak, and Tondeur 2012); and to build viable mental models of key programming concepts (Ma et al. 2011).

A point of frustration for GIS students arises as their GIS abilities build and yet they are faced with novice challenges in computer science and programming. A student's growing status and intuition as an expert GIS user might not be applicable in computer science and programming, slowing his or her capabilities of application and recall (Ertmer and Newby 1996). Further, novice and expert programmers structure their coding activities in different ways, requiring different types of learning support (McKeithen et al. 1981). The instructor can serve as a major barrier as well, as expert programmers are often not educators (Robins, Rountree, and Rountree 2003), and GIS instructors with computer science or programming experience often lack the formal programming training to effectively teach the subject (Muller and Kidd 2014) or might rarely approach the subject in course work at all (Etherington 2016). Because learning in computer science and programming is challenged by numerous barriers, students need to be motivated about the purpose, value, and utility of concepts within course work (Carter 2006). Meaningful motivators are essential to computer science and programming learning, whether they be games, explicit disciplinary contexts, or direct connections to professional utility (Forte and Guzdial 2005; Papastergiou 2009). Developing and structuring resources that help students construct useful knowledge while structuring concepts within the appropriate context is a vital component of integrating computer science, programming, geography, and GIS course work, especially as GIS careers and academic work integrates these concepts.

Design and Methodology

To investigate the degree to which computer science and programming are included in geography degree programs and to describe program requirements, we conducted a survey of curricula and course offerings in geography programs in the United States. Reviews of curricula can provide insight into the scope and nature of academic programs. Course description analysis is an established means of research, useful in diverse and related fields. In library science, such analysis has been used to track the emphasis of core topics in library and information science degrees (Irwin 2002); in psychology, it has been used to determine the types of alternative degree options available to undergraduates (Messer, Griggs, and Jackson 1999); and it has been used for establishing a baseline for curriculum design in management of information systems and computer information systems degrees (Kung, Yang, and Zhang 2006). In computer science education, Davies, Polack-Wahl, and Anewalt (2011) discovered a broad "uniformity" in how most departments teach the first courses in the computer science major sequence. Guo (2014) reported a switch to Python as the first language learned by new students in introductory computer science courses. This type of review is broadly used and useful to understand how courses and programs function.

We reviewed all geography programs listed by the most recent National Research Council (NRC 2010) rankings of geography programs, as well as those programs listed in the set of rankings by academic business intelligence company Academic Analytics (2015), for a total of fifty-five departments (Table 1). These rankings provide an easy-to-use reference of programs in geography to facilitate program analysis.

Table 1 *List of universities in this sample, extracted from the 2010 National Research Council and 2015 Academic Analytics reports*

Arizona State University	Johns Hopkins University	Oklahoma State University	Syracuse University	University of Colorado Boulder	University of Iowa	University of North Carolina at Chapel Hill	University of Texas at Austin
Boston University	Kansas State University	Oregon State University	Texas A&M University	University of Connecticut	University of Kansas	University of Oklahoma	University of Utah
Clark University	Kent State University	Pennsylvania State University	University of Arizona	University of Florida	University of Kentucky	University of Oregon	University of Washington
Dartmouth University	Louisiana State University at Baton Rouge	Rutgers University at New Brunswick	University of California at Berkeley	University of Georgia	University of Maryland Baltimore County	University of South Carolina	University of Wisconsin–Madison
Florida State University	Michigan State University	San Diego State University	University of California Los Angeles	University of Hawaii–Manoa	University of Maryland College Park	University of South Florida	University of Wisconsin–Milwaukee
George Mason University	Montana State University	Southern Illinois University at Carbondale	University of California Santa Barbara	University of Idaho	University of Minnesota–Twin Cities	University of Southern California	University of Wyoming
Indiana University at Bloomington	Ohio State University	State University of New York at Buffalo	University of Cincinnati	University of Illinois at Urbana–Champaign	University of Nebraska at Lincoln	University of Tennessee	

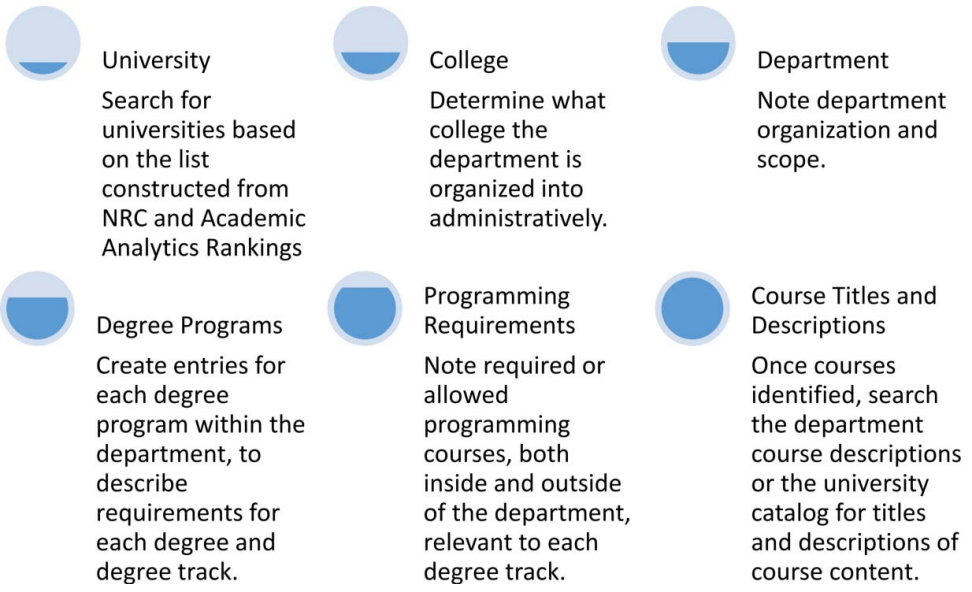

Figure 1 *A logic model indicating the progression of data collection for this course description. Note: NRC = National Research Council. (Color figure available online.)*

We executed the following steps to extract course data. Our work progression involved identifying the college in which the selected departments were located, what degree programs they offered, what courses were required for each degree, and obtaining and analyzing the course descriptions from the course Web site or university catalog. We provide a logic model of this process in Figure 1.

To begin, we visited each department's Web site and noted the type of college the department was housed in (College of Geosciences, College of Letters, etc.) We then listed each degree offered within the department. To determine what courses existed in this sample, we inspected each department's Web site for degree requirements and course listings for all undergraduate degrees offered by the department, as well as specializations (listed as tracks or options, depending on university terminology) within these degrees. We did not consider minors or certificates for this review. Although many departments provided this information on their Web sites, some Web site structures required additional reference to course catalogs and broader university resources, like requirements listed by the registrar. For each degree identified, we searched for terms in course titles and descriptions that indicated some form of relevant computer science and programming instruction, including the words *programming*, *database*, *cyber*, *web*, *model*, *computing*, *analysis*, and *server*. We also searched for terms that indicated specific programming language instruction, like *Python*, *Java*, *JavaScript*, *SQL*, and *C#*, although the languages *FORTRAN* and *MATLAB* were discovered unexpectedly. We used these terms as indicators for courses focused on computer science and programming applications in GIS.

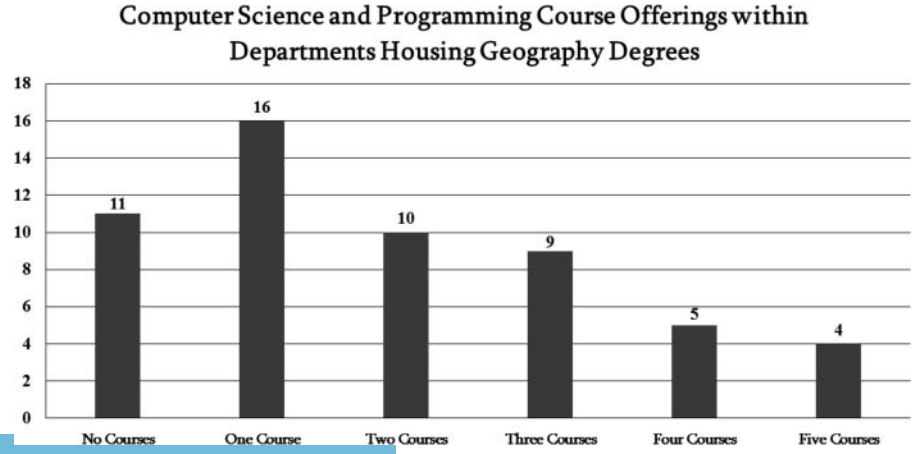

Figure 2 *Number of universities with number of computer science and programming courses offered within departments offering geography degrees.*

Table 2 *Types of computer science and programming courses identified within departments in the sample of 103 courses*

Course type	Count	Example titles
GIS programming	27	Introduction to Geo-Programming Programming Principles in GIS Geographic Information Systems Programming and Development
Introductory GIS	18	Geographic Information Systems Introduction to Geographic Information Systems and Geospatial Analysis Principles of Geographic Information Science
Advanced GIS	15	Advanced Geographic Information Systems Advanced Techniques in Geographic Information Systems GIScience II
Web/server GIS	14	Internet Mapping and Distributed GIServices Geography and the Internet Web Programming in GIS
Computation/modeling	14	Spatial Modeling and Geocomputation Integrating Time into GIS Introduction to Optimization Methods for Geographic Problems
Spatial databases	10	Spatial Data Design for GIS GIS Data Management Introduction to Geographic Databases
Visualization/cartography	5	Introduction to Computer Mapping Introduction to Cartographic Programming Analytical and Computer Cartography

Note: Many programming courses in this sample have "GIS programming" or similar titles. Some introductory and advanced levels of general GIS courses, including 18 courses introducing GIS, contain explicit descriptions of computer science and programming as part of the course. Specific applications of programming or computer science are also widely prevalent, as Web GIS courses, spatial database courses, and computation courses are evident in a broad variety of course types. GIS = geographic information systems.

After analyzing the course descriptions, we determined whether the computer science and programming courses included were required for degrees, elective options in degree plans, or not present in degree plans, namely, optional courses not required but offered by the department. Further, we noted any programming or computer science courses offered outside of the department listed as a requirement on each department's degree plans or degree tracks.

Results

Search Results: Universities, Degrees, and Courses

Of the fifty-five departments surveyed, forty-four offered at least one course with the department prefix in GIS programming. Of the forty-four universities with GIS programming courses, sixteen offered only one course within the department. Figure 2 shows a count of universities sorted by the number of programming courses offered.

Overall, we identified 103 geography programming courses offered among the fifty-five universities. Table 2 provides course titles and a count of courses. These courses fall into seven distinct categories. Most courses identified exist as specific and intensive GIS programming courses. Although programming components, topics, and instruction are present in many types of GIS and cartography courses, the courses we identified exist as explicit instruction in these topics. Some terms and components are more common throughout the data set than others, as shown in Table 3. Although the length and detail of course descriptions varies, the broad focus of these courses on combining the fundamental spatial components of GIS with programming concepts is clear across the sample. Table 3 shows a count of common words used in these course descriptions. These courses have obvious connections to geography and spatial analysis; hence, the prominence of the GIS terms (*geographic*, *information*, *science*) and *spatial* in the raw count. Other emphases in these courses are evident, as well: For example, these courses focus more on *application* (thirty-seven) than *technique* (twenty-two) and are seen at both introductory and advanced levels. After removing common words and terms like *GIS*, *programming*, *geographic*,

Table 3 *Count of terms with 20 or more occurrences in the set of 103 course descriptions*

179 GIS	32 advanced
107 data	29 computer
105 programming	28 topics
102 geographic	28 models
98 spatial	27 design
94 information	27 concepts
77 systems	24 Web
62 analysis	24 management
48 course	23 development
40 modeling	22 techniques
37 applications	21 software
36 database	20 science
34 introduction	20 basic

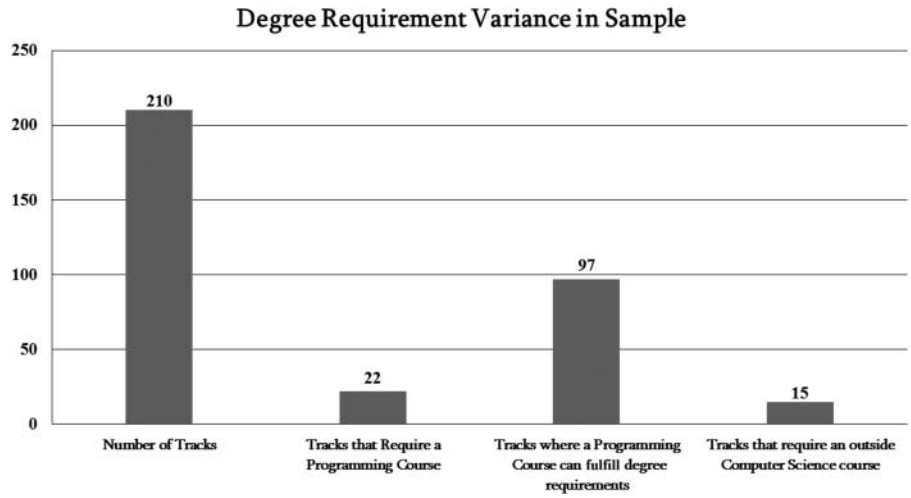

Figure 3 *Different types of programming course requirements in degree options in the sample.*

and *information*, the primary centering of these courses on spatial data is apparent.

Computer Science and Programming Courses by Degree Requirement

We identified 210 different degree options (noted on some university Web sites as tracks or specializations) that led to a degree (e.g., BS or BA). This count does not include certificates or minors. As shown in Figure 3, only twenty-two of these degree options required a course teaching GIS programming; an additional ninety-seven tracks allowed a GIS programming course to fulfill a degree requirement. Some of this count, though, is attributable to broad and flexible degree requirements; for example, "Take any 400-level course," which would allow a GIS programming course to count toward the degree. Of all 210 degree options, only 15 required computer science or programming courses offered outside of the geography department. Only one degree required both an in-department GIS programming course and a computer science course offered by a department of computer science.

Computer Science and Programming Course by Degree Program Type

Of the twenty-two degree options that required a computer science or programming course, five led to a BA degree, fifteen to a BS degree, and two to either a BS or a BA. Twelve of the tracks that require computer science and programming courses result in GIS degrees or geography degrees with an explicit GIS emphasis, five of the tracks confer an environmental emphasis, and three tracks are general geography degrees without any additional emphasis. The remaining two result in a remote sensing emphasis and a GeoDesign degree. Only two tracks require multiple

Table 4 *List of degrees and degree options that require a computer science or programming course from within the department*

University	Degree: Emphasis, option, or track
Arizona State University	BS in Geography: Geographic Information Science Certificate; BS in Geography: Urban Studies Concentration with Geographic Information Science Certificate
George Mason University	BA in Geography
Johns Hopkins University	BS in Environmental Engineering
Kansas State University	BA and BS in Geography
Southern Illinois University at Carbondale	BS in Geography and Environmental Resources: Environmental Sustainability, Geographic Information Science,* and Climate and Water Resources
Texas A&M University	BS in Geography: GIS
University of Arizona	BS in Geography: Geographic Information Science
University of Cincinnati	BA and BS in Geography: Environmental Emphasis; BS in Geography: GIS and Remote Sensing Emphases
University of Connecticut	BA in Geography: Geographic Information Systems; BS in Geography
University of Kansas	BS in Geography: Geographic Information and Analysis
University of Maryland College Park	BA in GIS*
University of Southern California	BS in GeoDesign
University of Wisconsin–Madison	BA or BS in Cartography and GIS
University of Wisconsin–Milwaukee	BA or BS in Geography: Geographic Information

Note: Degrees or options that require multiple courses indicated by an asterisk (*).

Table 5 *Outside computer science and programming courses required by degree and university*

University	College	Department	Degree	Emphasis, option, or track	Computer programming course requirement
George Mason University	Science	Geography and Geo-Information Science	BS in Geography	—	IT 103: Introduction to Computing Credits: 3
George Mason University	Science	Geography and Geo-Information Science	BS in Global and Environmental Change	—	IT 103: Introduction to Computing Credits: 3
State University of New York at Buffalo	Arts & Sciences	Geography	BA in Geography	Geographic Information Systems	CSE 113: Intro to Computer Science I also required
State University of New York at Buffalo	Arts & Sciences	Geography	BA in International Trade	—	One computer science course also required
University of California Santa Barbara	Letters & Science	Geography	BA in Geography	Geographic Information Science Emphasis	One computer science course also required
University of Georgia	Arts & Sciences	Geography	BS in Geography	—	CSCI 1100 & 1100L: Introduction to Personal Computing, or CSCI 1210: Introduction to Computational Science or CSCI 1301 & 1301L: Introduction to Computing and Programming
University of Illinois at Urbana–Champaign	Liberal Arts & Sciences	Geography and Geographic Information Science	BA in Letters, Arts, and Sciences	Geographic Information Science	One computer science course outside of department
University of Iowa	Liberal Arts & Sciences	Geographical and Sustainability Sciences	BA in Geography	Geographic Information Science	All GIS track students take one of these: CS:1110 (22C:005) Introduction to Computer Science 3 s.h. CS:1210 (22C:016) Computer Science I: Fundamentals 4 s.h. CS:2110 (22C:080) Programming for Informatics 4 s.h.
University of Iowa	Liberal Arts & Sciences	Geographical and Sustainability Sciences	BS in Geography	Geographic Information Science	All GIS track students take one of these: CS:1110 (22C:005) Introduction to Computer Science 3 s.h. CS:1210 (22C:016) Computer Science I: Fundamentals 4 s.h. CS:2110 (22C:080) Programming for Informatics 4 s.h.
University of Kansas	Liberal Arts & Sciences	Geography	BS in Atmospheric Science	General Meteorology	Computing and Programming. Satisfied by EECS 138 (Fortran preferred; C++ and Matlab accepted)
University of Kansas	Liberal Arts & Sciences	Geography	BS in Atmospheric Science	Air Pollution Meteorology	Computing and Programming. Satisfied by EECS 138 (Fortran preferred; C++ and Matlab accepted)

(*Continued on next page*)

Table 5 *Outside computer science and programming courses required by degree and university* (Continued)

University	College	Department	Degree	Emphasis, option, or track	Computer programming course requirement
University of Kansas	Liberal Arts & Sciences	Geography	BS in Atmospheric Science	Hydro-meteorology	Computing and Programming. Satisfied by EECS 138 (Fortran preferred; C++ and Matlab accepted)
University of Kansas	Liberal Arts & Sciences	Geography	BS in Atmospheric Science	News Media Forecasting	Computing and Programming. Satisfied by EECS 138 (Fortran preferred; C++ and Matlab accepted)
University of Oklahoma	Atmospheric & Geographic Sciences	Geography and Environmental Sustainability	BS in Geography	—	CS 1313: Programming for nonmajors, or METR 1313: Programming for Meteorology
University of Oklahoma	Atmospheric & Geographic Sciences	Geography and Environmental Sustainability	BS in GIS	—	Computer Related (6 hours, two courses) CS 1323: Intro. to Computer Prog. MIS 2113: Computer-Based Info. Sys. MIS 3013: Intro. to Programming and CS 1313: Programming for nonmajors, or METR 1313: Programming for Meteorology

Note: Course titles retain their originating university's numbering style. Comments in the course requirement column originate from department notes about the requirement or the university catalog. Course numbers and titles retain their originating university's numbering and titling style, as well as any administrative comments.

computer science and programming courses as degree requirements. Table 4 outlines the degree options requiring these courses by university and emphasis.

Requirements by Course Level

The courses required for geography and GIS degrees and degree options are primarily upper division undergraduate or undergraduate and graduate cross-listed courses. Only one program offered an introductory course with programming components, an introductory maps and mapping course that addressed Web services and geodatabases. The fifteen degrees we identified that required a computer science or programming course specified only introductory-level computer science or computer programming courses. Table 5 summarizes the computer science courses required for degrees by university, showing a general preference for courses that provide a broad introduction to computer science and programming.

Search Term Results, False Positives and Negatives

The terms we selected to search for courses did return a number of false positives, which required us to remove ten records from our analysis. For example, in the context of computer science the terms *model* and *modeling* can refer to computer models or models of workflow. These terms in geography, however, can refer to hydrological or environmental modeling. Although a course in these types of modeling might incorporate GIS programming and application of computer science, without confirmation through deeper syllabus analysis, they were not included in the analysis unless the course description confirmed an explicit computer science or programming component.

False negatives in our analysis resulted from vague course descriptions, no description, inaccurate description, or outdated descriptions. Whereas the nature of instruction in GIS courses might change in response to technological innovation, course descriptions might remain static and not reflect what knowledge, skills, and practices are being taught. This can skew the results of our analysis. A lack of updated Web-available information could be a reason for the small number of introductory courses located in our sample. For example, Texas A&M University, the home institution of the authors, does not list three new programming courses on its Web site due to university constraints on Web site updating.

Discussion

Review of Guiding Questions

We posed five distinct research questions that guided this research. We recap and discuss those questions next.

Are students acquiring computer science and programming knowledge and skills within their primary degree programs in geography or outside of them? Generally, degrees that require a computer science or programming course are more likely to offer that course within the degree-granting department (twenty-two instances) than outside of it (fifteen instances), with only one degree in this sample requiring both. This instance, however, the BA in Geography from George Mason University, does not proscribe which computer science course to take; instead, it only notes that such a course is required. Based on our research we cannot confirm whether the outside requirements are due to specific crafting of the geography degree curriculum or tied to broader university core requirements. We can speculate, though, that this almost binary approach might indicate that the strategy of adding programming courses to the degree requirements is more a function of department and university organization, culture, and process rather than explicit curriculum and course review. Nevertheless, as programming language skills like Python are rapidly becoming essential requirements for GIS careers, the lack of required course work in this area is a concern.

Table 6 *Breakdown, by college, of degrees, options, or tracks that require computer science and programming courses inside or outside of the degree-offering department*

College name	Instances where programming is required within department	Instances where programming is required outside of department
Arts & Sciences	6	3
Atmospheric & Geographic Sciences	0	2
Behavioral and Social Sciences	1	0
Engineering	1	0
Geosciences	1	0
Letters & Science	2	1
Letters, Arts, & Sciences	1	0
Liberal Arts	3	0
Liberal Arts & Sciences	5	7
Science	1	2
Social & Behavioral Sciences	1	0

What factors influence the number of computer science or programming courses required for geography and GIS degrees? There are no clearly evident college or program-level influences on programming course requirements. Table 6 lists the colleges where programming-requiring departments are housed. The amalgamation of these colleges (e.g., Letters, Arts, and Sciences) precludes much depth of analysis. Department focuses and university requirements, like faculty research areas and liberal arts or common cores, are likely bigger influences on the presence of outside computer science and programming courses in the geography degree. That degree requirements in this rapidly changing field could be governed by rarely addressed and seldom edited administrative oversight indicates a more proactive review and regular revision of degree requirements could benefit students in these programs.

Do BS degrees require more computer science and programming instruction than BA degrees? Given the wide variety of degree types, degree options, emphases, and the overall construction of degrees, it is not unexpected that large varieties of programming requirements exist. Of particular interest is the difference between a BS degree and a BA degree in geography. Many universities offer both (twenty-nine of the fifty-five universities in our sample), sometimes with identical tracks for both options. More often, however, different degree options rest inside the disparate degrees: Human Geography as a BA degree and Physical Geography as a BS, for example. GIS tracks are split nearly evenly, with twenty GIS tracks as parts of BS degrees and sixteen GIS tracks as parts of BA degrees.

Often, the BS degrees we investigated required or recommended biology, advanced mathematics, or computer science in the broad core of the degree plan. These are courses taken by all BS majors at a university, regardless of specific degree sought. For BA degrees, requirements included competency in a foreign language or world culture courses. For the GIS student, then, exposure to computer science and programming might be more likely within a BS degree, no matter the major or track requirements within the department. The situation and tradition of the department, however, is likely a greater influence on whether the geography degree in question is a BA or a BS, regardless of the content of that degree.

Do GIS degrees or GIS-specific degree tracks or options require more computer science and programming courses than non-GIS degrees or tracks in the same department? Overall, thirteen of the twenty-two degree program options we identified that require a computer science or programming course offered within the department are GIS specific, in either degree type or emphasis. Six of the fifteen tracks requiring an outside computer science or programming course result in a GIS-specific degree or degree emphasis. Generally, specialized degrees or degree tracks with an emphasis in GIS are more likely to require a programming course, whereas other emphases, especially in human geography, are more likely to accept such a course as an option in the degree plan. Although many degree plans offer "any" course of a certain level to complete a student's degree, without knowing what courses students are taking to fulfill that requirement, the degree of penetration of programming courses remains unclear.

Where are computer science and programming course work typically positioned in the curriculum? Our findings indicate that computer science and programming courses are taught either at the introductory level through an outside department or as a junior- or senior-level course within the department. The sequencing of these courses is not clear, however. Do students take the introductory computer science course at the beginning of their degree programs, or do they wait until they are deeper into their major requirements? When do students enroll in a geography degree program, and how does that influence their course selection? There is a clear need for further research in this area, especially considering the inputs of faculty and academic advisors on planning the scope and sequence of the GIS or geography degree. Just as spatial thinking requires specific support structures and instructional methods for student success, topics in computer science, programming, and computational thinking require a different set of these structures and methods. There is no clear trend to the introduction of computer science and programming knowledge in GIS and geography.

Additional Discussion

Web-accessible course descriptions provide a rough, coarsely scaled view of the state of programming instruction in geography and GIS programs. Broad university requirements and disjointed support and technical capability can also result in less centralized instruction of GIS, though. A geography department might not be the only "home" for GIS in a university, so specialized courses (in programming, computer architecture, or specific computer science techniques) might be offered outside of a home geography department. We cannot capture the important role of faculty and academic advisors in constructing individual student degree plans through course review. Further work involving how these stakeholders shape degree plans is necessary.

Other issues complicate this analysis. Department Web sites do not reflect course offerings. For students interested in learning more about department course offerings, or seeing updated course descriptions, this lack of updates reduces the amount of information available to interested students. A similar issue arises

with special topics courses. Although most departments have a course described as "special topics," the course topics described (or rotated) are not clear. We discovered some instances where special course topics were listed as a degree requirement but no course description was available.

Conclusions and Future Directions

We conducted a broad review of course descriptions in NRC- and Academic Analytics-ranked geography departments in the United States. In reviewing these descriptions, we discovered that most departments (forty-four of fifty-five) include some type of GIS programming course in their in-department course offerings. Of the 210 separate degree tracks we identified, however, only twenty-two (~10 percent) required one of these courses for completion of the degree. This lack of programming course work could stem from many factors: a lack of department awareness of the necessity of these skills in the workforce; no source of motivated and capable instructors to teach in this fused domain; inability to manage the material requirements of these courses, in cost, computer lab space, or otherwise; and other factors, ranging from whether GIS belongs to geography to the culture and capabilities of individual departments and instructors.

With the increasing need for graduates trained with a broad set of geospatial skills and increasing application of geographic data, skills in computer science and programming will continue to require additional emphasis in course work and degree programs. Determining how to best provide these skills requires attention to the course offerings and content within GIS and geography degrees. Two prominent GIS content resources exist for instructors and departments to determine where their courses and programs fit within established content realms: the Geospatial Technology Competency Model (GTCM) and the GIS&T Body of Knowledge (BoK). These resources provide a metric to compare and contrast course and program offerings. The abundant relevant applications of computer science and programming in geography are apparent in these consolidations of knowledge, skills, and practices in GIS. Although the high percentage (80 percent) of departments with these courses is encouraging, the low percentage (10 percent) requiring computer science or programming is a curious disconnect worth further investigation.

As outlined in Table 2, courses in GIS programming take many forms and consider a wide range of topics relating computer science and programming to geography and GIS. Different applications of GIS use different programming languages and approaches, so no single language dominates all GIS programming utilizations. Python, JavaScript, and Structured Query Language (SQL), however, all serve as common and useful programming topics that could structure course work. Python is a high-level, multipurpose coding language used commonly to extend GIS capabilities (Zandbergen 2013). A customized Python package, ArcPy, is used extensively in GIS scripting (Toms 2015). As GIS moves to Web, cloud, and server-enabled platforms, JavaScript is growing in prominence. It is a dynamic language for web development used in concert with Hypertext Markup Language (HTML) and Cascading Style Sheets (CSS), all of which are essential to maintaining Eeb pages with GIS components (Wang and Dong 2014). SQL serves the special purpose of defining, managing, and manipulating databases, the structural foundation of storing spatial data (Ďuračiová 2013). For departments or instructors looking to engage with GIS programming topics or components in course work or otherwise, these topics, in scripting, Web enabling, and database management, are useful GIS programming starting points.

This review provides a first step into understanding the state of the art in general instruction in GIS. Course descriptions provide a window into understanding course offerings and degree requirements at a diverse set of highly ranked geography departments. This course-level scale is relevant in identifying broad trends in course composition and degree requirements and can serve as one piece of a many-tiered investigation into the content and trends in the integration of computer science and programming. Courses in computer science and programming are clearly present in many geography departments but are not commonly required for these degrees. To investigate this disparity, future work should focus on other interfaces among computer science, programming, and GIS, like how students respond to computer science and programming courses, reviewing syllabi (including learning outcomes) for content in these courses, and seeking descriptions of skills employers value in students emerging from these degree programs. Further, the barriers to implementing such courses in a department or degree plan should be elaborated on. Are departments reacting to changes in the skill sets needed by their graduates, responding to their students' requests for course work, proactively designing courses and programs based on advances in research, or being influenced by other factors? Understanding the decision-making processes and barriers in creating and implementing these courses will provide needed context as the need for these courses continues to expand.

More research is necessary to further understand and assess the teaching and learning of programming and computer science in geography. We propose the following foci for work going forward. One track of research should be conducted within classrooms teaching computer science, programming, and GIS. An evidence-based understanding is vital to determining what advantages or disadvantages might exist for students who take a computer science and programming course outside of geography compared to those who take it within their home department. Considering the differences in instruction, would geography students be better prepared with the general concepts and experience in an introductory computer science

and programming course or with the application-focused instruction in a GIS programming course? Is there a set of key skills, actions, or activities of the GIS programmer? Any research and evidence-based documentation of these components would be incredibly valuable to GIS instruction. Additional classroom-based research concerning student learning through different instructional methods would bring important evidence into addressing the best practices in integrating computer science, programming, and GIS instruction.

Another beneficial track of research would consider the content from course syllabi to determine what ideas, concepts, methods, learning outcomes, and so forth are present in state-of-the-art classes. Because there is no widely agreed-on set of skills or practices to be taught in GIS programming or computer science courses related to GIS, an understanding of existing content would provide guidance for building standards in practice or content to inform instruction or realign course and program content. We are currently undertaking such a review, but repeated studies and varying viewpoints would add valuable viewpoint diversity to this effort. Further research tracks should consider computer science and programming knowledge, skills, and practices in GIS and geography careers and where academic preparation matches or falls short of professional expectations. The role of academic advisors or faculty in guiding students through their degree plans, selecting courses, and building their academic skills would be a valuable area of focus. There are numerous areas of GIS and geography education research that would be broadly beneficial within this realm.

GIS is the fundamental tool for spatial analysis in geography, yet the core components of how a GIS functions, the computer science and programming concepts, remain inconsistently taught within geography and GIS degree–granting departments. Future work should examine the implications of this disconnection and undertake deeper investigations into the structure of these courses. This work must operate on numerous scales, from studying learners within computer science, programming, geography, and GIS classrooms, to analyzing course and degree structures, to academic guidance, professional expectations, and more. Collaborations between geography and GIS education researchers and those investigating computer science education should build cross-disciplinary, theory-rich observations beneficial to both fields. This overview takes an important first, but by no means final, step into understanding how geography and GIS courses structure this vital computer science and programming content.■

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FORREST J. BOWLICK is a recent doctoral graduate of the Geography Department at Texas A&M University, College Station, TX 77843. E-mail: bowlick@tamu.edu. He will begin as a Lecturer in Geospatial Information Science and Technology at the University of Massachusetts, Amherst in September 2016. His research interests include GIS and geography education, especially in the context of CyberGIS.

DANIEL W. GOLDBERG is an Assistant Professor of Geography and Computer Science and Engineering at Texas A&M University, College Station, TX 77843. E-mail: daniel.goldberg@tamu.edu. His research interests include geocoding, geocomputation, CyberGIS, and HealthGIS.

SARAH WITHAM BEDNARZ is a Professor of Geography at Texas A&M University, College Station, TX 77843. E-mail: s-bednarz@tamu.edu. Her research interests include geography education and spatial thinking.