Understanding Geocomputation Education: A Survey and Syllabi Informed Review

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Abstract

Geocomputation is an interdisciplinary area of practice, intersecting at least three core areas: geographic and spatial analysis, computational approaches, and high-performance computing power. Along with the affordances of geographic information science (GIS), geography, spatial data, programming, and computation, geocomputation serves as a merger in different ways and forms to produce investigations into spatial science and geography with computational assistance. We explore the nature of teaching and learning in this variant and rapidly changing geocomputation education space through survey and syllabi review of geocomputation courses. In analyzing and summarizing responses and syllabus content, we find an area of educational practice based on a rough agglomeration of GIS, computer science, and programming, but with divergent approaches, resources, and learning methods within course structures. Given the general review here of the form of function of geocomputation courses, we present a community focused resource to continue this transformative work of understanding and linking how this area of practice functions.

Key Words: Geocomputation, GIS Education, Geography Education

Introduction

Geocomputation is not just geographic information science (GISci), not just programming or scripting, not just geography with computers, not just big data analytics, but many and all these ideas (Harris et al. 2017). Geocomputation rests at the intersection of three core components: geographic and spatial analysis, computational approaches, and the underlying computer power that enables doing geography with computers (Longley et al. 1998). The complex nature of these intersecting domains makes teaching and learning geocomputation difficult, as geocomputation as a concept is composed of many interlinked concepts woven together. However, as high-performance computing has become and continues to become more accessible, and as geospatial concepts have been integrated with artificial intelligence and other advanced computational approaches, geocomputation work can be applied in broader contexts (Kwan 2004). The challenges of managing these different knowledge areas in maintaining research programmes or solving geocomputational problems are difficult enough - translating these areas of knowledge into instructional contexts reveals an added layer of interdisciplinary complexity (Dean 2019). Exploring and understanding these teaching and learning challenges is vital in expanding the accessibility and utility of geocomputation and related computational geographies but remains an area that requires more research and more data (Shook et al. 2019).

We explore teaching and learning in geocomputation through analysis of geocomputation course syllabi. Using syllabi collected in a broadscale survey effort and those discovered through internet searches, we analyze, consolidate, and review the content and composition of these syllabi to understand the construction of geocomputation courses. In understanding syllabi construction, we seek to understand the topics, areas of practice, resources used, course formats, and overall nature of what it means to teach and learn geocomputation. Using core components of the course syllabus, like learning objectives, grading schema, and course topics, we outline the nature of how geocomputation courses function in our survey. We present more details on the conception, support, and deployment of these courses in diverse educational contexts through instructor surveys.

We present our findings as follows. First, we outline a brief background on geocomputation as a concept and link our exploration of geocomputation education to relevant geography and GIS education literature. We then describe the methodologies we deploy for gathering and analyzing syllabi and syllabi content. We present these results in tables, figures, and quantitative and qualitative analyses. Then, we contextualize our results in the discussion using additional evidence from syllabi, connect our work with broader efforts in coordinated geography education research, present facilitation platforms for future work, and provide a holistic conclusion that summarizes our work and recommends future research on the topic.

Background

Geocomputation

While geocomputation is a recent term that seeks to capture the conceptualization of human/spatial/computational interactions, the questions posed concerning these interactions are well established in geography. Geocomputation builds from ideas in automated geography (Dobson 1983) back to the quantitative revolutions, which integrated computational methods and analysis into geographic works in various waves and stages of geographic scholarship (Arribas-Bel and Reads 2018). The emergence of the term 'GeoComputation' from the 1st International Conference on Geocomputation, held at the University of Leeds in the UK, from September 17 - 19, 1996, reflects the energy to bring together researchers who seek to 'enrich geography with a toolbox of methods to model and analyse a range of highly complex, often non-deterministic problems' (Gahegan 2000). While much work since the quantitative revolution has used computational methods, applied statistical or mathematical approaches to spatial problems, and generally progressed geographic understanding, geocomputation sought to work on problems which faced 'the need to use more fundamental computing approaches (such as writing code) to solve certain kinds of geographical problems' (Brunsdon and Singleton 2015, pg xiii). Geocomputation thus enables means of investigation and exploration that would otherwise be impossible without the convergence of concepts and domains within the rich interfolds of the topic. Geography, computer science, programming and scripting, machine learning, AI, statistics, and many other domains contribute to the geocomputation concept - and can be deployed with or without GIS in many different contexts (Lovelace et al. 2019). Understanding how those interrelated topics are taught, however, requires additional work.

GIS and Geography Education

GIS and geography education research have long associations due to their shared vocabulary in spatial and visual teaching and learning and joined pedagogies and practices as manners of research (Baker and Bednarz 2003). GIS education research explores connections between spatial thinking and the affordances of GIS (Lee and Bednarz 2009), how GIS is taught and learned in various contexts (Schulze 2021), and the many different situations of GIS education in terms of domain and teaching context, among other topics (Hong 2017). Given the overlapping questions in geography and GIS education of pedagogy, curriculum, practice, and context, geography and GIS education practitioners sharing questions and approaches for investigating educational research topics is not a surprise (Bednarz 2004). For example, critical pedagogical approaches and ways of thinking present in geography programs, courses, and degrees also move into the GIS teaching and learning space, creating a shared understanding of methods and approaches to working with, and thinking about, spatial problems (Bearman et al. 2016).

However, less work exists connecting computer science education with questions and components of GIS and geography education. Extensive research on the difficulties of novice programmers (Lahtinen et al. 2005) and the operational challenges of learning how to program (Garner et al. 2005) connects foundationally with similar challenges in GIS education. This work serves to bring context to the function of education in these areas, seeking to understand how geocomputational courses are constructed, the topics present within those courses, the resources that those courses use, and how spatial and geocomputational thinking is addressed in these courses. As geocomputation serves as a combination of these components - geography, GIS, and computation - it functions well as an area of investigation to connect practices and outcomes.

Methodology

Data collected for this work came from two primary sources. First, we distributed a survey approved by the University of Massachusetts Institutional Review Board, asking instructors of courses in geocomputation (broadly and individually) to respond. We presented this survey, distributed to GIS listservs and AAG specialty groups, to collect and analyze syllabi for courses about geocomputation. The survey framed geocomputation simply as an advanced area in geographic information science (GIS) that integrates topics in computer science, programming, and computational thinking. No other restrictions, guidelines, or specifics were given. Therefore, all responses received in the survey are self-identified (by the respondents) geocomputation courses. The survey generated 20 responses and six syllabi submissions. Survey responses and syllabus responses are summarized in separate results sections below.

We collected another 27 syllabi during searches of publicly accessible academic websites. The collected syllabi form a valuable cross-section of different educational contexts and instructional modes to inform what kinds of courses exist in the geocomputational realm. Together with the survey information, we present a snapshot of the nature of geocomputation topics, themes, and content within this broad sample.

Survey Analysis

To understand the survey results, we conducted generalized reporting of survey outcomes, highlighting key trends from the survey results. We present this information in tabular form to summarize overall findings while contextualizing responses within broader GIS and geocomputation education trends. By weaving survey information into a broader review narrative, we aim to understand the variety in geocomputation courses while also identifying trends or patterns.

Syllabi Analysis

To understand what people are expected to learn and do by the conclusion of a geocomputation course, we also conducted a content analysis on the course objectives and course outcomes. Some content analysis involved summarizing components of the syllabi in our sample, while other work required coding and content analysis. For content analysis concerning learning outcomes and objectives, we imported learning outcomes and course objectives into NVivo, then coded them using Bloom's taxonomy codes (Bowlick et al. 2020). The analysis identified which general and specific codes (Table 1) were used the most often. The data was then exported to a spreadsheet and visualized with a treemap. We compared this automated classification with individual author analysis of Bloom's terminology, creating separate data views, resulting in a general model for understanding. We also conducted word counts and keyword densities on portions of the syllabi content.

Table 1. Bloom's taxonomy words used to code and analyze learning outcomes and course objectives from syllabi collected for this sample.

Bloom's Taxonomy Category	**Keywords**
Knowledge	copy, discover, duplicate, enumerate, label, list, listen, match, memorize, omit, quote, recall, recite, record, repeat, retell, tabulate, tell, examine, name, observe, select, state, identify, reproduce, locate, read, define, recognize, describe, visualize
Understand	cite, compare, contrast, convert, differentiate, discover, distinguish, estimate, express, illustrate, infer, judge, paraphrase, restate, rewrite, show, summarize, trace, ask, classify, group,

	indicate, observe, order, predict, represent, select, translate, demonstrate, identify, explain, extend, interpret, report, review, associate, generalize, discuss, describe, relate, research
Apply	act, calculate, choose, collect, discover, dramatize, illustrate, list, paint, show, sketch, transfer, construct, modify, prepare, change, demonstrate, explain, interpret, manipulate, operate, teach, write, relate, apply, complete, solve, experiment, simulate, practice, compute, use
Analyze	calculate, categorize, compare, conclude, connect, contrast, correlate, deduce, devise, diagram, differentiate, dissect, distinguish, divide, estimate, illustrate, infer, prioritize, separate, classify, order, outline, select, survey, question, explain, organize, plan, test, focus, analyze, evaluate, experiment, act, calculate, choose, collect, discover, dramatize, illustrate, use, list, paint, show, sketch, transfer, construct, modify, change, prepare, demonstrate, explain, interpret, manipulate, operate, teach, write
Evaluate	argue, assess, choose, compare, conclude, convince, critique, debate, decide, defend, discriminate, distinguish, editorialize, estimate, grade, judge, justify, persuade, rank, rate, recommend, reframe, score, summarize, weigh, appraise, order, predict, select, support, consider, test
Create	anticipate, arrange, assemble, choose, compile, facilitate, imagine, intervene, invent, originate, rearrange, rewrite, substitute, validate, adapt, compose, construct, formulate, hypothesize, modify, prepare, produce, propose, collaborate, support, combine, organize, plan, write, create, make, test, generalize, integrate, solve, manage, simulate, design, develop

Generally, our methodology is exploratory, seeking to understand the content, patterns, and trends within the data collected while linking findings from the survey sample to components from the syllabus sample. This research was approved as exempt by the University of Massachusetts Institutional Review Board, IRB: #2120 Understanding Geocomputation Education. We deployed the survey using Google Forms. We provide the survey questionnaire as appendix 1 for review, replication, revision, and redeployment by future researchers.

Results

We divide the reporting of results into two parts, with survey results reported first and then syllabi analysis results. We provide contextualization of the results and the tables and figures presented here.

Survey Results

We received 20 survey responses through our distribution to international listservs and interest groups in GIS, geography, and geocomputation education. The 20 responses outlined different types, formats, structures, and content of geocomputation courses of the respondents.

Respondents outlined diverse titles of their courses shown in Table 2. These titles represent different presentations of the course content, from direct connections with geocomputation ('Geocomputation' or 'Geospatial Computation' as course title, four instances each), to more general representations of the affordances of geocomputation ('Data Management' or 'Data Fundamentals for GIS' as course title, four instances total). Though most operate in the same area of domain presentation (Geospatial, Computation, Programming, etc.), other more specific course titles may hide the geocomputation course content from outside observers ('Complexity, Planning, and Urbanism'), for example.

Table 2. Summarized course titles from survey responses.

What is the title of your geocomputation course?	
Course Title Primitives	**Count of Titles Submitted**
Geocomputation	4
Geospatial Computation	4
Data Management / Fundamentals of Data for GIS	4
GIS Programming	3
Geospatial Modeling	3
Maps and Spatial Reasoning	1
Complexity, Planning and Urbanism	1

Note: Course title primitives indicate the core terms used in the course title, while the count of titles indicates how many courses with said term were submitted.

Generally, respondents were in Geography departments or units (Table 3). However, the Spatial Sciences Institute at the University of Southern California was well represented in the sample (four submissions). An additional five departments had representation from single department structures and are excluded here for privacy reasons. Those departments ranged from traditional natural sciences to social science disciplines.

Table 3. Departments represented in the sample.

What department or unit are you in?	
Department/Unit	**Count**
Geography	9
Spatial Sciences Institute	4
Marine, Earth and Atmospheric Sciences	2

Note: Most respondents work in Geography departments, though another five departments from single assorted disciplines are not represented here.

Geography departments are a clear plurality of the sample for both department and academic backgrounds (Table 4). However, more instructors of geocomputation courses earned a Ph.D. in another discipline than in Geography. Terminal Master's degree holders also teach courses in Geocomputation in this sample. The diversity of background in instructor preparation reveals the interdisciplinary nature of geocomputation clearly and directly.

Table 4. Reported education of respondents in the sample.

What is your background and education?	
Degree	**Count**
Geography PhD	8
PhD (other)	7
Masters	3
Computer Science PhD	2

Note: Geography PhDs are the most represented, but all other PhDs together form a higher percentage of the respondents.

Additional divisions in the nature of the geocomputation courses of instructors surveyed are apparent in the structure of interest and student composition (Table 5). Respondents relayed a mix of characteristics of the courses, though most geocomputation courses described here have moderate to strong demand, with strong student performance (primarily As and Bs), and primarily graduate or mixed graduate and undergraduate student populations. Potential crosstabs lack explanatory value and are excluded here. However, graduate students' general sense of demand for the course emerges from these responses.

Table 5. Course demand, grades, and student composition reported by survey respondents.

What is the demand for this course at your institution?	**Count**
Little to no demand - This course struggles to meet minimum enrollment requirements	1
Moderate demand - This course has strong, but not full, enrollment	12
Strong demand - This course usually has a wait list	7
How would you describe the grade distribution in this course?	**Count**
Primarily As and Bs	17
Primarily Bs and Cs (Normal Distribution)	4
What level is this course taught at?	**Count**
Primarily/Only Graduate	12
Mixed Undergraduate/Graduate	8
Primarily/Only Undergraduate	0

Note: While all courses are unique constructs, some general trends concerning graduate student status (graduate heavy), course outcomes (As and Bs), and demand (moderate to strong) are apparent.

Table 6. Course structures and formats reported in this sample.

Is this course required for any degrees or programs offered at your institution?	**Count**
Yes	11
No	9
How would you describe the structure of this course?	**Count**
Mix of lectures and labs	10
Lecture/Seminar	3
Entirely hands-on	1
N/A	6
How many credits is this course?	**Count**
3	10
4	7

Note: A mix of functions for degrees, organization of course content, and course loads are represented.

Respondents outlined more details on the structure and function of the courses in Table 6. Courses are described as a mix of lectures and labs, while three and four-credit course structures are apparent in the sample. Respondents reported that courses of this type are required for degrees and programs offered at their institutions in a slim majority, a major shift upwards in requirement from previous research on this topic (Bowlick et al. 2017).

The final collection of responses in the survey relating to the courses consider the temporality, support, and motivations of course instructors (Table 7). Most instructors of geocomputation courses have geocomputation as their primary research area. At the same time, most also share the instructional load of the course with other instructors at their institution. Offering the opportunity to students to learn about geocomputation as an in-demand GIS skill is a motivating factor for many offerings. Notably, geocomputation courses are offered at roughly yearly intervals, with more courses in the sample offered at longer (two or three-year intervals) intervals than shorter ones. Further, half of the respondents report no TA support in their geocomputation course, while the other half range from below five to over 15 hours of support in their instruction.

Table 8 presents basic demographic reports from the respondents for context. This sample of respondents was primarily white, male, and over 40, with most having four or more years of experience teaching. Taken as a whole, the survey reveals a range of course types and perspectives. Moreover, while some generalizations about course format, topic, and demand are possible, those generalizations will be complicated upon review of the collected syllabi in the next section.

Table 7. Timing, support, credits, and requirements of geocomputation courses in this sample.

Is this course required for any degrees or programs offered at your institution?	**Count**
Yes	11
No	9
How would you describe the structure of this course?	**Count**
Mix of lectures and labs	10
Lecture/Seminar	3
Entirely hands-on	1
N/A	6
How many credits is this course?	**Count**
3	10
4	7

Table 7. Continued

Is there TA support for this course? If yes, how many hours per week of TA support comes with the course?	**Count**
0	10
1 - 5	3
6 - 10	4
15 +	2
Yes, hours N/A	1

Note: An overall sense of some general course structure emerges, with many variants, especially in TA support.

Table 8. Demographics of survey respondents in this sample.

What is your gender?	**Count**
Male	13
Female	6
Prefer not to Respond	1
What is your race?	**Count**
White	12
Asian	4
Additional Single Responses	4
What is your age?	**Count**
30 or younger	1
31 - 40	4
41 - 50	5
51 - 60	5
61 +	3
N/A	2
How long have you been teaching this course? (YRS)	**Count**
1 - 3	5
4 - 6	7
7 - 10	4
11 - 19	2
20 +	2

Note: Respondents self-reported demographic information here without prompts or preselected options. Responses were collected into groups for presentation and to preserve anonymity.

Syllabi Analysis Results

Including the six syllabi received through the survey submissions, we discovered another 27 syllabi through public posts on academic websites. Together, these 33 syllabi reveal a deeper detail of the course content and instructional nature of geocomputation courses. Though syllabi are also imperfect representations of how courses function and are delivered, the different scale of analysis than the survey responses allows for alternative comparisons and outlines.

We discovered geocomputation syllabi from 23 distinct universities in the United States, the United Kingdom, Ireland, and Australia. Our search was limited to English language syllabi, so the dominant western sample is unsurprising. We recommend future geocomputation research at broader international scales. In our case, however, we outline some trends and patterns and wildly different approaches in the tables below.

First, the nature of the course structure bears reinvestigation. Roughly half of the courses in the sample require a prerequisite, though, as survey results revealed, most do not report TA support (Table 9). We took this information directly from the wording of the syllabi. As many syllabi best practices indicate (Gannon 2018, for example), this information should be included in syllabi, though we note in TA support that most do not mention the topic at all.

Table 9. Course prerequisites and TA support from syllabi in the sample.

Prerequisite	**Count**
Yes	17
None listed	16
TA Support	**Count**
Yes	6
No	12
N/A	15

Note: TA support distribution roughly matches survey results, and prerequisite division forms a notable parallel to degree requirement division from the survey

Syllabi allows a different view into how a course functions and the overall learning structure. Using syllabi information, we collated the software and programming languages used in these courses. Table 10 shows the 18 distinct software platforms and programming languages used by multiple courses in this sample. Appendix 2 shows the additional 28 software platforms and programming languages used in only one course in the sample. This variation shows a diverse, if somewhat overwhelming, nature of how geocomputation education functions technically. Another seven syllabi listed no languages or software platforms specifically. This lack of distinction might function as a hedge against software variability in this topic.

Table 10. Software and Programming Languages from collected syllabi.

Software and Programming Languages	Count
Python	23
ArcGIS	19
R Statistical Software	6
ArcGIS Online	3
GDAL	3
NumPy	3
ArcPy	3
QGIS	3
JavaScript	3
ArcGIS Pro	2
Pandas	2
Geopandas	2
PostGIS	2
SciPy	2
Modelbuilder	2
Excel	2
Netlogo	2

Note: Python and ArcGIS are most prominent, with R running a significant third most popular.

Further diversity in the formal texts used in courses in this sample reveals the wide range of associated texts and complicates the landscape of content and information delivered in geocomputation courses. As Table 11 indicates, only five texts across the syllabi are repeated - two as required texts and three as additional or referenced readings in the syllabus reading list. As the remaining 51 examples of single-referenced texts (as shown in Appendix 3) demonstrate, a great range of materials are used for these courses.

Table 11. Textbooks and Readings shared by multiple syllabi from this sample.

Required Textbook	Count
O'Sullivan, D. and Perry, G.L.W. (2013). Spatial Simulation: Exploring Pattern and Process, Wiley-Blackwell	3
Longley P.A., Goodchild M.F., Maguire D.J., and Rhind D.W. (2015). Geographic Information Systems and Science (Fourth Edition). Wiley	2
Additional Readings	**Count**
Zandbergen, P.A. (2014). Python Scripting for ArcGIS, ESRI Press	4 (Also once a required text)
Law, M. and Collins A. Getting to Know ArcGIS Pro, ESRI Press	3
Lawhead, J. (2015). Learning geospatial analysis with Python. Packt Publishing Ltd.	2

Note: A mix of GIS, python, and spatial computational texts is evident.

Finally, we conducted multiple reviews of course content through an analysis of course learning outcomes and objectives. The most common words mentioned in these components of the syllabi are shown in Table 12. These courses can be described as spatial data analysis courses using GIS and programming. The specifics of the courses are more detailed, as discovered through other analytics reported here.

Table 12. Keyword densities of learning objectives and course outcomes in syllabi in this sample.

Keyword Densities (One and Two Word) in Syllabi	
Keyword Density x1	**Keyword Density x2**
Spatial 50 (8%)	spatial data 14 (5%)
Data 39 (7%)	data analysis 6 (2%)
GIS 23 (4%)	cellular automata 4 (1%)
Python 20 (3%)	data spatial 4 (1%)
Programming 15 (3%)	programming basics 3 (1%)
Analysis 14 (2%)	object oriented 3 (1%)
Models 13 (2%)	geographic information 3 (1%)
Geospatial 10 (2%)	data mining 3 (1%)
ArcGIS 9 (2%)	analysis spatial 3 (1%)
Geographic 7 (1%)	methods spatial 3 (1%)
Algorithms 6 (1%)	spatial query 3 (1%)
Raster 6 (1%)	ArcGIS server 3 (1%)
Information 6 (1%)	data sources 3 (1%)
Simulation 5 (1%)	visual basic 3 (1%)
Cellular 5 (1%)	post GIS 3 (1%)
Mapping 5 (1%)	GIS models 2 (1%)
Uncertainty 5 (1%)	models cartographic 2 (1%)
Statistics 5 (1%)	python programming 2 (1%)
Methods 5 (1%)	data structures 2 (1%)
Excel 5 (1%)	vector raster 2 (1%)

Note: Numbers refer to the count of appearances of the word or word pair. Percentages refer to the overall composition of the word or word pair in the sample text. A 'mad libs' style course description could be built with this data, indicating that a geocomputation course might be about 'spatial data analysis using GIS and python programming.'

Bloom's Taxonomy Analysis

Bloom's taxonomy is a framework for organizing and understanding expectations for learning in some instructional settings (Krathwohl 2002). Revised in 2001 to add a knowledge dimension to the established taxonomy of cognitive processes, it serves as a non-hierarchical structure for arranging and outlining teaching and learning structures (Seaman 2011). Informing alternative lenses into learning cognition (Jo and Bednarz 2009, for example), Bloom's Taxonomy forms a valuable framework for understanding a course's teaching and learning structures.

For syllabi in our sample, we analyzed learning information in three ways. First, three authors (Bowlick, Ch. Thompson, Cox) conducted a review of the terminology within all syllabi and classified based on individual understanding and experience using terminology guides from Iowa State University (Heer 2015) and the University of Arkansas (Shabatura 2014). While the three analysts identified different numbers of terms, the combined (averaged) classification (Table 13) shows a general emphasis on 'understand' terms at the 'procedural' and 'factual' levels of cognition. Especially notable in this analysis is the absence of analytical and evaluative topics.

Table 13. Combined analytics of three analytics of Bloom's Taxonomy terms in syllabi in the sample.

Combined	Remember	Understand	Apply	Analyze	Evaluate	Create	Sum Rows
Metacognitive	2	7.3333333	6.666667	0.666667	3.666667	11.66667	32
Procedural	3	9.3333333	12	2.333333	8	8	42.66667
Conceptual	7.6666667	14.333333	6	1.666667	3.333333	2	35
Factual	13	10	4.666667	4.666667	6.333333	5.666667	44.33333
Sum Columns	25.666667	41	29.33333	9.333333	21.33333	27.33333	71.66667

Note: Generated by combining the three analyst's reviews of Bloom's terms and averaging across the three classifications, this table indicated an uneven spread of cognitive and knowledge components across the terminology.

Second, we conducted an automated analysis using qualitative coding software to identify terminology used in these syllabi. Author Co. Thompson created a coding schema using Bloom's terms which author Bowlick reviewed and verified. Terms were then coded automatically to generate relations and associations within the corpus of text (Ali et al. 2012). Due to conceptual difficulties coding the knowledge dimension terms, which are less structured, the output of cognitive taxonomy terms forms Table 14. This analysis indicates a stronger presence of 'apply' terms, though the prominence of 'compute' within a set of syllabi concerning geocomputation merits consideration. Nevertheless, this analysis does allow the identification of specific terms used or not used within the construct of these courses.

Table 14. Counts of Bloom's Taxonomy cognitive dimension terms from coded qualitative analysis.

Bloom's Taxonomy Category		**Keywords**
REMEMBER	Present (#)	visualize (10), describe (7), recognize (4), define (4), read (3), locate (3), reproduce (2), identify (2), state (1), select (1), observe (1), name (1), examine (1)
	Not present	copy, discover, duplicate, enumerate, label, list, listen, match, memorize, omit, quote, recall, recite, record, repeat, retell, tabulate, tell
UNDERSTAND	Present (#)	research (11), relate (7), describe (7), discuss (6), generalize (5), associate (5), review (4), report (3), interpret (3), extend (3), explain (3), identify (2), demonstrate (2), translate (1), select (1), represent (1), predict (1), order (1), observe (1), indicate (1), group (1), classify (1), ask (1)
	Not present	cite, compare, contrast, convert, differentiate, discover, distinguish, estimate, express, illustrate, infer, judge, paraphrase, restate, rewrite, show, summarize, trace
APPLY	Present (#)	use (54), compute (34), practice (17), simulate (12), experiment (12), solve (9), complete (8), apply (8), relate (7), write (3), teach (3), operate (3), manipulate (3), interpret (3), explain (3), demonstrate (2), change (2), prepare (1), modify (1), construct (1)
	Not present	act, calculate, choose, collect, discover, dramatize, illustrate, list, paint, show, sketch, transfer
ANALYZE	Present (#)	experiment (12), evaluate (8), analyze (7), focus (6), test (4), plan (3), organize (3), explain (3), question (2), survey (1), select (1), outline (1), order (1), classify (1)
	Not present	calculate, categorize, compare, conclude, connect, contrast, correlate, deduce, devise, diagram, differentiate, dissect, distinguish, divide, estimate, illustrate, infer, prioritize, separate

Table 14. Continued		
EVALUATE	Present (#)	criticize (9), evaluate (8), measure (7), test (4), consider (3), support (2), select (1), predict (1), order (1), appraise (1)
	Not present	argue, assess, choose, compare, conclude, convince, critique, debate, decide, defend, discriminate, distinguish, editorialize, estimate, grade, judge, justify, persuade, rank, rate, recommend, reframe, score, summarize, weigh
CREATE	Present (#)	develop (31), design (16), simulate (12), manage (10), solve (9), integrate (6), generalize (5), test (4), make (4), create (4), write (3), plan (3), organize (3), combine (3), support (2), collaborate (2), propose (1), produce (1), prepare (1), modify (1), hypothesize (1), formulate (1), construct (1), compose (1), adapt (1)
	Not present	anticipate, arrange, assemble, choose, compile, facilitate, imagine, intervene, invent, originate, rearrange, rewrite, substitute, validate

Note: Totals sum as follows. Remember (40), Understand (71), Apply (186), Analyze (53), Evaluate (37), Create (126).

Finally, we visualized these results in a hierarchy chart to highlight the prominent categories and terms in the analysis described in Table 1. As Figure 1 shows, this hierarchy demonstrates the dominance of ‘Apply’ terms in the sample and the relative lack of ‘Evaluate’ ones.

Figure 1. Hierarchy chart of Bloom's Taxonomy terms from qualitative analysis.
Note: This chart allows an easier-to-comprehend visualization of the dominant terms in the analysis.

Discussion

Synthesis of Syllabi and Survey Results

Our analysis of syllabi and survey responses in this work indicates a multi-faceted approach to geocomputation education. While diverse in approach, content, and consideration, it rests on minimal shared formal structures regarding resources, approaches, technology, or technology content. Given the distributed nature of how geocomputation has developed as a research area, this is not necessarily a surprise. Motivations within the course syllabi also indicate this share general desire, as one states that:

> *"This course provides general introduction to GIS automation, including GIS object-based model design (through ArcGIS*

> *ModelBuilder) and computer programming languages, such as Python, and their application in GIS related project development."*

This specific line from a syllabus captures most of the generalities of geocomputation described above and described in other syllabi. This linking of GIS, python, and computer science is a key aspect of the geocomputation course landscape. The methods of delivery of this type of course are captured well by another course description, which says:

> *"This course aims to develop advanced GIS concepts, techniques, analysis skills (e.g. spatial data manipulation), and provide hands-on experience with geoprogramming (sic) in GIS software programs. The emphasis will focus on the application of basic programming skills to solve real-world GIS problems."*

With these general descriptors covering the general structures of courses well representing the general types of courses in the geocomputation realm, other syllabi statements describe more specific contexts where a geocomputation builds on previous knowledge, skills, and practice:

> *"Methods for storing, processing, analyzing, and visualizing various types of geospatial big data using advanced Python programming will be introduced. The course is designed for students who have programming experience or have (met a prerequisite) and want to reinforce the programming skills and learn AI and machine learning methods for solving geospatial big data problems."*

In this case, geocomputation is something more than a 'general introduction' or 'basic programming skills' but instead an extension beyond those components. Geocomputation here is posited as something more than 'programming experience' but still integrated into geospatial (and other) problems. Another syllabus positioned geocomputation within a domain of practice, saying:

> *"The main objective of this seminar is to familiarize participants with the wide range of models of land use change that have been developed and applied in the environmental disciplines, with the practical, methodological, and theoretical issues surrounding such models, and with the strengths and weaknesses of each kind."*

'Models' here represent geocomputation, and environmental work is the domain of application for the practice, methods, and theories at play. This alternative form of presenting the functions and components of what geocomputation can do frames the affordances of geocomputation - modeling, in this case - as a service to a discipline (environmental ones). Contrasting with the stand-alone geocomputation course, this mirrors much of the past and ongoing discussion concerning the role of GIS in teaching, learning, and science (Wright et al,. 1997). One final example from the syllabi clarifies this distinction of the role of GIS in their course:

> *"This course focuses on spatial simulation, computation and analytics using GIS in conjunction with other analysis and modeling software packages."*

Conceptualizing geocomputation as 'GIS…with' is a powerful way to consider the alignment of knowledge, skills, and practices in this area of work. Given the variety of approaches, content, and use of variant learning materials, this statement is helpful to consider in the broader landscape of how these courses operate.

On the Nature of the Research Coordination Network Approach

This work was part of a National Center for Research in Geography Education research coordination network grant. Focusing on transformative research in geography education, we reflect on the opportunities this grant supported, considering how this project takes the form of 'transformative research' and how we have carried out potentially transformative activities. First, we consider this work to be transformative. It gathers tangible evidence of geocomputation education and reviews and analyzes these pieces of evidence for details on how the courses function. This evidence-based representation of geocomputation allows for future discussions built on this foundation to consider further and deeper questions of teaching and learning within geocomputation courses while investigating the technological links and practices within the course format. Further, this allows for a base of reference to continue tracking the development of geocomputation over time. Significant efforts like the Institute for Geospatial Understanding through an Integrative Discovery Environment (I-GUIDE) at the University of Illinois Urbana Champaign benefit from this general understanding of the basic landscape of the courses where future projects will integrate. Ideally, work like this is replicated, adjusted, adapted, and transformed into future projects and new means of investigation and understanding.

Second, this project also enabled us to develop a website for future work on this topic. This site also allowed the development of a community page for future discussions, sharing, and information transfer along the long axis of geocomputation. Without this research coordination network grant, such development would have been impossible. Debuting and live upon the publication of this work, our page on 'Resources for Geocomputation Education' shares the raw information gathered here for review and reflection by the community of interest. Available at https://sites.google.com/umass.edu/geocomputation/home, this represents another transformative aspect of this work. As designed, we intended to link instructors and educational practitioners to share their materials for community interest. Now, collated together in a single space, we can work forward to making more evidence-based and shared decisions concerning geocomputation education futures.

Conclusion

In this work, we explored the nature of geocomputation education through survey and syllabi analysis. While we revealed some general similarities among course structures, much of the content, learning structures, and course functions were different. This provides a useful and interesting base for future studies and future community efforts in organizing and understanding how geocomputation is taught across contexts. We strongly recommend further engagement and discovery of how instructors and learners are navigating this growing field of GIS, geography, and computational fusion, to best support all learners in understanding fundamentals of this educational edge.

Acknowledgments

This research project was supported by a research coordination network (RCN) grant from the National Center for Research in Geography Education, funded by the National Science Foundation (NSF Award BCS-1560862).

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Appendix 1

Survey questions distributed to participants for this work.

<u>Course Details</u>

1. What is the title of your geocomputation course?
    1. Open Response
2. What institution is this course being taught at?
    1. Open Response
3. What level is this course taught at?
    1. Primarily/Only Undergraduate
    2. Mixed Undergraduate/Graduate
    3. Primarily/Only Graduate
4. How many credits is this course?
    1. Open Response
5. Is there TA support for this course? If yes, how many hours per week of TA support comes with the course?
    1. Open Response

<u>Geocomputation</u>

6. How long have you been teaching this course?
    1. Open Response
7. How long have you known about geocomputation?
    1. Open Response
8. Is geocomputation your primary research area?
    1. Yes/No
9. Please describe your area of research.
    1. Open Response
10. How would you describe the grade distribution in this course?
    1. Primarily As and Bs
    2. Primarily Bs and Cs (Normal Distribution)
    3. Primarily Cs and Ds
    4. Other (Describe)
11. Why did you choose to teach this course?
    1. Open Response
12. What was the enrollment of this course when last offered?
    1. Open Response
13. How often is this course offered?
    1. Open Response
14. Do other instructors teach this course?
    1. Open Response
15. What was your role in developing this course?
    1. Open Response

16. How would you describe the structure of this course?
    1. Open Response

Instructional Context

17. What department or unit are you in?
    1. Open Response
18. What is your background and education? Please list your highest degree, field, and institution.
    1. Open Response
19. Is this course required for any degrees or programs offered at your institution?
20. What is the demand for this course at your institution?
    1. 1. Little to no demand - This course struggles to meet minimum enrollment requirements
    2. 2.
    3. 3. Moderate demand - This course has strong, but not full, enrollment
    4. 4.
    5. 5. Strong demand - This course usually has a waitlist

Demographics

21. What is your gender?
    1. Open Response
22. What is your race?
    1. Open Response
23. What is your age?
    1. Open Response

Syllabus

24. Please upload or provide a link to your syllabus here
    1. File Upload
    2. Weblink

Appendix 2

Software and programming languages with single instances in collected syllabi.

Software and Programming Languages	Count
ArcGIS Portal	1
ArcGIS Server	1
Hadoop	1
Google Map + Earth	1
OGR	1
R Statistical Software	1
Postgres	1
PostgreSQL	1
SciKit Image	1
Orange Data Mining Toolbox	1
Cesium	1
JMP	1
GRASS GIS	1
MapInfo	1
Amazon Web Services	1
CARTO	1
Google Fusion Tables	1
Mapbox	1
JMP	1
imageJ	1
GraphPad Prism	1
Photoshop	1
IDLE	1
Visual Basic	1
Jupyter	1
Leaflet	1
SQL	1
Neo4j	1

Appendix 3

Required course textbooks and additional readings present within a single syllabus in the sample. Please note that references to the textbooks are direct from the syllabi, and thus have variant formatting of text, title, author, etc.

Textbook	**Count**
Think Python: How to Think Like a Computer Scientist by Allen Downey et al., 2014, O'Reilly.	1
O'Sullivan, David and Unwin, David J., 2010, Geographic Information Analysis. 2nd Edition. New York: John Wiley & Sons, pp405	1
Zandbergen, P.A. 2020. Advanced Python Scripting for ArcGIS Pro (1st Ed.). Redlands, CA: Esri Press.	1
Erik Westra (2013). Python Geospatial Development, Second Edition	1
Silberschatz, A., Korth, H. F., & Sudarshan, S. (2009). Database system concepts, 6th edition. New York: McGraw-Hill.	1
Obe, R., & Hsu, L. (2011). PostGIS in action. Manning Publications Co.	1
Shekhar, S. and Chawla, S. (2003). Spatial Databases: A Tour. Prentice Hall.	1
Introduction to GIS Programming and Fundamentals with Python and ArcGIS By Chaowei Yang et al., 2017, CRC Press.	1
Python Scripting for ArcGIS, by P.A. Zandbergen. ESRI Press, 2014	1
Lawhead, Joel, Learning Geospatial Analysis with Python - Second Edition	1
GIS Algorithms, by Ningchuan Xiao	1

Additional Readings	**Count**
Introduction to GIS Programming and Fundamentals with Python and ArcGIS By Chaowei Yang et al., 2017, CRC Press.	1
Matthes, Eric, Python Crash Course: A Hands-On, Project-Based Introduction to Programming	1
GIS Algorithms, by Ningchuan Xiao	1
Assessing the Accuracy of Remotely Sensed Data: Principles and Practices, Second Edition by Russell G. Congalton and Kass Green	1

GIS and Cartographic Modeling, by C. Dana Tomlin	1
Interactive Data Visualization for the Web: An Introduction to Designing with , 2nd Edition by Scott Murray O'Reilly	1
Mapping Species Distributions: Spatial Inference and Prediction, by Janet Franklin	1
the Truthful Art: Data, Charts, and Maps for Communication by Alberto Cairo	1
Jo Wood. 2002. Java Programming for Spatial Sciences. New York: Taylor & Francis.	1
Smith, Goodchild, and Longley: Geospatial Analysis, 6th edition, chapter 8 on Geocomputation	1
De Smith M, Goodchild M F, Longley P A (2009) Geospatial analysis: a Comprehensive Guide to Principles, Techniques and Software Tools (third edition). Leicester, Troubador.	1
Getting to Know ArcGIS ModelBuilder, Esri Press, 2011. ISBN: 9781589482555	1
GIS Tutorial for Python Scripting, Esri Press, 2014. ISBN: 9781589483569	1
Pilgrim, M. 2011. Dive into Python 3.	1
Pilgrim, M., 2004. Dive into Python. http://www.diveintopython.net/.	1
Yang, Chaowei, and Qunying Huang. Spatial cloud computing: a practical approach. CRC Press, 2013	1
Géron, Aurélien. Hands-on machine learning with Scikit-Learn and TensorFlow: concepts, tools, and techniques to build intelligent systems. O'Reilly Media, Inc., 2017	1
Richert, Willi. Building machine learning systems with Python. Packt Publishing Ltd, 2013	1
Chollet, Francois. Deep learning with python. Manning Publications Co., 2017.	1
Petrasova A, Harmon B, Petras V, Tabrizian P, Mitasova H., 2018, Tangible Modeling with Open Source GIS. Second edition. Springer International Publishing	1
Bailey, Trevor and Anthony Gatrell. 1996. Interadive Spatial Data Analysis. Prentice Hall.	1
Haining, Robert. 2003. Spatial Data Analysis: Theory and practice. Cambridge University	1

Rogerson, Peter. 2001. Statistical Methods for Geography. SAGE Publications.	1
Lutz, M., 2009. Learning Python (n edition). Sebastopol, WA: O'Reilly, Inc.	1
Brunsdon C. and Singleton A. D. (2015) Geocomputation: A Practical Primer. Los Angeles: SAGE.	1
Schutt R. (2013) Doing Data Science: Straight Talk from the Frontline. O'Reilly Media.	1
Severance C. R. (2016) Python for Everybody. [Available online at: https://www.py4e.com/book]	1
Tufte E. R. (2001) The Visual Display of Quantitative Information. CT: Graphics Press USA.	1
Li, Linna. 2017. "Spatial Data Uncertainty." The Geographic Information Science & Technology Body of Knowledge (4th Quarter 2017 Edition	1
John P. Wilson (ed). - Miller, Harvey, and Michael F. Goodchild. 2015. "Data Driven Geography." GeoJournal 80, no. 4 (October): 449-461	1
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Rey, S.J. (2019) PySAL: the first 10 years. Spatial Economic Analysis, 14:3, 273-282, DOI: 10.1080/17421772.2019.1593495	1
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Tong, Daoqin, and Alan T. Murray. 2012. "Spatial Optimization in Geography." Annals of the Association of American Geographers 102, no. 6 (June): 1290-1309	1
Zent, Christopher. 2018. ArcGIS Pro SDK for .NET: "An introduction to Add-Ins and Configurations." Technical workshop. In Proceedings of the 2018 Esri User Conference	1
Marini, Joe. 2018. Learning Python	1
Pierson, Lillian, 2018. Python for Data Science Essential Training.	1

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