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In 2018, the American Association of Geographers has announced the Encoding Geography initiative, which is a long-term commitment to build capacity and broaden participation for computational thinking within the geography discipline. The initiative has several goals towards strengthening the future of geography, including training new generations of undergraduate and graduate students for the geospatial technology industry which is having a growing and significant impact. A 2017 global impact study on geospatial services estimates that this industry creates approximately 4 million direct jobs and generates 400 billion U.S. dollars globally in revenue per year. The growth of this industry is increasing the demand for graduates with training in both geography and computational thinking (geo-computational thinking), but they are hard to find. The limited availability of learning pathways towards geo-computationally intensive jobs requires employers across the public and private sectors to choose between hiring a geographer with limited or no computational skills, or a computer science graduate with limited or no expertise in spatial thinking and geographic information.

This workshop brings together experts from both geography and computer science disciplines who have primary interest in geospatial data and technologies, either from academia or industry, to discuss the grand challenges towards improving existing learning pathways through integration of geo-computational thinking in higher education. This could impact a variety of disciplines that increasingly deal with geospatial data beyond geography, such as social sciences, environmental sciences, public policy, climatology, and other geo-related disciplines. The workshop speakers are invited to discuss their vision on challenges and opportunities of topics within the workshop scope.

Some Observations Regarding Geocomputational Teaching through Interdisciplinary Teams

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ABSTRACT

Geocomputation is an inherently interdisciplinary topic, combining both geospatial information science (GISc) and computer science (CS). It could be taught by individuals with strong backgrounds in both areas, but it is argued that such individuals are rare and academia is poorly positioned to produce a future generation of such dual-skilled individuals. Interdisciplinary team teaching is presented as an alternative. Hurdles to developing such team-taught classes are identified, and possible ways to overcome them are presented. Finally, a way of restructuring academia to be more supportive of such interdisciplinary team projects is presented.

CCS CONCEPTS

• Social and professional topics • Professional topics • Computing education • Computing and education programs • Information science education

KEYWORDS

Education, Interdisciplinarity, Geospatial information science (GISc)

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1 Introduction

At U.S. universities, geocomputational teaching is most commonly performed by practitioners of Geospatial Information Science (GISc) who have become well versed in the practices (and hopefully the concepts) of Computer Science (CS). The success of this approach is dependent upon the CS skills of the instructor – whose training in this area is very likely to be significantly less rigorous that that of a true computer scientist. While some instructors have overcome this handicap and have become excellent geocomputational teachers, many more struggle with CS foundational ideas. The result is their teaching often focuses on the nuances of a particular programming environment – e.g., how to get ArcPy and Python to accomplish a particular task – rather than foundational CS concepts like data models and algorithm development and evaluation. This is problematic; programming environments change constantly, and students instructed in only the ins-and-outs of a particular programming environment may soon find their skills outdated. On the other hand, students instructed in underlying concepts and ideas can apply these ideas to any environment that they may encounter.

One obvious way to address this problem is to find instructors equally well qualified in both GISc and CS. Unfortunately, it is equally obvious that there are not enough of these dual-skill instructors to go around. Furthermore, it seems unlikely that U.S. universities will be able to produce a new generation of dual-skilled instructors anytime soon. At present, acquiring skills in both GISc and CS at U.S. universities basically requires students to pursue a double major. It is sometimes suggested that a double major is not required because GISc students can acquire the necessary CS skills by "taking a few CS classes," but this is not practical. The CS classes a GISc student would need typically have lengthy lists of prerequisites (making it difficult to fit all the necessary courses into the GISc curriculum) and are often restricted to CS majors. Given that both the number of individuals wanting to pursue double majors is quite small to begin with and that the economics of staying in college for the additional semester (or more typically the additional academic year) required to complete a double major have become quite daunting, it seems unlikely that double majors are going to solve the shortage of dual skilled geocomputational instructors anytime soon.

An alternative to relying on dual-skilled instructors is team teaching interdisciplinary geocomputational class with both GISc

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and CS instructors. Experience has shown that this approach can work extremely well, but interdisciplinary team teaching within U.S. universities can be problematic. University administrative structures, as well as faculty (and administrator) reward systems, often serve to discourage interdisciplinary teaching. The remainder of this essay will identify problem areas, propose work arounds to circumvent these areas, and (perhaps wishfully) suggest changes that could encourage interdisciplinary teaching in the future.

2 University Administrative Structures and Interdisciplinarity

From the perspective of administrative theory, modern universities are simple hierarchical organizations with (typically) four administrative levels. Confusingly, these levels (and the titles of the leaders of each level) go by different names at different institutions. Despite the different nomenclatures, these levels and their functions remain quite consistent across institutions. For the sake of clarity, I will refer to the four levels as the department (typically lead by a chairperson), the college (lead by a dean), the university's total academic enterprise (lead by a provost), and the university as a whole (lead by a president).

A convincing argument can be made that four is at least one too many administrative levels for a modern university, and further arguments can be made as to which level(s) should be eliminated. Those arguments are not germane to the current discussion. The question here is how does the existing four-level administrative structure help or hinder interdisciplinary teaching; specifically, teaching of geocomputational courses.

The most common category of interdisciplinary teaching seen in U.S. universities involves collaborations between two or more disciplines represented by different departments within a single college. Interestingly, these interdisciplinary efforts rarely develop in the manner envisioned by administrative theory – under that theory, possible synergies between two or more smaller administrative units (in this case, departments) should be recognized and efforts to implement interdisciplinary teaching should be initiated by the leaders of the next larger administrative unit (in this case, the college). That rarely happens in academia. The more common mechanisms are (1) individual faculty members from two or more departments within the same college, who meet and interact on a regular basis at college-level events, recognize and initiate interdisciplinary efforts on their own, or (2) the chairs of two or more departments, who once again meet and interact with one another regularly at college leadership meetings and other venues, recognize opportunities for collaborations and initiate interdisciplinary efforts between their departments.

Using these two mechanisms, within-college interdisciplinary efforts do occur, but they are relatively rare, and they typically occur at very small scales – for example, a class may incorporate "guest lecturers" from other disciplines, or in more ambitious cases, a certain portion of the course may be taught by a faculty member from another discipline. While these sorts of collaborations are frequently positive and helpful, they are basically separate, segregated discussions of two related disciplines that just happen to take place in a single course. They fall short of the truly integrated, multidisciplinary approach called for in many areas, including geocomputation. What is needed are courses designed to intertwine GISc and CS concepts and ideas. Courses should highlight how successful practitioners of geocomputation are able to look at issues from both a GISc and a CS perspective, understand how GISc theories and ideas will influence how CS theories and ideas are applied to that issue, as well as the reverse – understand how CS theories and ideas influence how GISc theories and ideas are applied to the issue. Asking students to develop this level of integrated thinking by exposing them to two disciplines separately is not particularly realistic.

For geocomputation, the situation is even more difficult, because the GISc and CS departments are typically not located within the same college. Under administrative theory, this situation should be handled by the lowest administrative level that encompasses both colleges – the provost's office – recognizing the opportunity for interdisciplinarity and taking steps to initiate that activity. This virtually never happens. First, the provost is probably unaware of the opportunity for interdisciplinarity – recognizing such opportunities requires a deep level of understanding of at least one of the disciplines involved and at least a solid appreciation of the other discipline(s) involved – and given that a typical university has departments representing dozens if not hundreds of disciplines, it is not realistic to expect the provost to have solid understandings of any more than a tiny handful of them. Second, in academia any effort by an administrator to "tell a faculty member" what or how to teach runs the risk of raising a messy and usually counterproductive dispute centered on academic freedom. As a result, most provosts are very reluctant to do anything that might lead them down this road – including initiating interdisciplinary efforts.

In addition, the unofficial mechanisms that can initiate interdisciplinary teaching found within single colleges – informal meetings among faculty and/or depart chairs – are much less effective between colleges. University colleges tend to be fairly well "siloed," even to the point that it is rare for multiple colleges to share office space – on most campuses, each college has it own building(s) or at least its own floors (or wings) in shared buildings. Social activities where faculty can meet and interact focus almost exclusively on the department or college level; faculty from different colleges have very little opportunity to meet. Given this, it is unsurprising that faculty from different colleges rarely come together to organize interdisciplinary teaching; they simply lack any effective mechanism to interact with one another in a setting that lends itself to developing such efforts.

3 How University Resource Allocation and Reward Systems Hinder Interdisciplinary Efforts

How universities allocate resources and reward faculty (as well as administrative units) poses additional problems to interdisciplinary teaching. Leaving aside the perennial debate over the relative weights given to teaching versus research, at some level all universities have to evaluate teaching, provide resources for the university's teaching efforts, and in some fashion reward outstanding teaching efforts and modify or perhaps discontinue unsuccessful efforts. The resources being distributed are usually faculty time (what and how many courses is a faculty member going to be asked to teach in order to meet their teaching workload requirements), graduate teaching assistant positions, non-tenure track faculty hires, and in the longer term, future tenure track faculty hires. At the individual faculty level, the rewards being discussed are usually annual evaluation ratings, which translate into annual salary increases. At the departmental (and perhaps college) levels, additional rewards involved are typically increased budgetary allocations (and possibly increased allocations of manpower), and perhaps even increased administrative autonomy.

Universities struggle mightily with how to evaluate teaching. The debate and opinions in this area are endless, but most people would agree that evaluating teaching involves at least three areas – the *quantity* of teaching (how many courses are taught, how many students are in each of these courses, and how much effort goes into teaching each class), the *quality* of teaching (are students learning the material presented in the course), and the *impact* of teaching (how much do students benefit, either during the rest of their tenure at the university or during their professional careers after they leave the university, from the teaching). Unfortunately, both the quality and especially the impact of teaching are very difficult to measure, so most teaching evaluation efforts tend to focus on quantity. Team taught geocomputational classes suffer in this area. Such classes tend to have small to modest enrollments, which is a strike against them when they are assessed for teaching quantity. Further, since they are team taught, the "credit" for the teaching effort is distributed among multiple faculty members, which hurts each faculty member in terms of reaching their individual teaching workload requirements.

Most universities at least pay lip service to evaluating teaching quality, usually through student surveys and occasionally with teaching peer review. The efficacy of both of these techniques is debatable, but this debate is not relevant to the current discussion. Team taught geocomputational courses may do very well or very poorly in these measurements, just like any other course. Individual instructors vary in the quality of their teaching, and some instructors who do well with certain courses struggle with others. Instructors participating in team taught geocomputation classes are no exception.

Where team taught geocomputational class should shine is in the impact area, because such classes give students the ability to approach issues from multiple perspectives. This should make students better academic and real-world problem solvers, which is an outstanding benefit found in few classes. However, very few universities make any sort of concerted effort to measure teaching impact, so this benefit of team taught geocomputation courses usually goes unnoticed.

Given that teaching evaluations – focused on quantity and to a lesser extent quality of teaching – go into both resource allocation and reward decisions for both individual faculty and for the departments/colleges they represent, their impacts are quite significant. They are also incomplete measures of teaching, and their failings disproportionately impact team taught interdisciplinary classes like geocomputation. This makes team taught interdisciplinary classes unattractive to both individual faculty and departments/colleges. Given this, it is hardly surprising that such courses are rare in today's academia.

4 How to Foster Team Taught Interdisciplinary Courses Within Academia as it is Currently Structured

Given the obstacles arrayed against team-taught geocomputation courses, how can such courses be successful in contemporary academia? While there is no single silver bullet that can overcome all of the hurdles facing such classes, a number of things can help:

- *Courses must be conceived and instigated by faculty*. In previous portions of this document, I have mentioned the possibilities of courses being created through the actions of department heads, deans, or others, and while such things do occur, the overwhelming majority of new classes are instigated by small groups of faculty. Being that GISc and CS faculty are unlikely to meet socially at university functions (since they are in deferent colleges), the onus is on the faculty themselves to seek out their colleagues from other departments and explore the possibilities.

- *The course must have support not only from the faculty teaching it, but from the faculties in the GISc and CS departments*. Faculty support makes administrative support much more likely. If a class with little support also fares poorly under the previously-discussed teaching evaluation system, it becomes an easy target for elimination. Conversely, if the faculty support a class, administrators are much more likely to find ways to work around mediocre teaching evaluations. As the old adage says, there is power in numbers, and courses supported by entire departmental faculties are much more likely to enjoy administrative support than courses advocated by only their instructors.

This begs the question of exactly how to garner such faculty support. In my experience, most GISc faculties do not require much convincing; faculty teaching subsequent courses see the benefits of having students with strong geocomputation skills in those courses. CS faculties can be more difficult to convince. Typically, CS departments are struggling to keep up with demand for their teaching; there are a plethora of students seeking CS degrees and many universities require "Intro to CS" courses as part of their core curriculums. The burden of teaching such classes falls on CS faculties. This high demand for teaching masks the benefits instructors may experience from having a relatively small proportion of their students having gained geocomputational skills. Finally, in my experience, CS as a discipline places much more emphasize on grantsmanship and less on teaching as compared to GISc. Together, all of these experiences make CS faculties understandably reluctant to take on additional teaching responsibilities.

The way to overcome such reluctance is to demonstrate that a geocomputation class can benefit CS students. Like all good faculty members, the vast majority of CS faculty want to provide their students with a high quality education, and if they see a geocomputation class as contributing to that education, they will support it. The issues faced in geocomputation (e.g., data mining, information security, processing performance when working with extremely large datasets, parallelization, opportunities in computer graphics/data visualization limited only by the imaginations of the students and instructors, etc.) provide wonderful platforms upon which broad CS issues can be taught. When CS faculty see this, they will support such classes.

- *The course must become a required component of at least one degree program*. This is largely an extension of the previous point. When resources are tight, elective courses are easier targets for elimination than required courses, and in other times, it is easier to maintain courses that may not perform well under the flawed teaching evaluations systems in place at most universities when those courses are a required component in one or more curricula.

- *The instructors must work with their department chairs, who must work with their deans, who must reach out to the provost to ensure that the special nature of courses such as a team taught geocomputation class is recognized and addressed in resource allocation and reward decisions*. Perpetually fighting a defensive battle to justify team taught interdisciplinary courses that do not perform well under the metrics most universities use to evaluate teaching is a fool's game. If program heads, deans and the provost support team taught interdisciplinary classes, it is in their power to find alternative ways to evaluate these courses and their instructors. For example, faculty can survey (formally or informally) graduates regarding the impact the class has had on their careers; if the class is living up to its expectations, it should do well in that area. This information can be provided to department chairs, deans and possible even the provost. Supportive university administrators can use this sort of data to justify giving positive evaluations to courses such as geocomputation that do not perform as well under the conventional teaching evaluation metrics used in other courses.

5 How to Restructure Academia so it Supports Interdisciplinarity

The fundamental structural problem found in academia today is that universities are undeniably "bottom up" organizations but they are administered in a "top down" fashion. Academic freedom gives individual faculty members almost unlimited control over their teaching efforts and the academy's ubiquitous emphases on faculty developing their own research programs gives faculty almost unlimited freedom in that area as well. Coupled this with the job security granted through tenure, and it is clear that faculty members have almost complete control over their activities; they are essentially independent contractors. They all share the university's overarching goals of teaching and research, but they do not work in prescribed areas to accomplish specific goals established by university administrators. Furthermore, even the one teaching-related decision that does not fall to individual faculty members – the design of the overall curricula required to earn degrees – is not decided upon by higher administration. Instead, it falls to the combined decision making of the faculty of individual departments – and departments form the *lowest* level of the university's administrative hierarchy. All of this focus on individual faculty and low-level administrative units clearly demonstrates that universities operate through the collective decisions made by individuals and small groups of faculty; despite what higher administrators may think, they really do not run the university.

However, university administrators do control resource allocation throughout the university, and they control the evaluation processes that are used to determine future resource allocations (including annual salary increases). There is a legitimate debate to be had about the obvious conflicts of interest in controlling both allocations and the mechanism that drives future allocations, but that is not the point vis-à-vis team taught interdisciplinary courses. The issue here is the degree of alignment of between the goals and aims of the faculty and those of the administration. When both sets of goals and aims align, resources flow into the areas supported by the faculty, and the university operates smoothly. Problems arise when the goals and aims of the faculty and the administration do not align. These problems could be eliminated by restructuring university administrative structures to reflect the *de facto* bottom up nature of university operations. This sort of restructuring is the most profound change needed in contemporary U.S. universities.

Perhaps understandably, university administrators have constructed resource allocation and performance evaluation systems that function best when universities are fully "siloed." If to the extent possible, each department is responsible for only its own set of course and degree offerings, and handles all of the university's research in a certain academic area, the department can be evaluated using simple metrics and it can be rewarded or censured based on those metrics. If departments are intertwined and highly collaborative, the evaluation and resource distribution processes become much more complex.

But complexity in this area is unavoidable. Whether the university is a liberal arts institution where the concern is providing students with a broad, interdisciplinary background that spans many fields or a public university facing the public's demands to prepare graduates for employment in the real world, where jobs seldom if ever are restricted to individual academic disciplines, the demand for interdisciplinary, team-taught experiential classes is only going to grow. University administration systems, and even university accreditation organizations, are going to have to be redesigned to encourage interdisciplinarity rather than merely tolerate it.

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Geo-Computational Thinking in the Third Grade

Making Computational Thinking Truly "For Everyone, Everywhere"

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ABSTRACT

The concept of computational thinking originated in the computer science community and has therefore focused on concepts and terminology drawn from that discipline. However, to make computational thinking an integrated, accessible concept within other parts of the K-12 curriculum, the concepts and terminology must be adapted to fit the new curricular context. We focus on elementary social studies, specifically a third grade geography lesson on absolute location using a teaching strategy of a scaffolded geocache. We present a selection of computational thinking elements, adapt them to social studies, and then organize them into a four-part heuristic: Data, Patterns, Rules, and Questions. Through this selection, adaptation, and sequencing, computational thinking can become a relevant and accessible integrated concept within the elementary social studies curriculum.

CCS CONCEPTS

• Computing and education programs

KEYWORDS

Computational thinking, Social studies, Geography, Scaffolded geocache, Elementary education

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1 Computational Thinking as a Curricular Concept

Jeannette Wing's brief March, 2006 article[1] in *Communications of the ACM* consists of 1500 words (very approximately), yet it set off a firestorm. To date, per Google Scholar, that article has been cited approximately 5000 times, and the top articles citing that piece have themselves been cited more than one thousand times. Clearly, Wing, 2006 is the epicenter of the contemporary scholarly discussion of computational thinking.

However, the term originated before 2006. According to Google Trends, the term "computational thinking" first peaked as a search term in 2004. (See Figure 1, below.) In addition to tracking time, Google Trends tracks place: the United States peaked in its searches for "computational thinking" in April, August, and October of that year; the United Kingdom peaked in May. We can observe the specific impact of Wing's initial piece, with a peak in US in April, 2006 (albeit with puzzling initial spikes back in January, in Pennsylvania and New Jersey), and resurgences in July, October, and December. Again, the UK peak followed, in November-December, 2006. In the following year, the search term spread, geographically--the top five search locales for that term in 2007 were Hong Kong, South Korea, India, Mexico, and Australia. However, that initial 2004 peak was not exceeded until 2014. Since 2014, the term has been on a steady upward trajectory and has adopted a pattern typical of school-related subjects: the low points are consistently in July (summer holidays) and December (winter holidays). (As a point of reference: see the Google Trends graph for 'algebra' in Figure 1, below. The lowest points are in July, the highest points are in September, and low points following that peak are all in December.)

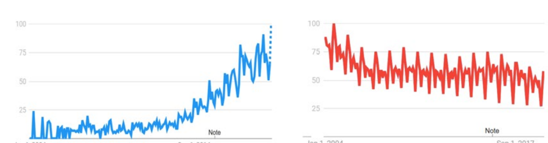

Figure 1: Google Trends data for 'computational thinking' and 'algebra' between 1 Jan 2004 and 12 Sep 2019. The vertical axis is not an absolute measure but a scaled index for

the number of searches for the specified term over this period of time, with '100' representing the peak (largest number of searches) and '0' representing no searches. Accordingly, the two graphs are not on the same scale for the vertical axis. Retrieved from https://trends.google.com.

Based on the patterns above, the concept of computational thinking is working its way into school curricula throughout the world, powered in part by the emergence of curricular materials such as ISTE's *Computational Thinking Competencies* (https://www.iste.org/standards/computational-thinking) and Google's *Exploring Computational Thinking* resources (https://edu.google.com/resources/programs/exploring-computational-thinking/). Can we therefore assume that Wing's assertion that computational thinking is "For everyone, everywhere"[2] is now made true? We argue that it is not. Computational thinking is in the K-12 curriculum somewhere, but where? Where is it actually being used?

By all appearances, the majority of the work done on computational thinking remains tied to computer science. The computer science community was the first to integrate computational thinking into its curriculum standards documents[3]. The NSF-funded work that led up to these standards[4] featured predominantly computer science and coding-focused examples of curricular integration[5]. Wing's own words suggest that computational thinking and programming are overlapping domains: "Computational thinking will have become ingrained in everyone's lives when words like *algorithm* and *precondition* are part of everyone's vocabulary; when *nondeterminism* and *garbage collection* take on the meanings used by computer scientists [emphasis added]".[6]

Our position is that as long as computational thinking remains tied to computer science and the specific terminology of programming, it will only belong to a subset of people and stay sequestered within the curriculum. If computational thinking is truly to become 'for everyone, everywhere,' it cannot remain tied to the discipline of computer science and the specific terminology and constructs used in programming. Instead, we suggest (a) adapting the language of computational thinking to the cross-curricular contexts in which it might be introduced, and (b) simplifying the language used to make it both more relevant to the content area and more accessible to teachers and learners alike. As a point of focus for this discussion, we select elementary social studies, specifically a fundamental geography education concept: latitude and longitude.

In the elementary social studies curriculum, absolute location—that is, the use of the latitude-longitude grid—is introduced in third grade. (For example, consult the curricula of our home states, Like many states, our home states of Pennsylvania and North Carolina specify absolute location as a topic that must be taught by the end of third grade[7]. The traditional lesson on absolute location involves maps and globes, discussion of the equator and prime meridian, and application of these reference points on worksheets or tasks such as identifying landmarks along the same line of latitude or longitude. (For an example, see https://www.nationalgeographic.org/activity/introduction-latitude-longitude/) However, alternative approaches can involve hands-on activities such as giant maps[8] or integrating authentic technologies such as handheld GPS units[9]. Among these approaches, the use of handheld GPS units to conduct some form of geocache[10] is particularly suitable for integrating computational thinking. We will use the strategy of a scaffolded geocache[11] to expose the process and challenge of integrating computational thinking into the broader curriculum and making it more accessible for everyone, everywhere.

2 Geocaching as a Pedagogical Technique

A geocache is a hidden object--usually small, usually discrete: A hide-a-key placed on the underside of a metal railing, a film canister slipped into a knothole, a jar tucked under a tree root. These objects function as containers, and inside them is often a logbook to be signed by people who successfully find the cache. To locate a geocache, participants look up the latitude and longitude on a website (for example: https://www.geocaching.com). They then use a GPS unit to navigate to the correct coordinates and then carefully examine the area, scanning for where a cache might be hidden. This stage can be an exercise in frustration, however, since the cache may have been carefully hidden or (worse yet) displaced by weather, animals, or previous finders.

Geocaching can be adapted for the purposes of classroom instruction, presuming that the teacher is willing to take the class outside and that he or she can procure some GPS units. The targets for school-based geocaching typically take place on school property and can either be a traditional geocache located via latitude and longitude[12] or can use riddle-like location prompts[13]. Additional instruction around the lesson can include the basic concepts of absolute location, the latitude and longitude grid, the referents of the Equator and Prime Meridian, and even approximations of the circumference of the earth[14].

The model we are using is a scaffolded geocache[15]: A traditional, latitude-and-longitude-based geocache that focuses on navigation rather than searching. In the scaffolded geocache, the targets are clearly visible, obvious targets--over the years, we have used sets of orange cones, tennis balls, and red cups as the geocaching targets. The choice of clear, consistent targets is part of the scaffolding--students will know that they are at the correct location as soon as they spot the target. The lesson begins with an introduction to GPS—how to read latitude, longitude, and the error term—and then a geospatial orientation: which way is the Equator? The Prime Meridian? Which number will change as you approach one of these lines? Which way will the number change?

Following this initiation orientation, students are given a list of targets to locate. (See Figure 2, below.) Each target is identified by a number, its latitude and longitude, and its error term. Whenever possible, we place the first two targets so that they are aligned with the start location -- one directly north or south (and hence sharing the same longitude) and the other directly east or west (and hence sharing the same latitude) relative to the start location. This alignment is a second scaffold, allowing the students to practice their spatial decision-making in the simplest possible case (changing only in latitude or only in longitude) and while in direct dialog with the instructor. As a group, the class resolves which target is which--is the target to the east #1 or #2? Is the target to the south #1 or #2? Once the group reaches a consensus, they go to check their answer, confirming that they could use the provided latitude and longitude to determine in which direction the target lay. At this point, students who need further support can work with the teacher while the others split off in pairs to navigate their way to the remaining targets. The paired-up student teams are advised to decompose the task by having one student focus on latitude and the other focus on longitude. After locating an assigned sequence of targets, they meet at a final gathering point. (A more thorough description of the activity and additional detailed images are in Hammond, Bodzin, & Stanlick, 2014.)

Target ID	Latitude	Longitude	Accuracy
Start	N 40° 36' 7.5"	W 75° 21' 38.7"	14’
1	N 40° 36' 6.0"	W 75° 21' 38.7"	12’
2	N 40° 36' 7.5"	W 75° 21' 36.4"	13’
3	N 40° 36' 2.3"	W 75° 21' 31.1	12’
4	N 40° 36' 5.8"	W 75° 21' 28.3	11’
5	N 40° 36' 7.1"	W 75° 21' 35.5"	18’
6	N 40° 36' 2.4"	W 75° 21' 37.9"	14’
7	N 40° 36' 6.7"	W 75° 21' 35.1"	17’
8	N 40° 36' 5.2"	W 75° 21' 32.9"	17’
Finish	N 40° 36' 3.8"	W 75° 21' 36.9"	9’

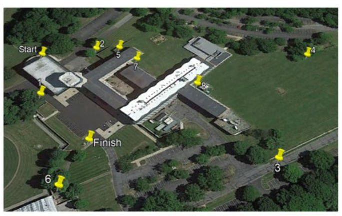

Figure 2: Example of a scaffolded geocache set up around a school building. On the left, a data table with the latitude, longitude, and error term (‘accuracy’) for each location. Students assemble at the start location and then use GPS units and the data table to navigate to the targets. On the right, a satellite image is overlaid with the locations of the starting point, finish, and the 8 targets that students will be locating.

The scaffolded geocache is the centerpiece of a week-long sequence of instructional activities. Research with three third grade classes showed significant improvement in students’ understanding of latitude and longitude and their geospatial orientation and awareness relative to local landmarks[16]. For our current purposes, however, we are interested in the scaffolded geocache as a vehicle for not only geography education but also for teaching computational thinking. If we can make a meaningful, effective integration between this core geographic education activity and computational thinking, we will demonstrate the ubiquity of computational thinking--that it may indeed be for everyone, everywhere.

3 Computational Thinking During a Scaffolded Geocache

Geocaching is a form of a game, in which students must solve a problem (locating the assigned targets) by using the tools (GPS unit, list of targets’ coordinates, and their own geospatial understandings and orientation) to reach a win state (completing the target and arriving at the correct finish point). At each step of the task, students are engaged in a constant process of monitoring their current position (via the GPS unit), comparing it against the target’s coordinates (provided on the sheet), and determining whether to move further north, south, east, or west (using their geospatial understandings and orientation). If we were teaching a computer science lesson, we might represent this process in pseudocode:

IF current latitude > target latitude THEN move toward Equator ELSE move away from Equator	IF current longitude > target longitude THEN move toward Prime Meridian ELSE move away from Prime Meridian
LOOP until current latitude = target latitude & current longitude = target longitude.	

However, most third grade teachers, when engaged with teaching a geography lesson, will be neither inclined nor able to integrate a co-lesson in computer programming. Even if a teacher were to present such a lesson, we question whether many third grade students would be able to track the integration of two such disparate frameworks for approaching their task. (Furthermore, due to the imprecision of the GPS units, the conditions of the above pseudocode can never be satisfied! Even if you are standing still, the coordinates on your GPS unit will shift.)

Instead, our experience tells us that we must adapt the language of computational thinking to the task at hand. The scaffolded geocache presents a wealth of opportunities to connect to many discrete concepts embedded within computational thinking.

- The use of latitude and longitude to express locations demonstrates abstraction of the source data--that is, the physical characteristics of the location (say, a red cup placed under a tree).
- The GPS unit continually updates its position data without requiring user input; this is an example of automation.
- As students continually check their current position and compare it to the target, they are engaged in recursion.
- When students work in pairs to focus on just latitude and just longitude, they decompose the task and employ multithreading.
- As students observe imprecision in the GPS coordinates--that is, the coordinates on their GPS will not precisely match the coordinates of the target--they engage their data definition to understand that they have, in fact, arrived at their target.
- The entire process of navigating to the targets (when done correctly!) is an enaction of algorithmic control.
- Whenever students need to return to the teacher for more instruction or scaffolding, they are debugging their algorithm.

Clearly, students’ behaviors during a scaffolded geocache lesson present rich connections to the actions and understandings of computer scientists. But do these terms and understandings connect to the objectives of the geography lesson? At best, they are a useful alternate representation of the task; at worst, they are a tremendously confusing distraction. We therefore propose an adaptation of computational thinking to make it appropriate to the context. In this case, the context is an elementary social studies lesson. Therefore, we have proposed a cross-walk between computational thinking concepts and social studies activities (see Table 1, below).

Table 1
Elements of Computational Thinking, Selected and Adapted for Social Studies Purposes

Selected Elements of Computational Thinking[17]	…Adapted and Explained for Social Studies
• Symbol systems & representations • Abstractions & pattern generalizations • Algorithmic notions of flow control • Structured problem decomposition • Debugging & systematic error detection	• Data definition: *What is being included? What is being excluded?* • Pattern recognition & generalization: *What do I see? Does it apply elsewhere?* • Abstraction: *Can I remove detail to make it easier to see patterns or connections?* • Rule-making: *Does a pattern always apply? Can it predict what will happen in a new situation?* • Automation: *Can technology help me identify or confirm a pattern?* • Decomposition: *Can I break this question or dataset into smaller parts?* • Outlier analysis: *Which parts of the data do not follow the pattern? What can they tell us?*

Following this selection and adaptation, we have constructed a heuristic that chunks and sequences the use of these concepts into a sequence of Data-Patterns-Rules and Questions. This heuristic helps bridge the geography education objectives of the scaffolded geocache and its resonances with computational thinking.

- Data
  - *What are latitude and longitude?*
  - *What is the error term and why does it exist?*
- Patterns
  - *As I walk towards or away from the Equator, what happens? Why?*
  - *As I walk towards or away from the Prime Meridian, what happens? Why?*
- Rules
  - *If I match my latitude and longitude to the target, I will be right on or next to the target...*
  - *...except for the error term--I can never exactly match the latitude and longitude.*
  - *(My partner and I should stay on the school property and/or within eyesight of the teacher at all times! Expressed in terms of absolute location: My latitude and longitude should stay within a specified range….)*
- Questions
  - *How do the GPS units and satellites work? Who created them?*
  - *How do GPS units in cars and on smartphones use this technology to tell people not just where things are but also which way to go?*
  - *What kind of jobs or professions use GPS units and other geospatial tools?*

With this adaptation of computational thinking to the context of social studies education, we feel that the resulting lesson both enriches students' learning about the specific geographic concepts and skills and it meaningfully integrates computational thinking into a more mundane context, or at least a context less obviously derived from computer science-derived. To make this integration possible, however, we had to adapt the language used and find specific points of connection between the social studies topic and skills of computational thinking. Subsequent lessons can further refine students' understanding of computational thinking and advance their mastery of the terminology that Wing had in mind. As a starting point, however, we advocate for an adaptive framework such as our Data-Patterns-Rules and Questions heuristic.

4 Conclusion

We share Wing's enthusiasm for computational thinking, and we wish to support her assertion that computational thinking is for everyone, everywhere. To make a claim, however, is one thing; to be able to show that it is true is another. Our example of a scaffolded geocache to teach the fundamentals of geography to elementary learners is our attempt to make this claim true, at least for this one context. Where we depart from Wing is in the tactics to be followed--she appears to be confident in the accessibility of the language of computer scientists for audiences of non-computer scientists. As she wrote in 2008, "even at early grades we can viscerally show the difference between a polynomial-time algorithm and an exponential-time one" (p. 3721). While this may be true, we feel strongly that in social studies contexts, we must adapt the language and concepts of computational thinking to make possible any integration of computational thinking--at least in its initial stages. Our adaptation and accompanying heuristic are just one strategy for supporting this integration, and others are of course possible. We welcome alternative approaches and feel that any parallel work can only bring us closer to making computational thinking truly for everyone, everywhere.

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Observations on the Gaps and Opportunities for Geocomputation

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ABSTRACT

Traditional geographical approaches to acquiring new knowledge and understanding problems varies significantly from the primary *modus operandi* of computational thinking that is practiced by computer scientists. These differences have contributed to a persistent absence of geocomputational courses within academic geography departments and an underdeveloped and limited understanding of spatial thinking by computationally-minded scholars.

CCS CONCEPTS

• Computing and education programs

KEYWORDS

Geographical thinking, geocomputation, enumerations, coordinates, spatial thinking, spatial relationships

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1 Early Geographical Thinking about Computation

Computational thinking involves logical and necessary sequences and workflows, systematic and procedural steps, and solution-oriented processes. Extending this to *geo-computational* thinking means that geographic and/or location-based elements become relevant components in one way or another, such as natural patterns or processes being modeled, or location data are being considered. The issue or problem under consideration need not be completely or entirely "geo" focused, but once geographic components are included, factors such as scale and spatial dependencies become necessarily relevant.

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Thinking in linear, systematic, or sequenced approaches is not part of the disciplinary history or traditional practices of Geography or geographers. The "-graphy" (description) part of geography was traditionally most often accomplished by writing, sketching, drawing, note taking, or otherwise graphically making representations, often following a period of direct observations (e.g., field work). That quintessential geographic question of "Why is it like this, here" has long been pursued via explorations and surveys that were both initially much more qualitative than quantitative in nature. Eminent geographer Carl Sauer placed the highest priority on the experiences, methods, and approaches of individualistic approaches. As he noted in his 1956 treatise on *Education of a Geographer*,

> "*What* (italics his) geography is, is determined by what geographers have worked at everywhere and at all times. Method is means; the choice is with the workman for his particular task; the critic may object to incompetence but not to what the author has sought. Let us ask "what is geography'' by looking for and appreciating whatever has been done well and with new insight." (Sauer, 1956, 297).

He was particularly skeptical about approaches that allowed aggregation or synthesis to preempt an interpretation of the individual or singular experience.

> "The 'unit area' scheme of mapping may be a useful cataloguing device like the decimal systems of librarians, though I doubt it, but as a means of research I should place it below almost any other expenditure of energy.
>
> These misgivings about mapping programs and their techniques rest on a growing conviction that we must not strain to make geography quantitative. Quantification is the dominant trend in our social sciences, which are imitating the more exact and experimental sciences; it happens to be fostered at the moment by the liking of those who dispense funds for long-term programs and institutional organizations. I think we may leave most enumerations to census takers and others whose business it is to assemble numerical series. To my mind we are concerned with processes

> that are largely non-recurrent and involve time spans mainly beyond the short runs available to enumeration." (Sauer, 1956, 298).

Sauer's ideas were strongly influential on generations of geographers and academic geography departments, in part because they represented an (overly) idealized view of geographical research and inquiry that was nostalgically remembered following the disciplinary-disruptive quantitative revolution of the late 1950s and 1960s. By the mid-1980s when computers and computational thinking were increasingly integrated into scholarly lines of inquiry, the late geographer Peter Gould described the tension that he observed.

> "Of the problems that geography faces, along with all of the other human sciences, is that its mathematics is borrowed, and much of it was originally generated by the need to describe a physical world of *mechanism*. This means that if geographers borrow what is essentially a mathematics of mechanism to describe certain aspects of the human world, and that mathematics comes straight out of mechanics – levers, forces, attracting masses, atoms like billiard balls and so on – then the human world expressed in this borrowed 'language' *cannot look like anything except a big machine*. And since language shapes thinking, geographers employing such mathematical 'languages' are going to have their thinking channeled and directed towards mechanistic models. So in a sense, within this pre-chosen but unthought-about mechanistic framework, the thinking of geographers may already be trapped, pre-structured and disposed towards a mechanical view of human society." (Gould, 1985, 42).

With these ideas Gould admits that he is deliberately highlighting the negatives in order to get to his main point: his prescient sense of machines dominating human thought that directly forebodes expressed fears of artificial intelligence today.

> "For mechanics, quite properly and legitimately, is a science of knowing and manipulating physical things, and there is no question that our modern word could not exist without our capacity to manipulate by devising technical solutions to some problems. The difficulties come when thinking about technical solutions shifts sideways into the parallel human world where the 'things' are not things at all, but you and me, human beings with consciousness, with the capacity for self-reflection, and the ability to judge and make choices on moral, ethical, aesthetic, religious and many other grounds – including those of love and concern." (Gould, 1985, 43).

2 Vive la Difference

These words of Sauer and Gould hint at the gaps that have long persisted between the practices of geographical and computational thinking. Traditionally, geographers pursued lines of research that were characteristically idiosyncratic. Over the decades a handful of theories and models did develop and emerge, usually involving the variable of distance (e.g., gravity models) and its role in the formation and recognition of patterns (e.g., Central Place theory, spatial autocorrelation).

However, the primacy that spatial heterogeneity is not only an observation but an expectation continued to be dominant. "The essence of geography is variation; a fundamental assumption of geography is that there is not one single environment," noted Golledge (1996, 475). Thus much geographic research has been pursued that was by definition *not* aligned with tenets of computational thinking. The methods and approaches have *not* been formulaic, systematic, procedural, or solutions-oriented, those defining aspects of computational thinking. One particular outcome of this has been that much geographic research would score very poorly on marks for scientific replicability or reproducibility.

3 Problematic Areas: Measurements and Aggregations

Our societal resistance to settle on a global standard of longitude (to aid in navigation and time-telling) until the late 19th century is analogous to the effect of computers on our ability and need to measure location with varying degrees of precision. In 1956, Sauer (the then President of the American Association of Geographers) noted that the "Time-consuming precision of location, limit, and area is rarely needed; sketch maps of type situations, cartograms at reduced scales serve most of our purposes. Field time is your most precious time - how precious you will know only when its days are past." (1956, 298).

Latitude and longitude are the poster children for geo-computation novices. Naïve users latch on to these coordinates like a fly to honey because they make sense to them: 1) they can be easily construed as X, Y values; 2) a computer will readily report these back to the 12th decimal place (because more must be better); and therefore, 3) spatial analysis of any item or phenomena can be pursued because that item's location has been machine-read and understood.

Latitude and longitude are also the poster children for geo-computation experts who are resigned to correcting the misunderstandings and their incorrect usage, and anxious about the ways that the false knowledge permeates applications and instructional exercises.

Census enumerations were dismissed by Sauer as being irrelevant for their time scale and quantitative nature, but in the digital decades since his writings, Census data have become essential components of geographical analysis and geo-computation. In the United States, the data cover all geographies comprehensively and offer the best available proxies for recent and current social and economic patterns. And their formats are tantalizingly machine-readable for geo-computation.

That said, computers are better at space than place. Census data are readily and frequently misunderstood and misused due to factors such as sampling, changes to the questions and coding over time, the modifiable areal unit problem/dilemma, ecological fallacies, and related issues of scale and zoning. These are opaque issues that most people are unlikely to know or care about, but they do affect analyses, results, and interpretations.

4 Classroom Thoughts

Interestingly, Gould noted in 1985 that "Courses in computer programming – the actual writing of the instructions to tell a computer what to do – are standard parts of geographic curricula today, and most students go on to take more specialized work necessary for courses in analytical methods, remote sensing and computer cartography" (Gould 1985, 48). What evidence Gould had to make the claim about computer programming is unknown, but nevertheless, it is not like that today (Bowlick et al. 2017). Computers and computing power are ubiquitous components of geography programs today, especially in the geospatial and mapping sciences of GIS and remote sensing, but it is uncommon for a geography instructor or student to demonstrate or develop programming skills. That lack of confidence and competence by instructors and faculty at modeling computational thinking practices for their students is a persistent barrier to advancing the practice at the curricular level. Students are sent to other departments to acquire skills with programming and other computational capacities and are then additionally challenged to link, integrate, and transfer their new knowledge to their home base learning.

One approach in higher education that has demonstrated success is to recognize that acquiring the capacity for computational thinking is beyond the outcomes of one single university course. At DePaul University, almost 20 different courses were "re-worked" to have computational thinking be an explicit component and method of instruction (Perkovic, et al. 2010). Multiple and diverse contexts proved to be more robust and effective than solitary insertions. In another situation, thoughtful design of a single course that was unambiguously problem-driven, relied on simple code that can be written rapidly, and had a significant visualization element was the right combination to encourage further computational-study (Harmbrusch et al. 2009).

Geospatial technologies serve as an effective platform to engage both geography and non-geography students with practices of computational thinking because of the nature of the digital tools and the diverse range of applications, problems, and contexts (Knobelsdorf, Otto, and Sprenger 2017). In particular, emphasis of the computational components of *information science* itself rather than GIS software was a notable outcome. Muller and Kidd (2014) found that the R platform provided the right blend and level of computational thinking and programming for exploration of geographical problems and issues. Shook and his colleagues (2016) approach the geo-computation connection by mitigating the more technologically complex dimensions via incremental, brief (one-hour), and non-threatening tutorials. I find that the systematic and regular use of tools such as Esri's ModelBuilder are efficient and effective at supporting the types of sequential and iterative workflows that computational mindsets expect. Moreover, being able to see the big picture view of an analytical process is the type of "thinking with space" that benefits all mindful activity.

5 Spatial Thinking and Spatial Relationships

In their 2016 article on Defining Computational Thinking for Mathematics and Science Classrooms, Weintrop et al. designed a taxonomy of computational thinking that bridged across four STEM dimensions: 1) data practices, 2) modeling & simulation practices, 3) computational problem solving practices, and 4) systems thinking practices. By thoughtfully breaking down the whole of computational thinking in this way, and explicitly listing tasks and behaviors that a computational-thinking practices within each of these, a holistic vision of the practices is easy to appreciate. One can appreciate how the simple practice of "collecting data" eventually builds to "defining systems and managing complexity."

Being able to articulate the practices of a savvy and seasoned geo-computational thinker in this way is an elusive but desirable goal. In this way one could specify how and where one moves beyond a rudimentary understanding of latitude & longitude to more interesting and nuanced topics. How the practices of spatial thinking constantly and consistently span methods and applications is unfamiliar to most everyone (Sinton 2016). Notably significant in its absence is the idea of spatial relationships. Understanding how objects, phenomena, ideas, entities, and other things are related– physically, conceptually, intellectually, socially, culturally – and at varying scales – is extremely rich fodder for understanding how the world works. There is key knowledge here that is typically goes unnoticed by computer scientists aiming to become more geo-enabled.

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Geocomputation with open-source software under Linux: Hands-on training for computational thinking and skills

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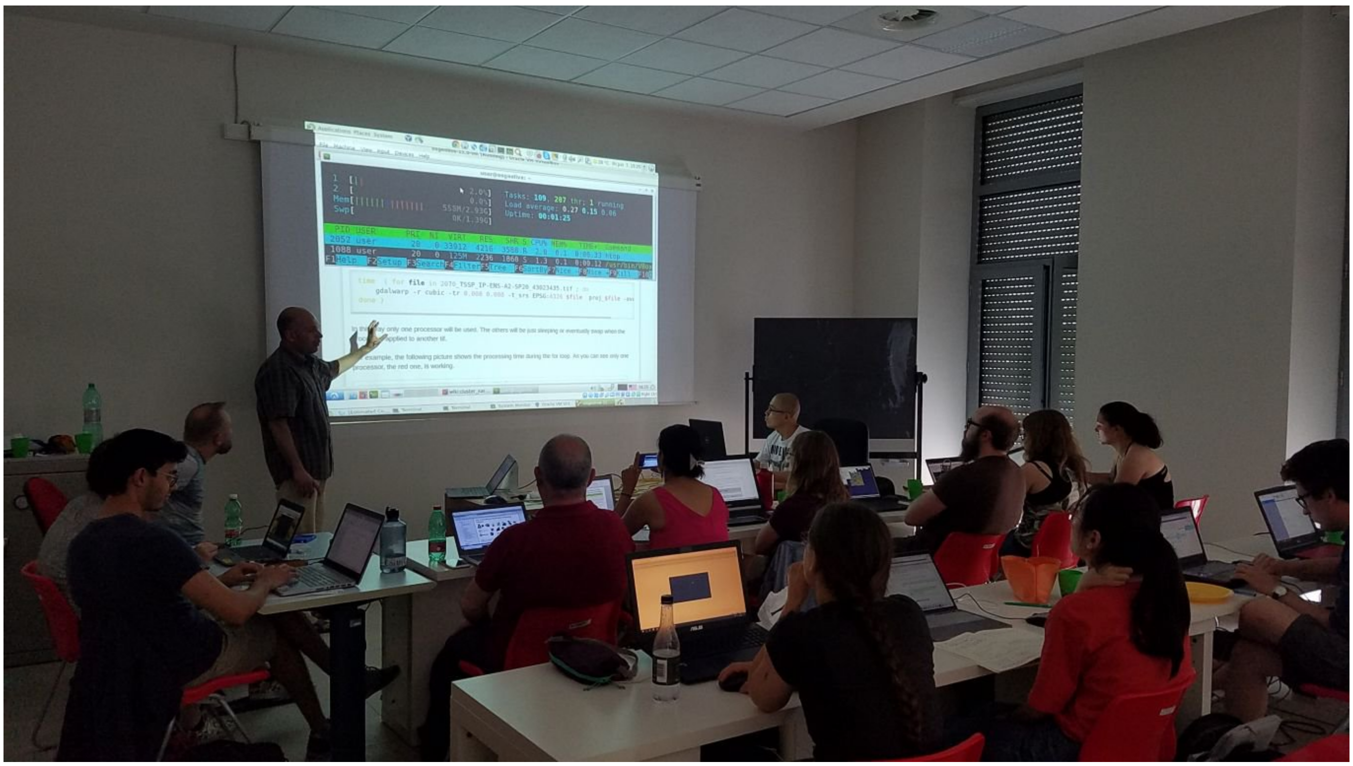

Figure 1: International Summer School in "Geocomputation Using Free and Open Source Software" 3rd - 7th June 2019, Matera, Italy, organized by www.spatial-ecology.net

CCS CONCEPTS

• **Social and professional topics** → **Information systems education**.

KEYWORDS

geocomputation courses, learning programming, computational thinking

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1 INTRODUCTION

In recent years, there has been an explosion of geo-datasets derived from an increasing number of remote sensors, field instruments, sensor networks, and other GPS-equipped "smart" devices. Processing "Big GeoData" of this kind requires flexible tools that combine efficient programming, on either personal or supercomputers. Open Source geo-software such as GRASS, GDAL/OGR, PKTOOLS, CDO and Orfeo ToolBox allow for the fast and efficient processing of geo-datasets found as rasters and vectors. These programming languages can be integrated into complex workflows using a BASH or Python interface.

Mastering skills for the analysis of spatio-temporal data is fundamental for most environmental and engineering disciplines. However, academic curricula often do not equip students for utilising these new data streams and programming languages. People trained in scientific fields are not normally endowed with the level of programming proficiency required for high performance computing but they can reap tremendous benefits from geodata processing, once such skills are acquired.

GIS and Remote Sensing courses that deal with geodata are typically based on proprietary and/or graphical user interface-based software. These platforms are limited in their scope of application and cannot be user-modified to meet sophisticated data needs. As a result, cross-disciplinary researchers and analysts are seldom able to design and implement complex geospatial workflows. In the absence of suitable courses, acquiring programming skills often requires long-term independent learning and strong personal motivation.

2 METHOD

To address the aforementioned educational need, the team at www.spatial-ecology.net has been organising intensive geospatial training workshops for the past 15 years. The curriculum is based on open source programming under a standardised Linux OS, with training delivered through pre-installed software, and readily available tutorials and exercises. The courses comprise of lectures, personalised tutorials and exercises, and round-table discussions. To aid the learning process, all course documentation and exercises are made accessible online (through wikis at www.spatial-ecology.net). These tutorials are compiled by researchers and experts who use open source tools in their respective professions.

Our approach to teaching data analysis is unique, as it integrates multiple programming languages such as AWK, BASH, PYTHON, GRASS, GDAL/OGR, PKTOOLS, CDO, Orfeo ToolBox and other software to build workflows. Nevertheless, our teaching methods complement the work of existing communities, such as OSGeo, which also provide specific tutorials and tools for the analysis of geographic data. From the outset, basic programming concepts that use command-line utilities to process large data sets are taught on our course. With simple scripts, we demonstrate how to automate essential tasks and modify programs to solve specific problems, all while achieving optimal performance and dependable results. Despite first impressions as a computer programming course, the curriculum is, in fact, focused on the application of scientific concepts: participants are guided towards solving discipline-specific problems with the help of customised computer scripts.

Rather than focusing on one programming language or software package, we introduce several tools and languages, and teach how to combine the most useful functions from each. Most of the scripts taught are based on powerful geo-tools that act as modular building blocks for the data processing tasks at hand. Each language/tool is taught under the following structure:

- Language syntax, including details on various flags and options
- Accessing help manuals and understanding available documentation
- Explaining common syntax problems and procedures to solve them (debugging)
- Structuring a script to connect various tools and/or languages
- Working with computed outputs: how to visualise and interpret data
- Assessing and validating results based on a comprehensive sketch of the analysis

Nowadays, with the advent of cloud computing, large amounts of data can be processed and stored in remote servers. Moreover, multi-core computing allows several processes to run simultaneously. To enable course participants to access the most advanced computing technologies, we also offer an introduction to cluster computing tools towards the end of each course. Training includes topics such as the transformation of a simple *for loop* into *multicore for loops*, which allow the simultaneous processing of massive datasets. Specific R libraries (*foreach, doParallel*) and BASH commands (*xargs, parallel*) are covered in the material. The teaching of this advanced module is contingent on the participants' skill levels.

3 CONCLUSION

Learning programming languages enhances problem-solving skills, and can inspire new research ideas by stimulating critical, analytical and lateral thinking. It also enables users to run preliminary tests on the viability of analytical objectives. We believe that the computational thinking process can be a natural outcome of learning code, and the former cannot be initiated without mastering the latter. This concept is akin to learning a foreign language, where a person cannot think or dream in that language without first learning its structural rules.

Overall, as trainers, the diversity of our backgrounds adds additional value to the learning experience. We come from various professions, such as geoinformatics, quantum chemistry, neuroscience, ecology and agriculture, and have taught our course globally. This rich experience uniquely positions us to understand different perspectives and learning needs. Despite our disparate backgrounds, we are equipped to teach a practical and uniform approach to data analytics, and offer our students a truly well-rounded learning opportunity. Information for new courses can be found at www.spatial-ecology.net or by registering to the Spatial-Ecology mailing list at https://lists.osgeo.org/mailman/listinfo/spatial-ecology.

On the Epistemological Aspects of Geo-Computational Thinking and Curriculum Design

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ABSTRACT

What should we teach students who are interested in geospatial data science and what should an undergraduate or graduate curriculum in this area look like? This paper addresses such issues from an epistemological perspective and discusses the critical linkages among different fields that are related to geo-computational thinking.

CCS CONCEPTS

• **Social and professional topics** → **Computational thinking**; **Information systems education**.

KEYWORDS

geo-computational thinking, curriculum design, actionable knowledge, levels of abstraction

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It is undeniable that the popularity of Python is ever growing in the field of data science. On top of this trend, many software venders have implemented numerous application programming interfaces (APIs) or development kits for users to utilize the functionalities of the software. Some of the general packages include numpy, pandas, and TensorFlow, and special packages involving geospatial data and analysis include geopandas, PySAL, and arcpy. There is an obvious benefit of this trend: a regular user can start to use any of these packages almost immediately when they find it and finish those easy-to-follow online tutorials. This trend also begs a question: is the teaching of geo-computational thinking relevant or even necessary? A follow-up question is about the need of training in computer science: should today's students in non-computer science disciplines learn core computer science concepts?

To address these questions, it is important to reasonably position geo-computational thinking. Let us start by defining geo-computational thinking as a process of using computational methods to generate actionable geospatial knowledge. Such a definition is not provided as an assertion. Instead, it is made to start a conversation. Here, actionable knowledge [1] refers to propositions that cause actions that will in turn make actual and effective real-world influences. A simple form of actionable knowledge is decision making, a process of finding alternatives that will be adopted by an organization or by individuals as a plan of action. Some examples with geographic components are whether a new industrial facility should be located at a certain place, or an individual finds the best commuting route for a certain day.

The entire process of geo-computational thinking involves various levels of abstraction. The first level of abstraction is how the reality is transformed into data. A data model is often required to make such a transformation, which is referred to as representation in the geographic information science (GIScience) literature [4]. In general, a space-time-attribution (STA) tuple of $\{x, t, a\}$ can be used to ultimately represent the geographic phenomenon in location x at time t with a set of attributes a. Different computer science theory and methods are essential to develop efficient data structures to encode the STA tuple. However, in order to understand the effectiveness and consequences of the data, it is critical to understand the data models, and therefore the theory and methods in GIScience.

The next level of abstraction is modeling, a process of developing computational models to solve problems with geographic components. While it may seem that everyone can build a model, it is reasonable to argue that an effective model, one that exhibits external validity, can only be built with the understanding of the system being modeled. Such an understanding can be considered as a metamodel that can

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be used to specify and guide the development of the actual model. Developing models requires the design of efficient algorithms [2], and the metamodel can help us understand the input and output of the model under various domain specific conditions such as uncertainty [3] and error [5].

In the above short discussion, we elaborate on the epistemological essence of geo-computational thinking. In summary, geo-computational thinking is in the intersection between computer science and geographic domain knowledge. It should be clear that programming is important but it should not replace what a formal and thoroughly designed curriculum that covers important topics from both disciplines. While it is important for students to acquire certain skill sets so that they can be competitive in job markets, as educators we should also have a clear picture about what makes geo-computational thinking and why it is important for students to receive complete training. The challenge is to identify what concepts are in the intersection, and more importantly, how different concepts from the two different fields can be cohesively combined into the curriculum design process. It will be necessary for workshops like GeoEd 2019 to take a leading role in this direction.

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