Solving Geospatial Problems under Extreme Time Constraints: A Call for Inclusive Geocomputational Education

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Abstract—**To prepare our next generation to face geospatial problems that have extreme time constraints (e.g., disasters, climate change) we need to create educational pathways that help students develop their geocomputational thinking skills. First, educators are central in helping us create those pathways, therefore, we need to clearly convey to them why and in which contexts this thinking is necessary. For that purpose, a new definition for geocomputational thinking is suggested that makes it clear that this thinking is needed for geospatial problems that have extreme time constraints. Secondly, we can not further burden educators with more demands, rather we should work with them to better understand the existing curricular context and implement sensible changes where it is most impactful. Lastly, the impacts of these implementations need to be carefully measured, and particularly in terms of broadening participation. A few examples are provided that show promise.**

Keywords— computational thinking, geocomputation, geospatial, education, broadening participation

I. GEOCOMPUTATIONAL THINKING FOR ALL

In order to prepare our next generation to face geospatial problems that have extreme space/time constraints, I propose geocomputational thinking as a skill to develop in all students. Examples of “problems that have extreme space/time constraints” are those requiring a rapid response to disasters with both a local coordination and coordination with other areas and/or at other spatial scales (e.g., state, nation, international). I would also qualify climate change under this type of problem. It is a problem that is geospatial in nature (risks, impacts, and responses will heavily depend on the local context) and that is extremely time constrained. Even though the time constraint with climate change does not compare to the immediacy a disaster can cause, there is a global urgency to coordinate solutions that mitigate or respond to climate change.

The latest summary for policymakers by the Intergovernmental Panel on Climate Change (IPCC) uses the following language:

> “All global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, and those that limit warming to 2°C (>67%), involve rapid and deep and, in most cases, immediate greenhouse gas emissions reductions in all sectors this decade. Global net zero CO2 emissions are reached for these pathway categories, in the early 2050s and around the early 2070s, respectively. (high confidence).” [1]

This statement is one of many in the IPCC report that call for significant social changes which we are used to taking a long time, therefore, these statements create a sense of extreme time constraint.

Not everyone will need to become a geocomputational expert, but in the case of a disaster, for example, everyone benefits when we know our local context (both social and environmental), when we understand basic social and environmental processes (geography), and when our communities can leverage geocomputational approaches to solve complex problems.

A. *Supply and Demand for a Geocomputational Workforce*

A report about the geospatial services industry, calculated that this industry creates approximately 4 million direct jobs, and generated 400 billion U.S. dollars globally in revenue per year [2]. Finding, recruiting, and hiring workforce with knowledge and skills in both computer science and geography (e.g., geocomputation, spatial data science), however, is difficult.

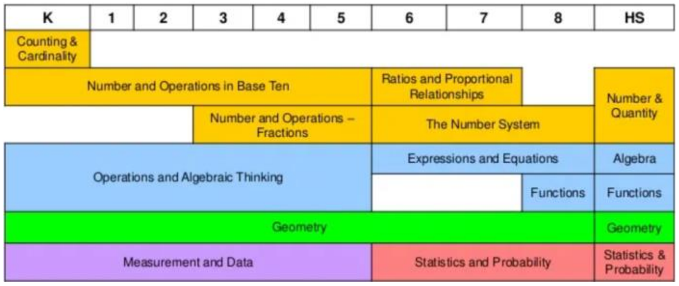
There is a general lack of awareness and understanding around careers in geography or computer science, and even less so at the intersection of those two disciplines. Among those in spatial data science or geocomputational careers, many graduated with credentials at the right level, but not in the right field, which means they end up having to learn key skills on the job. From a survey of hundreds of leaders in enterprise-level organizations and across all sectors, [3] finds that nearly 50% of respondents learned their spatial data science skills at work, and another 18% through online tutorials.

As we build capacity for workforce development in this area, we should center our efforts to also broaden participation. Broadening participation is a significant challenge in both geography and computer science [4]. As we increase our need for a workforce that requires skills and knowledge in both, geography and computer science, we should acknowledge that we will not solve our challenges with broadening participation simply by bridging both disciplines; on the contrary. Workforce development solutions should be designed with broadening participation at its foundation.

B. *Current Capacity for Workforce Development*

To better understand why there is such a shortage in the workforce at the intersection between geography and computer science, this section summarizes the educational capacity in the U.S. to train anyone with spatial thinking, computational thinking, or both (geocomputational thinking).

1) *K-12: Math, English, and Computer Science*



K	1	2	3	4	5	6	7	8	HS
Counting & Cardinality									
Number and Operations in Base Ten						Ratios and Proportional Relationships			Number & Quantity
			Number and Operations – Fractions			The Number System			
Operations and Algebraic Thinking						Expressions and Equations			Algebra
								Functions	Functions
Geometry									Geometry
Measurement and Data						Statistics and Probability			Statistics & Probability

Fig. 1. Representation by grade level of the sub-competentcies for the Mathematical standards in the Comon Core State Standards initiative for the Orting School District in Washington State [5].

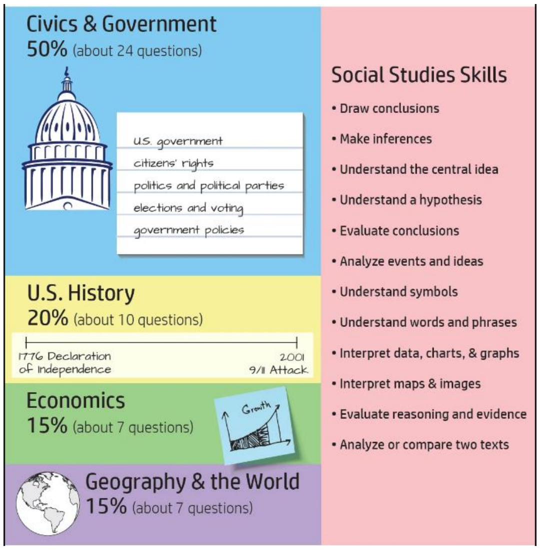
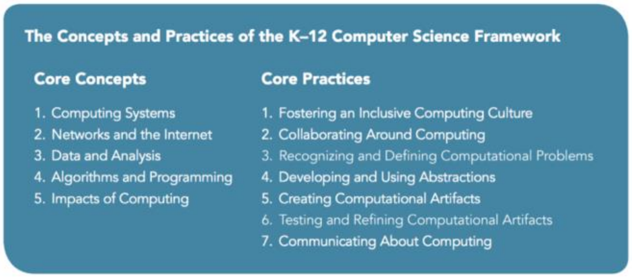


Fig. 2. Representation of the subjects within the History/Social Studies skills for the English Language Arts standards of the Common Core State Standards initiative [6].



The Concepts and Practices of the K–12 Computer Science Framework

Core Concepts

1. Computing Systems
2. Networks and the Internet
3. Data and Analysis
4. Algorithms and Programming
5. Impacts of Computing

Core Practices

1. Fostering an Inclusive Computing Culture
2. Collaborating Around Computing
3. Recognizing and Defining Computational Problems
4. Developing and Using Abstractions
5. Creating Computational Artifacts
6. Testing and Refining Computational Artifacts
7. Communicating About Computing

Fig. 3. The Concepts and Practices of the K-12 Computer Science Framework [7].

In the U.S., at the elementary and secondary education levels (K-12), the 2009 “Common Core State Standards” are the set of educational standards adopted by most states. The Common Core standardized – to an extent, what competencies students should graduate with across the U.S. When a state adopts the “Common Core”, it means that schools within that state will organize their curriculum, so their students achieve key competencies in two main areas: Mathematics and English Language Arts, or “Math” and “English” for short.

The Math and English standards are further broken down into sub-competencies by grade-level. The Math standards are well structured (see Fig. 1), and the curriculum tends not to vary much from state to state. The structure and content of the English standards, on the other hand, tend to vary from state to state. They are broken down in three separate branches, namely “Literature, “History/Social Studies”, “Science, and Technical Subjects”. The branch for “History/Social Studies” is also typically further broken down into 4 core subjects: Civics, Economics, Geography, and History (see Fig. 2). Although some of the curriculum for these subjects will look the same across states, it is also easy to see how each state or school district would also be interested to cover more local events or perspectives and thus also use some of their own set of materials to teach those subjects.

Shortly after the release of the Common Core, a coalition of individuals and organizations rallied around developing standards for Computer Science. In 2016, they published the “K-12 Computer Science Framework” [7], which outlines a set of standards (see Fig. 3). Although the need for early training in CS has been recognized by many, it has been hard for states and schools to adopt it. Most schools in states who adopted the Common Core around 2010, already aligned their curriculum around those standards and already grapple with a packed curriculum training students in Math and English. The added standards for CS, coming a few years later, create added pressure on instruction time, require new teacher training, and require tech tools (student access to computers and broadband). The latter creates an added digital divide between schools that can teach CS and those that do not [8].

2) *Higher education: Geography and Computer Science*

At the post-secondary education levels, many faculty in programs such as geography, earth science, computer science, environmental studies, and the like, see the need to offer more training at the intersection of computing and geography. There are several barriers to offering such courses [9], including barriers associated with overlap these cross-disciplinary courses create in a campus catalog.

Some colleges, however, have been able to offer courses or degree programs in spatial computing (e.g., University of Maine) or spatial data science (e.g., University of Oregon), or have invested resources into developing separate campus entities that offer interdisciplinary training (e.g., Spatial Sciences Institute at the University of Southern California Dornsife). These efforts remain limited compared to the increased demand for a workforce trained in these cross-disciplinary skills and knowledge.

C. *From disciplinary to convergence workforce development*

At the K-12 levels, we need to recognize the enormous pressure teachers already facing [10]. The increased teacher shortages are a sign that the demands we put on teachers to adapt and do more are untenable. Given these existing pressures, and this paper calling for yet more demands, I propose two things:

1) If we propose additional training needs (e.g., geocomputational thinking), we ought to be able to communicate the importance to teachers of these new needs (in comparison to all the already existing educational needs).

In the research I am leading to build capacity for geocomputational pathways, which involves social studies and computer science teachers, the first questions they ask is "what is (geo-)computational thinking?" and "why does it matter to students?". Urging educators to make adaptations to the curriculum, require us to be clear about the motivations begind those changes. In the next (section II), I will propose a definition of geocomputational thinking for educators.

2) We ought to think about additional training needs in more integrative ways rather than in additional and disciplinary siloes.

Even just within the Common Core's Math and English standards, there are already opportunities to strengthen spatial thinking, or computational thinking, or both (e.g., geometry, functions, geography, technical subjects). So, rather than suggesting new courses or curriculum, we should invest in understanding what is already being taught, and work with teachers to make adaptations that are sensible. In section III, I will cover a few examples that build geocomputational pathways without creating added burden on teachers. The proposed approaches also have promising benefits in terms of broadening participation, which is an important requirement for our workforce development.

II. DEFINING GEOCOMPUTATIONAL THINKING FOR EDUCATORS

In 2006, Jeanette Wing offers her viewpoint on computational thinking stating that "computational thinking is a fundamental skill for everyone, not just for computer scientists" [11]. Yet, educators are still trying to understand what computational thinking is, and why it should be fundamental. Again, given the increasing demands teachers face, it is fair for them to ensure these demands are not temporary crazes.

A. Defining Computational Thinking

In trying to demystify computational thinking [12] did a review of the literature starting in 2006, using Wing's viewpoint as a benchmark. Based on their inclusion and exclusion criteria they draw on 45 manuscripts and categorize computational thinking into 6 main facets, namely decomposition, abstraction, algorithms, debugging, iteration, and generalization. They also consolidate perspectives from these manuscripts into the following definition:

- Computational Thinking is "the conceptual foundation required to solve problems effectively and efficiently (i.e., algorithmically, with or without the assistance of computers) with solutions that are reusable in different contexts" [12].

With their review of the literature, [12] recognize that there is still ambiguity and that teachers still have a hard time making the connection between computational thinking and their curriculum. They blame the ambiguity and unfamiliarity associated with computational thinking to the immaturity of the field.

In a review of 96 studies to find trends in research and student assessments on computational thinking between 2006 and 2016, computational thinking is often reduced to mean computer programming because it is easier to assess a student based on something tangible like the computer code they wrote [13][13]. But they see equating computational thinking to computer programming as a limitation.

B. Computational thinking described by geographers

In trying to demystify the concept within my own discipline (geography), I asked geographers to define computational thinking. Through targeted emails and distribution during several events, an online survey was used to gather responses to the following question:

- In your own words, how would you describe computational thinking in the context of the geography discipline?

The online survey was shared during workshops at the following 2019 events:

- Annual Meeting of the Great Plains Rocky Mountain Division of the American Association of Geographers (Lawrence, Kansas)
- Annual Meeting of the American Pacific Coast Geographers (Flagstaff, Arizona)
- Annual Meeting of the Middle Atlantic Division of the American Association of Geographers (Catonsville, Maryland)
- Annual Meeting of the Southeastern Division of the American Association of Geographers (Wilmington, North Carolina)
- International Conference on Advances in Geographic Information Systems, ACM SIGSPATIAL (Chicago, Illinois)
- AAG-UCGIS Summer School on Reproducible Problem Solving with Geospatial Data Science at the University of Illinois, Urbana-Champaign (Champaign, Illinois)
- 10 targeted emails towards geographers

The survey was shared with about 110 participants and resulted in 38 complete responses in describing computational thinking in their own words. Two examples below showcase the wide-ranging responses:

- "[Computational Thinking] involves learning ways of thinking through both descriptive and analytical methods. In particular, focusing on techniques to visualize and analyze spatial data is a key skill."

- "Two main aspects of computational thinking in Geography are: 1) understanding the computing demands, limitations, and considerations, in terms of memory and time constraints of geographic algorithms for analysis and display. 2) The capacity to conceive and precisely describe a workflow (to perform geographic data manipulation or applied analysis) and the ability to streamline and implement such a workflow."

The first description of computational thinking above does not compare very well with the definition by [12], which states that "Computational thinking is the conceptual foundation required to solve problems effectively and efficiently (i.e., algorithmically, with or without the assistance of computers) with solutions that are reusable in different contexts". The second description, however, does contain similar aspects of the definition by [12].

TABLE I. contains a list of words (and their frequency in parentheses) appearing at least 4 times across these definitions. In bold are words that also appear in the definition by [12], namely problem, solve, algorithms, efficient, and solution.

TABLE I. WORDS (AND THEIR FREQUENCY) APPEARING IN DESCRIPTIONS OF COMPUTATIONAL THINKING BY GEOGRAPHERS. WORDS THAT APPEAR LESS THAN 4 TIMES WERE OMITTED FROM THIS TABLE.

Compute (37)	Geography (9)	Techniques (4)
Problem (22)	Logic (7)	Spatial (4)
Think (21)	Geographic (7)	**Efficient (4)**
Solve (13)	CT (7)	Approach (4)
Process (12)	Step (5)	Method (4)
Use (10)	Understand (5)	Part (4)
Data (10)	**Algorithms** (4)	**Solution (4)**
Way (10)	Analysis (4)	Skill (4)

Geographers were not able to further demystify the concept of computational thinking, and even geographers who use computational approaches to their research were unsure what computational thinking really meant or how to define it.

C. Defining Geocomputational Thinking

So far, however, the definitions we have are basically a combination of key parts of this type of thinking (e.g., algorithms, automation, efficiency, etc.), but they do not help anyone understand when or why this thinking should or should not be applied (compared to other types of thinking). Yet, when or why a type of thinking is required, is so important for educators to understand if they want to motivate their students to use it, and to use it within the proper context. Therefore, it would benefit educators if the definition also described the need for this thinking (compared to other types of thinking).

In my own attempt at defining (geo-)computational thinking, I use a computational approach – decomposition. I decompose the question in three sub-questions:

*1) **What is thinking?***

When we think, what we are trying to do is access parts of our brain (memory, creativity, etc.) to answer a question or solve a problem. Any thinking – whether practical, rational, critical or computational, is what we do to solve problems.

*2) **What problems require computational thinking?***

Human computers carried out difficult and time-consuming mathematical calculations by following a set of mathematical instructions (like you would follow a recipe). The thought of a machine replacing human computers came as an idea to save both time and "mental labor" as Charles Babbage put it. Ada Lovelace is considered to have written the first step-wise instructions (a.k.a. algorithm) for Babbage's conceptual mechanical computer. It is almost 100 years later, during the Second World War – when cryptologists of the Allies are tasked to decipher encrypted German intelligence messages, that huge technological leaps are made to develop electro-mechanical computers. These machines are said to have reduced wartime by several years, and in doing so, advertised – quite literally, their value in terms of time-saving. From then on, the further development of computers supported time-saving for scientific inquiry, businesses, communication, and our daily lives. The common thread here is *time*, which aligns with the definition by [12] who find that computational thinking is the solving of problems in a way that is effective and efficient, which would be especially important when time is the most important constraint.

When asked to define or describe computational thinking, many tend to describe it as thinking that mimics computers. Put that way, computational thinking may feel foreign to many today, even off-putting (I don't want to think like a machine!). With this exercise, I include the context in which this thinking is needed. Computational thinking did not emerge for the sake of computational thinking, but out of a pressing need (war) to solve a specific problem (decipher messages) and with a specific domain knowledge (cryptology). This leads me to define it as:

- "Computational Thinking is the thinking needed to solve problems that have extreme time constraints, and this thinking results in solutions that are effective, efficient, and reusable in different (social) contexts"

*3) **What is geocomputational thinking?***

Advancing the latter definition to "geo-" computational thinking, I propose the following definition:

- "Geocomputational Thinking is the thinking needed to solve geospatial problems that have extreme time constraints, and this thinking results in solutions that are effective, efficient, and reusable in different social and environmental contexts"

III. INCLUSIVE GEOCOMPUTATIONAL PATHWAYS

This paper is a call to create inclusive (i.e., visible and accessible) pathways that lead to geocomputational thinking for all, because geocomputational thinking will prepare our next generation in facing geospatial problems that have extreme time constraints (such as disasters or climate change). The challenges, however, in attracting students of all backgrounds to the geography and computer science disciplines are well-known, and have yet to be addressed. In this section, I share a few ways we can build geocomputational pathways for students while considering broadening participation.

In the U.S., the geography course subject is typically incorporated in social studies classes (see section I.B.1). Nationwide, K-12 students have been assessed on their competencies in geography (through the National Assessment of Educational Progress). This assessment measures achievement in 3 content domains: “Space and Place”, “Environment and Society”, and “Spatial Dynamics and Connections”. Achieving these skills and knowledge are clearly important for future generations to thrive within communities as a part of a changing Earth.

Yet, geography has slowly lost its prominence in the U.S. over the years. Social studies teachers reported spending only 10% of their time teaching geography. History, civics/government, and economics are often prioritized [14]. As of 2021, there are only three states (Minnesota, New Hampshire, and Utah) that require a standalone geography course for high school graduation [15]. The declining prominence of geography in the U.S. curriculum is clearly reflected in student outcomes [see [16] [14]. If we want to better prepare the next generation, we can work to ensure the geography curriculum finds its place. This will require efforts to better advocate for and communicate the importance and relevance of geography instruction within the current social context.

This could mean ensuring sufficient space for geography in social studies, but it would also be relevant for geography to find space in the math curriculum (e.g., geometry) and in the new computer science curriculum. After all, the push behind science, technology, engineering and mathematics (STEM) education is really about training the next generation to become integrative problem solvers, so seeing courses covering or integrating several subjects around one topic may be preferrable rather than teaching our students in siloed ways. In fact, an assessment about the rollout of the new CS curriculum reveals persisting disparities in terms of access and participation [8].

Exposing students to both geography and computer science may have benefits in terms of broadening participation. The Geospatial Semester, for example, helps K-12 students master geospatial technologies and the authors describe spatial thinking skills as a gateway to STEM careers. Their curiculum has shown that their use of geographic information systems augments student problem solving, particularly for females [17]. Therefore, we should test more integration of course subjects (e.g., geography in computer science curriculum, and vice versa).

Another promising avenue to broaden pathways is the use of “community-responsive education”. This pedagogical approach inquires about the lived experience of students to develop lessons that are relevant within their context, so that concepts, skills, and knowledge can “stick” [18]. The Powerful Geography framework is rooted in the same line of thinking [19] [20].

One example brings these concepts together (integrative geography and CS curriculum, and community responsive curriculum). The American Association of Geographers initiated a Research-Practice Partnership (RPP), which now includes 2 universities (San Diego State University and University of California Riverside), a community college (San Diego Mesa College), and a high school district (Sweetwater Union High School District) [21]. The RPP works with educators directly and measures the impacts of any curriculum adaptations on the aspirations and awareness of students to pursue geocomputational careers [22]. These evidence-based approaches to develop pathways is important to ensure we generate lasting change.

Finally, beyond the K-12 levels, it should become easier to create integrative workforce training (or as NSF refers to it, convergence). The new NSF Institute for Geospatial Understanding through an Integrative Discovery Environment (I-GUIDE) and this Forum, opens opportunities for convergence training.

IV. CONCLUSION

Preparing our next generation to face geospatial problems that have extreme time constraints will require us to create pathways for all students to develop their geocomputational thinking skills. Broadening participation is a significant challenge in both geography and computer science, so the pathways we create should be inclusive, and some frameworks, such as Powerful Geography [19] or community responsive pedagogy [18], are particularly promising.

Educators are central in creating those pathways. Therefore, we need to be able to convey clearly to educators why this thinking is necessary, so they share our urgency to teach those skills while also understanding why and in which contexts this type of thinking is required. For that purpose, I propose a definition for geocomputational thinking that makes it clear that this thinking is needed for geospatial problems that have extreme time constraints.

Conveying this need to educators is one thing, but we will also need to be creative when creating those pathways. Educators already face high workloads and demands with the existing curriculum [10], so rather than adding additional demands, we ought to work with them to better understand the current curricular context they are working with and implement sensible changes where it is most impactful. The impact of these implementations, however, need to be carefully measured, and particularly to ensure the impact is shared among all types of students. Research Practice Partnerships [21], for example, offer a good model to make that happen.

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