Geo-Computational Thinking in the Third Grade

Making Computational Thinking Truly "For Everyone, Everywhere"

Thomas C. Hammond
College of Education
Lehigh University
Bethlehem, PA United States
hammond@lehigh.edu

Julia Oltman
College of Education
Lehigh University
Bethlehem, PA United States
julie.oltman@lehigh.edu

Meghan M. Manfra
College of Education
North Carolina State University
Raleigh, NC United States
mmmanfra@ncsu.edu

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.

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.)

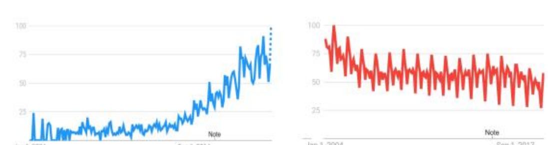

Figure 1: Google Trends data for 'computational thinking' and 'algebra' between 1 Jan 2004 and 12 Sep 2019. The vertical axis is not an absolute measure but a scaled index for

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'

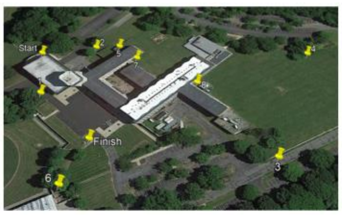

Figure 2: Example of a scaffolded geocache set up around a school building. On the left, a data table with the latitude, longitude, and error term ('accuracy') for each location. Students assemble at the start location and then use GPS units and the data table to navigate to the targets. On the right, 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.

REFERENCES

[1] J. Wing (2006). Computational Thinking. Communications of the ACM, 49, 33-35.
[2] Ibid., p. 35.
[3] A. Tucker, D. Seehorn, S. Carey, D. Moix, B. Fuschetto, I. Lee, D. O'Grady-Cuniff, C. Stephenson, and A. Verno (2011). CSTA K-12 Computer Science Standards. Revised 2011. CSTA Standards Task Force.
[4] D. Barr, J. Harrison, and L. Conrey (2011, March/April). Computational Thinking: A Digital Age Skill for Everyone. Learning & Leading With Technology, 20-23.
[5] National Research Council. (2011). Report of a Workshop of Pedagogical Aspects of Computational Thinking. Washington, D.C.: The National Academies Press.
[6] Wing 2006, p. 36.
[7] Pennsylvania Department of Education. (2012). Academic Standards for Geography, http://static.pdesas.org/content/documents/PreK-2_Geography_Standards.pdf; North Carolina Essential Standards. (2010). Third grade Social Studies, http://www.dpi.state.nc.us/docs/curriculum/socialstudies/scos/3-5.pdf
[8] P. Anthamatten, L.M.P. Bryant, B.J. Ferrucci, S. Jennings, and R. Theobald (2018) Giant Maps as Pedagogical Tools for Teaching Geography and Mathematics, Journal of Geography, 117(5), 183-192, DOI: 10.1080/00221341.2017.1413413; P.W. Blank (2002). The "Big Map": A Hands-on, Shoes-off Tool for Geographic Education. The California Geographer, 42, 77-87.
[9] H.W. Broda and R.E. Baxter. (2003). Using GIS and GPS Technology as an Instructional Tool. The Social Studies, 94(4), 158–60; R. Hagevik (2011). Developing 21st Century Learning Lsing the Power of the Globe and GPS. The Middle School Journal, 43(1), 16-23.
[10] L.M. Lary (2004). Hide and Seek: GPS and Geocaching in the Classroom. Learning and Leading with Technology, 31(6), 14–18; L. Matherson, V.H. Wright, C.T. Inman, and E.K. Wilson (2008). Get Up, Get Out with Geocaching: Engaging Technology for the Social Studies Classroom. Social Studies Research and Practice, 3(3), 80–85; J. Oigara (2011). Using GPS Technology and Geocaching as a Method to Teach Social Studies Curriculum. Proceedings of Society for Information Technology & Teacher Education International Conference. AACE, Chesapeake, VA, United States; E. Shaunessy and C. Page (2006). Promoting Inquiry in the Gifted Classroom Through GPS and GIS Technologies. Gifted Child Today, 29(4), 42-53.
[11] T.C. Hammond, A.M. Bodzin, and S.E. Stanlick (2014). Redefining the Longitude/Latitude Experience with a Scaffolded Geocache. Social Studies, 105, 237-244.
[12] Shaunessy & Page, 2006.
[13] Matherson, Wright, Inman, & Wilson, 2008.
[14] Lary, 2014.
[15] Hammond, Bodzin, & Stanlick, 2014.
[16] T. Hammond (2015). "You are Here": Developing Elementary Students' Geography Skills by Integrating Geospatial Information Technologies. Research highlights in technology and teacher education 2015, pp. 129-136. AACE, Waynesville, NC, United States.
[17] S. Grover and R. Pea (2013). Computational Thinking in K−12: A Review of the State of the Field. Educational Researcher, 42, 38-43. See also previous representation of this table in T.C. Hammond, J. Oltman, and S. Salter (2019). Using computational Thinking to Explore the Past, Present, and Future. Social Education, 83(2), 118-122.