Integrating Computational Thinking into Elementary Mathematics and Science Curriculum Materials and Instruction

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Abstract

This paper reports on a collaboration between curriculum developers, classroom teachers, researchers, and education administrators to develop and test curriculum materials that integrate computational thinking into elementary grades science and mathematics instruction. It discusses different levels of integration, provides an example, and shares questions and challenges that have grown out of this work.

Keywords: computational thinking, disciplinary integration, elementary, science, elementary mathematics;

1. Introduction

The proliferation of digital technology is changing not only the ways we live, but also the kinds of problems we can pose and solve, and the kinds of jobs that will be available in the future. This phenomenon has led to an interest in computational thinking (CT), a way of thinking that involves formulating problems, decomposing them, and structuring and communicating solutions so that humans can understand them and machines can process them. While CT is often viewed as a foundational aspect of computer science (CS) learning, it actually serves as a connection between CS and many disciplines. Computational thinking has led to profound changes in how we formulate and solve scientific, economic, social, and environmental challenges. And as computational power and availability increase, the importance of being able to think computationally also increases. Many educators believe that these foundational CT skills and practices, which are needed for success in the high-tech workforce, should be fostered beginning in elementary school so that students can develop the knowledge, skills, and practices that will prepare them for more advanced study of CS in secondary school and beyond.

While high schools and, increasingly, middle schools in the U.S. are offering stand-alone CS courses as one way to promote students' CT, it is extremely difficult to add more subjects in the elementary grades, where the school day is already filled to capacity. Instead, many elementary educators are exploring ways to integrate CT into instruction in existing subject areas. There are several benefits to this approach:

- By integrating CT into existing subjects, teachers are more likely to find instructional time to explore CT concepts (and to feel less overwhelmed by the idea of taking on wholly new instructional responsibilities).
- CT shares much in common with problem solving in other disciplines—for instance, it is referenced explicitly as an important science and engineering practice by the Next Generation Science Standards [1]. Integration allows elementary teachers to exploit the substantial overlap between CT and important skills and practices in many subject areas.
- Taking an integrated approach facilitates the development of students' CT concepts and skills in a disciplinary context while also deepening students' disciplinary understanding.

This paper reports on a collaboration between curriculum developers, classroom teachers, researchers, and CS educators/advocates. Working with over 60 teachers and administrators from 15 school districts across the state of Massachusetts, we have adapted and piloted-tested teacher-written units to integrate CT into topics within physical science, earth science, life sciences, and mathematics. These materials will be freely available at the end of the project, along with additional resources for

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integrating CT more broadly into science, mathematics, and other disciplinary instruction. Our goal is to create materials that develop CT skills and practices within disciplinary contexts, while further enhancing the learning in the underlying discipline as well.

2. Contexts for integration

Collectively, the materials we have developed focus on integrating practices related to several key aspects of CT: abstraction, data collection & analysis, modeling & simulation, and algorithms & programming [2,3]. While some of the units involve coding activities, the bulk of our effort has focused on cultivating the problem-posing and problem-solving skills and practices that are central to thinking computationally, but not specific to computer programming. By focusing on a broader characterization for CT, we aimed to develop problem-solving dispositions and skills that are both necessary for future CS study (including coding) and important for reasoning in a variety of disciplinary contexts.

2.1 Three levels for integration

In creating our materials, we have identified three levels of integration that relate to the degree to which the existing unit already engages CT through the scientific/mathematical thinking that is already part of the lessons.

1. CT concepts, skills, and practices that already **exist** in the lessons and can simply be called out or elaborated upon with examples of how they can also relate to computers or other technology (e.g., students use physical models to understand a science phenomenon).
2. Additional tasks or lessons to **enhance** the disciplinary concept and provide clear connection to computing concepts (e.g., students initially gather data on their own, create a visual representation by hand, and analyze their data; CT enhancement activities might be to plan a strategy for data collection on a larger scale, and use spreadsheets to log, organize, and create representations of the resulting data set for further analysis).
3. New lessons or sequences of lessons that **extend** the disciplinary concept as a basis for CS exploration, likely involving programming activities (e.g., students use and modify variables or underlying code in a computer simulation to investigate how dynamic systems change over time).

2.2 An example: Modeling population growth and decay

One of the units we developed, built on a Grade 3 life sciences unit, illustrates all three levels of integration as described above. An essential question the unit addresses is: “What happens to the survival of local populations if they cannot meet their needs with the resources available?” The source unit included the *Oh Deer!* game adapted from *Project Wild* [4]. This game models interconnections between a deer population and available resources over a period of time. Students are assigned roles as deer or as resources (food, water, shelter). The game is played outdoors, in rounds. In each round, deer seek out a resource; those that find their resource survive into the next round and “reproduce” (the paired resource becomes a deer in the subsequent round); those deer that cannot find their resource “die” and become a resource for the next round (Fig. 1). After a number of rounds, a wolf is introduced and the simulation continues, with additional rules taking the predator into account. Students record the counts of resources, deer, and wolves at the end of each round.

Similar number of “deer” and “resources” Few “resources”

Fig. 1. Playing "Oh Deer" game

We modified the unit by integrating CT at all three levels. The *Oh Deer!* activity already *existed* in the original unit as a model/simulation of population dynamics and interrelationships. We added information to the teacher support materials to make the CT connections explicit, and prompts for teacher-led discussions to explore the role of models and simulations in understanding systems by:

- making sense of how the game represents an actual habitat
- identifying the critical elements in the game (population totals and their interrelationships)
- identifying simplifications in the game (deer only selected a single resource type in any round)
- identifying elements were not included in the game (e.g., competition by other species for resources or other threats to resources).

This discussion is designed to help students think about the benefits of modeling in science and why scientists may choose to build simple models and run simulations with them to study complex systems and phenomena.

To engage students more directly in CT, we *enhanced* the lesson to include a broader study of the data they collected during the activity. Using a spreadsheet, students created a chart of their collected population data similar to the one in Fig. 2. Their teacher then led a class discussion asking students to describe and analyze the patterns they saw in the chart.

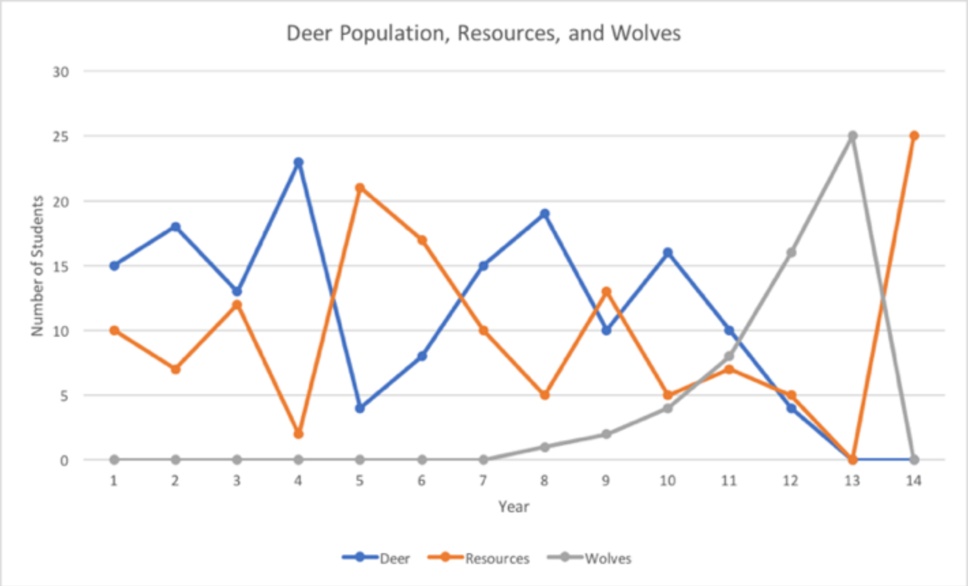

Fig. 2. "Oh Deer" data

Students made observations such as “both the blue line and the orange line go up and down” and “the blue is like the orange line, only upside down, at least at first.” These observations led to a class discussion of the interdependencies of populations, such as:

- when the resources were low one year, the deer population would go down the following year because they wouldn’t have enough resources to survive.
- when the deer population was low one year, the resources would go up the following year because fewer deer were around to consume the resources.

Students also discussed the effects of local extinction of the deer population on wolves and resources, supporting a separate goal of the overall unit that links the concept of localized extinction with the broader idea of global extinction.

We *extended* the unit to view a more complex spreadsheet-based model built to reflect the same rules they used in the *Oh Deer!* game. Simulations run using this model produce charts that demonstrate fluctuations in any number of deer and resources over 100 years. The model provides an example to young students of how a computer can be used to simulate the game they physically acted out.

In addition, by performing multiple simulations using this model, students can see different outcomes, allowing them to abstract the common relationships and patterns that emerge over more than one run of the simulation. Figs. 3 and 4 demonstrate two different runs of the simulation. The data are quite different, yet the same key patterns, initially discussed with students’ own data, emerge.

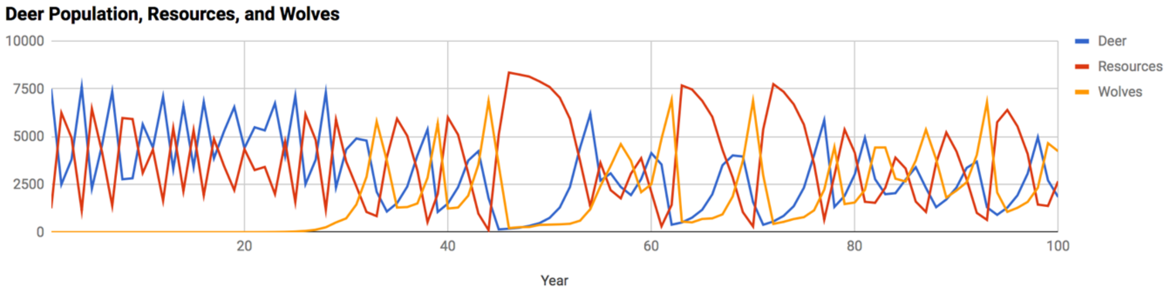

Fig. 3. Simulated data: spreadsheet model run 1

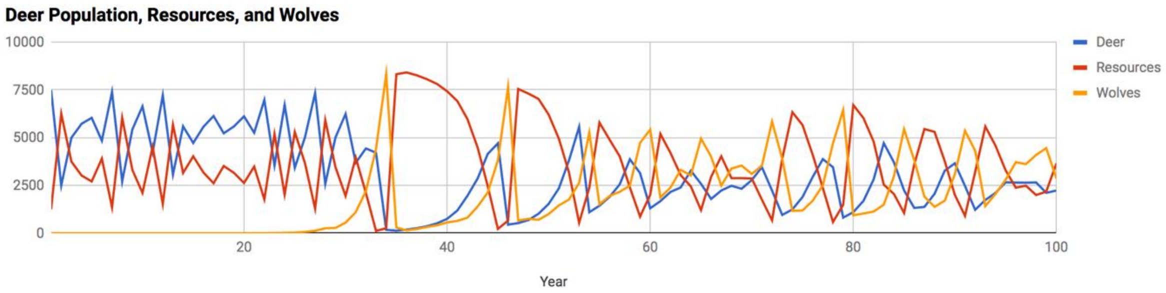

Fig. 4. Simulated data: spreadsheet model run 2

Teachers reported that the lessons developed target CT while also promoting their students' scientific sense-making. During the physical simulation, students debugged the model, identifying limitations, and suggesting clearer rules to improve it. They relied on their experiences to interpret the data they charted and to understand the electronic spreadsheet and the graph it produced. They also connected the game and their own data to the 100-year simulations produced by the spreadsheet model. Teachers were surprised and excited by the depth of their students' thinking.

3. Conclusions

Our efforts to integrate CT with core elementary content area show promise. We have observed students expressing ideas that demonstrate CT while also leveraging the integrated CT tasks to enhance their science and/or mathematics understanding. Further, teachers have expressed interest in continuing their work, with a majority reporting that they are either already finding additional opportunities to integrate CT into their lessons or are planning on doing so in the future.

We found that science is a good context for promoting CT related to models and simulations, and mathematics provides good opportunities to promote algorithmic thinking. Data analysis can be integrated with both disciplines, and in fact often brings science and mathematics learning together. There are other productive points of CT integration in both science and mathematics, but we have found these good starting points.

This work has also raised new questions and challenges to address:

- It is an open question for us as to when, or even whether, teachers should be explicit in making students aware of CT, or whether highlighting the CT integration is more for teachers' benefit, helping to motivate them to engage their students in practices that serve both CT and disciplinary learning.
- We advocate for more professional development for teachers. Many teachers lacked a deep understanding of CT, equating it with coding. While coding offers an obvious context for developing CT, the knowledgeable teacher can support students' CT through other activities as well. Furthermore, coding, particularly when integrated into disciplinary study, was often new and unfamiliar to elementary teachers and created substantial instructional challenges for them.
- We also advocate for more professional development focusing on core subject area content and instructional approaches, specifically in terms of promoting problem solving and sense-making. When teachers lacked strong science or mathematics instruction, the context for engaging CT was relatively weak.

- The lack of tested measures for both student and teacher CT understanding limit our current ability to rigorously investigate learning.

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