

Exploring the science *Framework* and NGSS: Computational thinking in the science classroom

by Cary Sneider, Chris Stephenson, Bruce Schafer, and Larry Flick

“Computational thinking is a fundamental skill for everyone, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child’s analytical ability” (Wing 2006, p. 33).

A *Framework for K–12 Science Education* identifies eight practices as “essential elements of the K–12 science and engineering curriculum” (NRC 2012, p. 49). These practices are embedded in the *Next Generation Science Standards (NGSS)* (NGSS Lead States 2013), where they are wedded closely to core ideas in the science disciplines.

Most of the practices, such as Developing and Using Models, Planning and Carrying Out Investigations, and Analyzing and Interpreting Data, are well known among science educators. In contrast, Using Mathematics and Computational Thinking, specifically “computational thinking,” may be less familiar. The vision of computational thinking as a powerful intellectual tool is described in the *Framework* as follows:

Since the mid-20th century, computational theories, information and computer technologies, and algorithms have revolutionized virtually all scientific and engineering fields. These tools and strategies allow scientists and engineers to collect and analyze large data sets, search for distinctive patterns, and identify relationships and significant features in ways that were previously impossible. They also provide powerful new techniques for employing mathematics to model complex phenomena—for example, the circulation of carbon dioxide in the atmosphere and ocean (NRC 2012, p. 64).

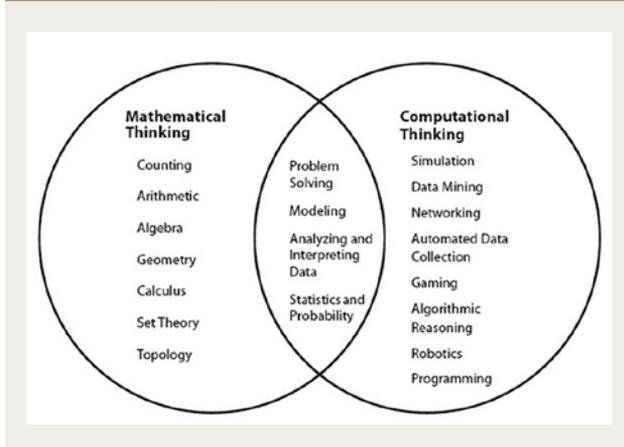


When considering the different forms of computational thinking suggested in this description, we should also reflect on how computational thinking differs from mathematical thinking. Students develop *mathematical thinking* when they approach a new situation with mathematical skills at their disposal. Similarly, they develop *computational thinking* when they approach a new situation with an awareness of the many ways that computers can help them visualize systems and solve problems. Many students have already begun their journey into computational thinking through informal use of computers. Teachers aware of the features of computational thinking can leverage students’ informal understanding and take students to the next level of knowledge and skill.

One way to understand computational thinking is to look at capabilities that can be considered mathematical thinking, those that can be considered computational thinking, and those capabilities that are both. The Venn diagram (itself a mathematical tool)

FIGURE 1

Venn diagram of mathematical and computational thinking



in Figure 1 shows how we (the authors) see the relationship between mathematical and computational thinking.

As illustrated in Figure 1, analyzing and interpreting data is just one of several capabilities common to both mathematical and computational thinking. Others are problem solving, modeling, and statistics and probability.

The NGSS describes the practice of mathematics and computational thinking for middle school as follows:

“Mathematical and computational thinking in [grades] 6–8 builds on K–5 experiences and progresses to identify patterns in large data sets and using mathematical concepts to support explanations and arguments.

- Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends.
- Use mathematical representations to describe and/or support scientific conclusions and design solutions.
- Create algorithms (a series of ordered steps) to solve a problem.
- Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.
- Use digital tools and/or mathematical concepts and arguments to test and compare proposed solutions to an

engineering design problem.” (NGSS Lead States 2013, Appendices, p. 59)

In the examples that follow, these practices are combined with others to support student learning from a number of performance expectations in the NGSS.

Simulation

Simulations that allow students to use computational thinking are not simply animations, they are dynamic computer models that involve students in changing conditions and observing new outcomes. In most cases, simulations are best used after students experience a physical phenomenon. However, some phenomena, such as natural selection, are difficult to experience directly. In these cases, simulations can be even more valuable, as they enable students to elaborate their own thinking by exploring “what if…” scenarios. Figure 2 illustrates a simulation that can provide students with experiences to help them meet a performance expectation from the middle school physical-science section of the *Next Generation Science Standards*, MS-PS3-2 (see sidebar, p. 14).

In the energy simulation in Figure 2, students are introduced to the conversion of kinetic energy to potential energy and vice versa through watching a skateboarder move up and down a ramp. As he moves down the ramp, potential energy is converted to kinetic energy as he picks up speed. As he moves up the ramp, kinetic energy is converted to potential energy as he slows down. Students can choose how much friction the ramp has and whether the skate park is on Earth, the Moon, or Jupiter, or in space, which affects the gravitational force and thus both the potential energy and the rate that the skateboarder’s speed changes. To help your students understand energy, ask them to observe how the bar graphs of kinetic and potential energy on the right side of the simulation screen change as the skateboarder rides up and down. To promote computational thinking, ask them how the simulation helps them visualize energy changes and whether the results of the simulation match what they might see at a skate park. Students might also reflect on how the simulation could be misleading if the friction is set to an unrealistic value. They can use computational thinking for a deeper understanding of how the simulation operates.

It is even possible for middle school students to create their own simulations using simulation software

(e.g., StarLogo TNG). An article by Irene Lee and colleagues describes a three-step process in which students are (1) invited to use a simulation; (2) shown how to modify the software; and (3) challenged to apply what they learned to design an entirely new simulation from the ground up (Lee et al. 2011).

Data mining

Data mining is different from data acquisition and analysis in three ways: (1) Someone else has already acquired the data, (2) the data sets are very large, and (3) the primary focus is on obtaining insights from the existing data. When students analyze data from an experiment that they have performed, the number of data points is small and the meaning is usually straightforward. In contrast, the amount and variety of data available through today's computer networks is vast. Consequently, the process for using these data for scientific investigations is different.

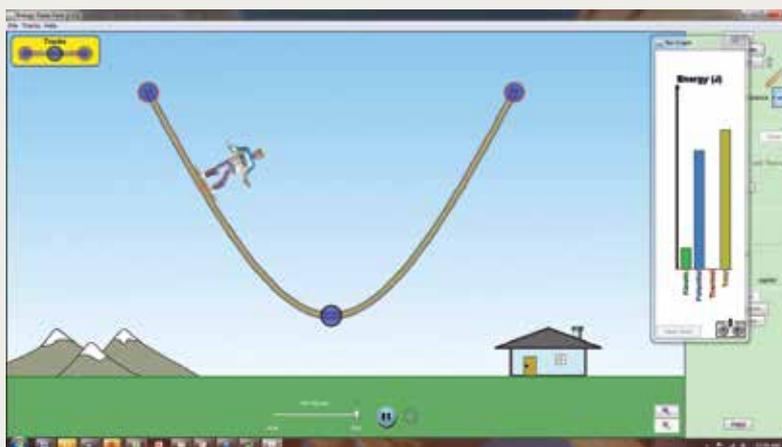
A number of programs (see Resources) help students mine the mother lode of information available through the internet today. For example, the Earth Exploration Toolkit provides Earth-system science data and scientific tools to manipulate data. Software developed for the Hands On Universe project, SalsaJ, enables students to mine astronomical databases to search for previously undiscovered asteroids. The My NASA Data website is a free data-mining resource that has several well-developed activities for elementary, middle, and high school. Two of the activities on this website support NGSS performance expectations on weather and climate, MS-ESS2-5 (see sidebar).

In the lesson plan Great Lakes Snow Analysis Collaborative Network on the My NASA Data website (see Resources), students learn about lake-effect snowfall that occurs when cold, dry arctic air passes over warmer Great Lakes water. Students develop hypotheses based on lake-effect theory about how temperature and precipitation will vary in the Great Lakes Basin. They then mine large snow and ice data sets to gather evidence for or against their hypotheses.

Gathering the evidence and discussing its significance with respect to weather theory is an excellent

FIGURE 2

Energy simulation



COURTESY OF PHET INTERACTIVE SIMULATIONS, UNIVERSITY OF COLORADO: [HTTP://PHET.COLORADO.EDU](http://phet.colorado.edu)

means of meeting this performance expectation. Students can also extend the activity to examine weather data sets in their local region. To meet the performance expectation, students will need experience with other weather phenomena, such as the conditions that give rise to tornadoes in the Midwest; they may mine the vast bank of NOAA data to see where such phenomena usually occur.

The “evidence” called for in this next performance expectation, MS-ESS3-5 (see sidebar), cannot be gathered from a classroom activity. It can, however, be gathered from the internet in a number of ways.

One lesson plan that can be used to help students achieve this performance expectation is called Is Grandpa Right? Were Winters Colder When He Was a Boy? (see Resources). In this lesson, students mine data from the NOAA paleoclimatology website. They use the provided tools to graph changes in temperature, precipitation, and cloud cover over the past 100 years and discuss possible reasons for the changes they observe. Students can also find historic images of extreme weather from NOAA's image galleries, as shown in Figure 3. Although this activity does not address causes, it provides evidence of century-long climate change and stimulates questions that students can answer through further data mining, for example the following: Were winters colder everywhere? Did cold winters last longer, as well? If so, what might cause such differences?

FIGURE 3

Deep snow



COURTESY OF NOAA: WWW.PHOTO.LIB.NOAA.GOV/700S/WEA00963.JPG

Data mining illustrates that computational thinking does not always mean using a computer to do complex calculations or to write computer programs. In this case, the power of computers allows scientists and students to investigate the natural or designed world in ways that were impossible before. The data available via computer networks include not only numbers but also images, sound recordings, and video. Using these data to answer scientific questions, or to solve engineering problems, means developing new skills, such as formulating search strategies, using the structure of the data to better understand the data's meaning, evaluating data sources, synthesizing and reporting findings, providing appropriate citations and credit for others' intellectual contributions, and in some cases making ethical judgments about the use of certain types of data.

Automated data collection and analysis

This last example involves the use of computers to automate data collection and analysis through a lesson called Photosynthesis (see Resources). This lesson gives two choices for data collection: a calorimeter or a spectrometer; at the middle school level we recommend you use the calorimeter. The lesson has several goals, including studying the effect of light on photosynthesis and comparing the rates of photosynthesis in different light conditions. To align the lesson with the performance expectation MS-LS1-6 (see sidebar), focus on developing students' explanations of conversion of water and carbon dioxide to glucose and oxygen and how the combination of glucose and

oxygen has more chemical energy than water and carbon dioxide.

While the main focus of the lesson is photosynthesis, you can also help students develop explanations of matter and energy cycles and encourage discussion about how glucose and oxygen are inputs to cell respiration (producing water and carbon dioxide and releasing energy to be used by the cell).

The lesson Photosynthesis uses data from a calorimeter to measure energy transfer over 20 minutes and then uses a computer application to perform a linear regression to estimate the rates of photosynthesis in several different situations. Students connect the calorimeter sensor to a computer, structure the data so they can be used by the computer, and manipulate the software to produce the regression. This process engages students in computational thinking as a path to developing their understanding of photosynthesis.

From computer use to computational thinking

As students learn more about what computers can do, and about their limitations, they will have an increased understanding of scientific issues (such as predicted effects of climate change) and engineering projects (such as construction of bridges and skateboard ramps and restoration of wetlands) that depend on computers. In some cases, students' increased computational-thinking abilities will encourage them to pursue science, technology, engineering, and mathematics in college and possibly as a career.

We still have much to learn about how best to engage students in computational thinking. Our goal is to enable a growing number of students and teachers to use computational thinking for a wide variety of problems—including many that we cannot even begin to imagine today.

Additional resources

The examples in this article are a small sample of the resources available on the web for teachers in all disciplines. Here are four websites to get you started:

- The Computer Science Teachers Association website (csta.acm.org/Curriculum/sub/CompThinking.html) provides articles, brochures, teachers manuals, PowerPoint documents, and even a Camtasia presentation.
- Google has an excellent website on computational

Addressing the Next Generation Science Standards (NGSS Lead States 2013)

Performance expectation: MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

Science and engineering practice: Developing and Using Models: Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to describe unobservable mechanisms.

(Each NGSS performance expectation incorporates a science and engineering practice. The one quoted here incorporates the practice of developing and using models. Computer simulations enable students to manipulate models in various ways.)

Performance expectation: MS-ESS2-5. Collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions.

Science and engineering practice: Planning and Carrying Out Investigations in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or solutions.

- Collect data to . . . serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions.

Performance expectation: MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

Science and engineering practice: Asking Questions and Defining Problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables, clarify arguments and models.

- Ask questions to identify and clarify evidence of an argument.

Performance expectation: MS-LS1-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.

Science and engineering practice: Constructing Explanations and Designing Solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories.

- Construct a scientific explanation based on valid and reliable evidence obtained from sources (including students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

thinking (www.google.com/edu/computational-thinking), which includes a link to an excellent TED Talk about computational thinking and a variety of other resources for educators.

- The Center for Computational Thinking at Carnegie Mellon (www.cs.cmu.edu/~CompThink) includes links to education resources for all grades.
- The University of Colorado's PhET Interactive Simulations (<http://phet.colorado.edu>) offers a large number of excellent, free simulations. ■

Acknowledgments

We wish to thank the PhET Interactive Simulations group at the University of Colorado for providing a wide

array of free simulations; NASA and NOAA for providing access to scientific databases in a form that students and teachers can use; researchers at TERC for their pioneering efforts in developing ways to engage students in computational thinking; and Irene Lee and colleagues for their ideas on how to help students create their own simulations.

This article was developed with partial support of the National Science Foundation (IIS-1041322 Supporting Continued Improvements to K–12 Computer Science Education). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Resources

- Earth Exploration Toolkit—<http://serc.carleton.edu/eet>
- Great Lakes Snow Analysis Collaborative Network—<http://tinyurl.com/ne3botc>

The Hands On Universe project—www.handsonuniverse.org/software

Is Grandpa Right? Were Winters Colder When He Was a Boy?—<http://tinyurl.com/oojrh32>

My NASA Data—<http://mynasadata.larc.nasa.gov>

Photosynthesis—<http://tinyurl.com/m8o3e5w>

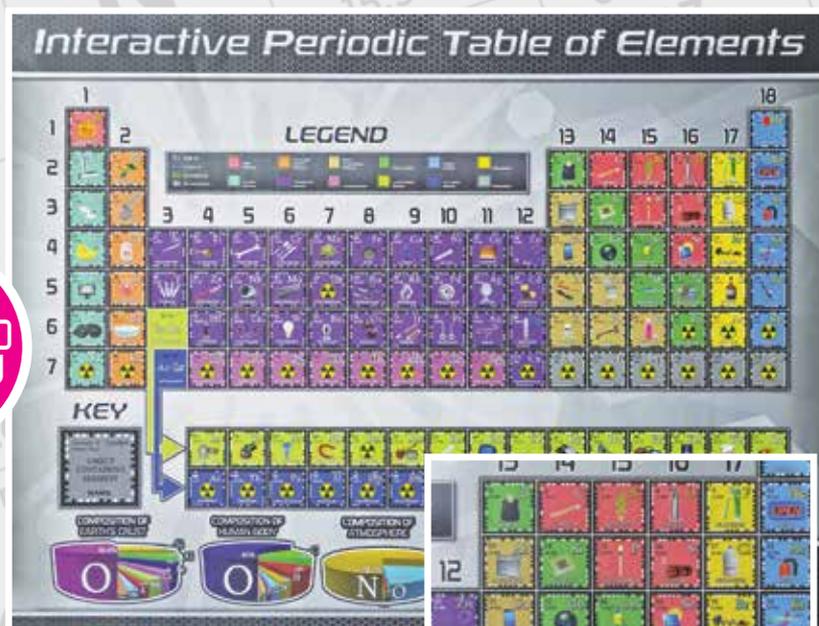
Cary Sneider (csneider@pdx.edu) is an associate research professor in the Center for Science Education at Portland State University in Portland, Oregon. **Chris Stephenson** is computer science education program lead at Google in Mountain View, California. **Bruce Schafer** recently retired from the Oregon University System in Portland, Oregon. **Larry Flick** is dean of education at Oregon State University in Corvallis, Oregon.

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