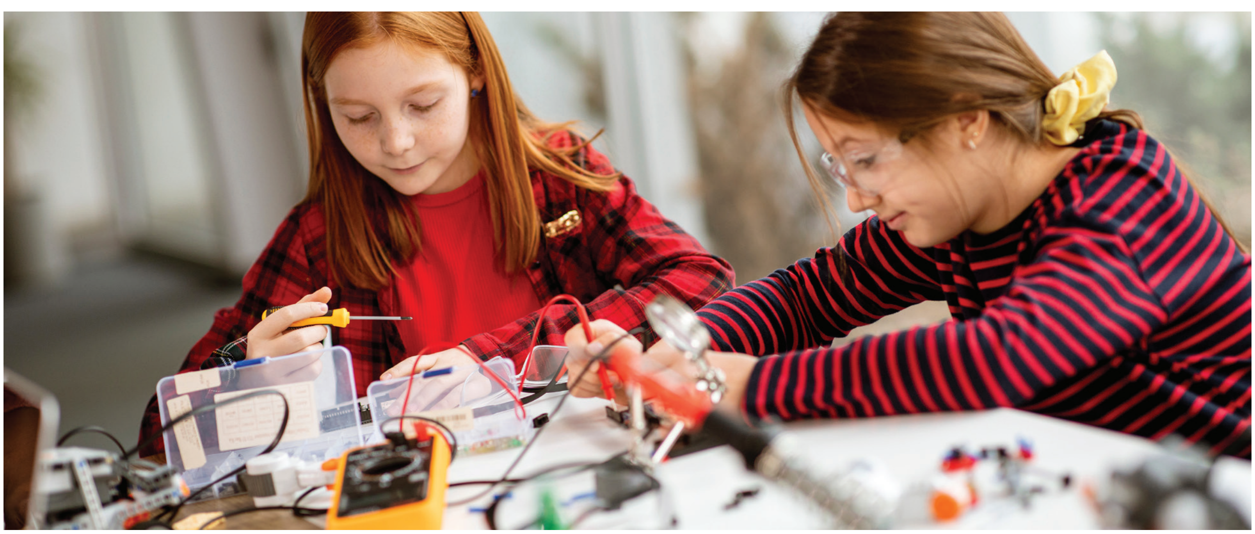
High Touch to High Tech: Computational Thinking in 3-D Science

In a kindergarten classroom, students follow steps to investigate what happens when a moving ball coming from each of three different directions collides with a wall, collecting data and finding the pattern that the ball changes direction in each test. Grade 4 students examine energy by using models of electrical systems to analyze patterns that demonstrate that energy moves and changes. And in a middle school science class, students make a model to simulate an earthquake, gather data on its effects on land and human-built structures, and then analyze the data to inform the design of earthquake-resistant buildings.

In all three cases, students are developing and using three-dimensional science practices that parallel computational thinking competencies.

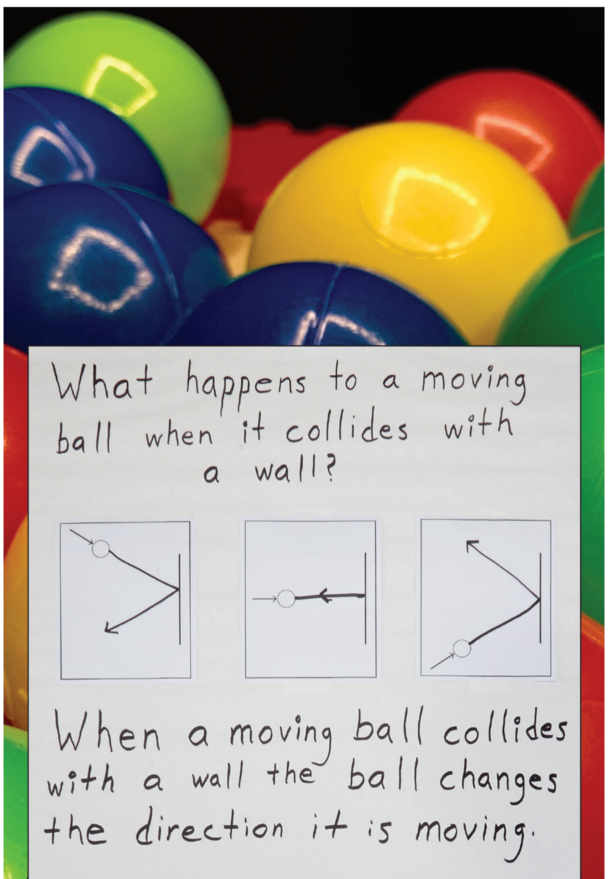
Once thought to be only a necessary framework for understanding computer science, computational thinking (CT) is increasingly recognized as a fundamental approach to problem-solving that can be applied beyond computer science to other disciplines, including the arts; humanities; social sciences; and science, technology, engineering, and math (STEM). Research supports CT as crucial for US students to develop beginning in elementary grades to prepare for future careers in or out of science (Kaya et al. 2020) and as needing to be as foundational as reading, writing, and arithmetic (Wing 2006, 33).



Upper elementary students use CT as they analyze patterns that show that energy moves and changes.

Unsurprisingly, CT is an integral part of the *K–12 Computer Science Framework* and the National Educational Technology Standards. But CT is also in the Next Generation Science Standards* (NGSS) and other state standards based on *A Framework for K–12 Science Education* (NRC 2012, 42). Using mathematics and computational thinking is one of eight essential science and engineering practices (SEPs) in NGSS. Additionally, aspects of CT competencies also appear in the SEPs of designing and building models, planning and carrying out investigations, and data analysis and interpretation.

"Computational thinking is embedded in the NGSS," Smithsonian Science Education Center (SSEC) Director Dr. Carol O'Donnell says. The NGSS states, "Students are also expected to engage in computational thinking, which involves strategies for organizing and searching data, creating sequences of steps called algorithms, and using and developing new simulations of natural and designed systems" (NGSS Lead States 2013, 58).



Kindergarten students use CT as they investigate motion and force by rolling a ball and describing its motion, leading to an understanding that motion is predictable.

O'Donnell explains that building CT abilities does not necessarily require using a computer: "Developing problem-solving skills—the ability to decompose or break down a problem into parts, pattern recognition, algorithms, modeling and simulation, evaluation—this can all be done without a computer."

CT: A Human Ability

While the term *computational thinking* may imply the use of computers, CT is essentially a problem-solving process—a human ability to process information (*K–12 Computer Science Framework* 2016, 79). It's commonly defined as "the thought processes involved in formulating problems and their potential solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (Wing 2010). That information-processing agent can be a human, a machine, or a combination of the two.

In a September 2016 CSTA webinar, then Microsoft Research Corporate Vice President Jeannette M. Wing described how she would explain CT to third-grade students: "Computational thinking is a way of solving problems where you could have the solution to that problem executed by a computer. The computer could be a human or a machine. . . . Pretend that one of your friends is in the kitchen at your home, and you want to instruct your friend to bake some chocolate chip cookies in a very precise way so that you start out with nothing and at the end, you get some cookies. . . . This person [third grader] would be essentially describing an algorithm, describing a way in which to accomplish a task that a computer—human or machine—could carry out effectively."

Wing's primary focus in her description are students' thought processes. The nuance that CT fundamentally is a human ability underscores how it can be developed outside of computer science classes through academic subjects that include science and engineering.

A Framework for K–12 Science Education calls out specific applications of computational thinking in science and engineering education (NRC 2012, 51). Students are using CT when they:

- Use models to investigate natural phenomena or to test engineering solutions
- Collect data that represent physical variables and record this data in an organized manner
- Analyze data by looking for patterns and use observed patterns to describe relationships between variables

Therefore, in a three-dimensional science classroom, students are actively engaged in CT and its application in answering questions or solving problems about real-world phenomena. And in engaging in hands-on investigations, they're able to develop CT competencies without using a computer.

When considering the natural phenomenon of an earthquake, middle school students use CT as they gather information on an earthquake's effects on land and human-built structures.

Why Unplug CT Learning?

During the first years of the COVID-19 pandemic, students and teachers mostly relied on virtual learning and digital interactions. But as of April 2022, 99.8 percent of US students had returned to in-person education (US Department of Education 2022). This return to the classroom, O'Donnell explains, provides a renewed opportunity to integrate CT competencies into hands-on, phenomena-driven science education that supports digital literacy and digital knowledge through high-touch (unplugged, or tactile) investigations.

Example of Developing and Using CT Competencies and SEPs in Investigating a Solution to an Earthquake Engineering Problem

Student Activity	CT Competencies	SEPs
Research a problem related to earthquakes causing damage.	Decompose or break down a problem into parts	Asking questions and defining problems, designing solutions
Simulate an earthquake.	Modeling and simulation, abstraction	Planning and carrying out investigations
Gather data on the earthquake's effects on land and human-built structures.	Abstraction, algorithms	Planning and carrying out investigations
Analyze the data.	Abstraction, pattern recognition	Analyzing and interpreting data
Inform the design of earthquake-resistant buildings.	Decomposition	Analyzing and interpreting data
Simulate an earthquake test.	Modeling and simulation, abstraction	Planning and carrying out investigations
Gather data on effects of the earthquake on the designed structure.	Abstraction, algorithms	Planning and carrying out investigations, designing solutions

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>
> — *Dr. Carol O'Donnell*

"A high-touch approach helps students develop computational thinking skills whether they have access to broadband or not," O'Donnell says. "There are still students who don't have access to devices and schools that may not have access to broadband. Because of that, we need to be talking about digital equity, ensuring every student is allowed to develop the skills needed."

A US Census Bureau's Household Pulse Survey found that as of March 2021, 94 percent of adults who had schoolchildren in the home had internet that was always or usually available for educational purposes (NCES 2021). With 49.4 million students enrolled in the 2020–21 school year (NCES, n.d.), that 6 percent of children who do not have home internet access represents nearly 3 million students. And despite growth in access, those living in rural areas of the country consistently have lower levels of technology ownership than urbanites and lower broadband adoption than suburbanites (Vogels 2021). For students who do not have access to computers or the internet, incorporating high-touch CT strategies can help alleviate the learning gap resulting from the digital divide.

Research has shown that by concentrating on the thought processes and practices that are associated with computing rather than specific computer tools, educators can reduce barriers for students in computing courses later in their academic years (Margolis et al. 2010, 5). Zeroing in on unplugged learning focused on problem-solving also can help teachers differentiate when students are building CT skills from when they are simply using computers (Sands et al. 2016, 13). Additionally, the Organisation for Economic Cooperation and Development's Programme for International Student Assessment found that maintaining a baseline level of inquiry-based, experiential high-touch learning and high-quality pedagogy does "more to create equity in a digital world than can be achieved by expanding or subsidizing access to high-tech devices and services alone" (OECD 2015, 3).

"Now we're returning to high-touch, physical interaction that makes a difference in students' learning," O'Donnell says. "What we can see, touch, hear, smell, taste—these perceptions matter."

The High-Touch to High-Tech Spectrum

To reiterate, research supports that high-touch, hands-on learning positively impacts students and develops CT competencies. But when available, technology can offer an additional avenue toward comprehension, providing a multimodal/multisensory approach across a high-touch to high-tech spectrum to further support diverse groups of students.

"Today, students are engaging with scientific phenomena and designing solutions to complex problems in a multimodal environment, combining the physical and the digital so they can construct their own knowledge just like scientists do," O'Donnell says.

A three-dimensional science curriculum that focuses on hands-on learning but supports moving students along a high-touch to high-tech spectrum as it integrates STEM and reading can further build CT competencies as students solve problems and engineer solutions about real-world phenomena that are relevant to them. Look for a three-dimensional science curriculum that:

- Builds toward answering a question or solving a problem through hands-on, student-centered investigations that follow a coherent storyline. This provides a logical progression from the student perspective.
- Draws on students' prior knowledge and experiences as robust resources for sensemaking. As students expand CT competencies while engaging in SEPs, they build on their initial ideas through an iterative process of critique and revision.
- Regularly engages students in structured collaboration, or group work, to improve communication and problem-solving skills.
- Incorporates digital tools that enhance learning while recognizing the tremendous variation in access to technology. Tools such as videos, web links, and simulations can connect students to places or things that are too large, too complex, too far away, or too small for them to observe firsthand.

"In our digital world, we cannot lose sight of the importance of the tactile experience. It's about the importance of bringing object-driven, phenomena-based, problem-based learning together with digital learning so they complement one another," O'Donnell says. "Using a high-touch to high-tech pedagogy that integrates STEM, art, and computational thinking, all students can improve their digital literacy—even without access to computers and other high-tech devices."

High Touch to High Tech in Three-Dimensional Science

Grade	Focus Question	Performance Expectation	High Touch	High Tech
1	What do parents and their young do to survive?	**1-LS1-2:** Read texts and use media to determine patterns in behavior of parents and offspring that help offspring survive.	Students read a story that explores behavior patterns in animal parents and offspring, communicating to the class how these behavior patterns help offspring survive.	Students assume the role of a penguin parent in a digital simulation, using trial and error to learn which behaviors keep their chick growing and alive.
3	Why measure weather?	**3-ESS2-1:** Represent data in tables and graphical displays to describe typical weather conditions expected during a particular season.	Student pairs go outdoors with weather-reading instruments to collect data over several days. They chart and compare their observations, noting similarities and differences.	Using the National Weather Service website, students analyze local wind, temperature, and precipitation data to realize that different parts of the same town can have different weather.
5	What happens when materials are mixed with water?	**5-PS1-2:** Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved.	Following a sequence of steps, students measure the weight of sugar and water separately. Then they dissolve incremental amounts of sugar in the water and measure the weight to show that when materials are mixed, their weight is conserved.	Using an Excel spreadsheet, students evaluate their data using bar graphs to demonstrate the weight of sugar and water after mixing.
6—8	How can we use models to understand wave properties?	**MS-PS4-1:** Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.	Students use a beaded chain to create model waves. They measure and compare amplitude and wavelength, leading them to realize that as energy increases, amplitude increases and wavelength decreases.	Using a digital simulation, students further investigate how observable wave characteristics are related to energy. They then create a table describing the models they used and their strengths and limitations.

Examples are from Smithsonian Science for the Classroom and Science and Technology Concepts™ Middle School.

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How the Smithsonian Science Education Center Supports High-Tech and High-Touch Science Learning

The Smithsonian Science Education Center (SSEC) is transforming K–12 education through science in collaboration with communities across the globe. One way to achieve this ambitious objective is by designing science curricula that support the science and engineering practices of three-dimensional learning. In grades K–5 Smithsonian Science for the Classroom and grades 6–8 Science and Technology Concepts™ Middle School (STCMS™) modules, students develop and use computational thinking competencies in tandem with science and engineering practices through high-touch and complementary high-tech activities as they answer questions about and develop meaningful solutions to problems in real-world phenomena.

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