By David Barr, John Harrison, and Leslie Conery

Computational Thinking: A Digital Age

The National Science Foundation has assembled a group of thought leaders to bring the concepts of computational thinking to the K–12 classroom.

A group of high school students cluster around a computer looking at a series of graphs and charts on the screen and talking quietly but intently. They are collaborating with a group of students in South America using Skype. Together they have gathered data and created a model depicting the rate of deforestation of the rain forests around the world. Today they are discussing the changes they need to make to their data representation and algorithm before running their simulation. These students are engaged in what is called *computational thinking*.

What Is Computational Thinking?

In a seminal article published in 2006, Jeanette Wing described computational thinking (CT) as a way of "solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science." She noted that computational thinking involves some familiar concepts, such as problem decomposition, data representation, and modeling, as well as less familiar ideas, such as binary search, recursion, and parallelization. She also argued that "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's article gave rise to an often controversial discussion and debate among computer scientists, cognitive researchers, and educators regarding the nature, definition, and application of CT. While many people have proposed revisions and refinements to Wing's original description, so far no single, widely accepted definition of computational thinking has emerged. As a result, PK–12 educators who recognize the importance of CT and want to help students acquire these skills have lacked a clear and practical definition to guide their work.

How Can We Make CT Accessible?

In 2009, the National Science Foundation (NSF) funded a project titled Leveraging Thought Leadership for Computational Thinking in PK–12. Led jointly by ISTE and the Computer Science Teachers Association (CSTA), the project is intended to make the concepts of computational thinking accessible to educators by providing an operational definition, a shared vocabulary, and relevant, age-appropriate examples of computational thinking tied to current educational objectives and classroom practices.

A year ago, the project convened a diverse group of educators with an interest in CT from higher education, PK–12, and industry to help define a common language surrounding computational thinking, articulate the challenges and opportunities of integrating it throughout PK–12 education, and identify the most promising practices and strategies for moving computational thinking from concept to deep integration.

From that meeting a consensus emerged regarding the essential elements of CT, its importance as a learning objective for all students, and how it might be introduced into the PK–12 educational environment. The outcomes of the meeting were summarized and synthesized into a tentative "operational definition" of CT—that is, a description of its components that educators can use to build CT skills across the curriculum through all grade levels and content areas.

Skill for Everyone

Computational thinking is a problem-solving process that includes:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them
- Logically organizing and analyzing data
- Representing data through abstractions, such as models and simulations
- Automating solutions through algorithmic thinking (a series of ordered steps)
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
- Generalizing and transferring this problem-solving process to a wide variety of problems

These skills are supported and enhanced by a number of dispositions or attitudes that are essential dimensions of CT, including:

- Confidence in dealing with complexity
- Persistence in working with difficult problems
- Tolerance for ambiguity
- The ability to deal with open-ended problems
- The ability to communicate and work with others to achieve a common goal or solution

More than 82% of the 697 respondents agreed or strongly agreed that this definition captured the essential elements of CT. An additional 9% confirmed that the definition would do as a means to build consensus in the PK–12 community. On the basis of this survey and feedback from educators gathered through conference presentations and other informal data collection, project leaders have begun implementing the next phase of the project, which involves

Learn More

To learn more about how to teach the concepts and vocabulary of computational thinking in PK–12 classrooms, please visit iste.org/computational-thinking or the CSTA website at http://csta.acm.org. Check back in a few months to find curriculm resources, vocabulary tools, and a toolkit for leaders.

developing examples of what CT skills look like in the classroom as well as assembling resources to support and guide the implementation of computational thinking concepts in PK–12 education.

How Is CT Different?

Many of the concepts, skills, and dispositions listed in this operational definition are not new. So how is computational thinking different from critical thinking or mathematical thinking?

This question has given rise to much debate but, as yet, no widely accepted consensus. The participants in the workshops sponsored by the ISTE/CSTA project proposed that CT differs from critical thinking and mathematical thinking because:

Computational Thinking in the Classroom

Here are some scenarios, developed by participants in the ISTE/CSTA practitioners workshop, that illustrate how computational thinking concepts and skills play out in various grade levels and disciplines.

In these examples, students are learning computational thinking skills in nontraditional settings so that they become internalized and can be easily transferred from one setting to another. These students are developing skills that can be applied in a variety of situations—in other classes, in the workplace, in their hobbies—from a variety of perspectives and in an authentic setting. As more and more teachers emphasize these skills, students will begin to apply them naturally in new and exciting ways.

Ms. Martinez's sixth grade social studies class is studying the Roman Empire. Students will compare events in an ancient Roman child's life to their own life experience by writing responses on the Ancient Roman Life Blog. They will also identify the lifestyle of ancient Roman children and compare it to their own. The teacher calls attention to the vocabulary of "modeling" and "simulation" and asks students to reflect on other activities in which they have used these concepts and skills. She also asks them to reflect on where they might use them in the future, including their careers. These students are learning the computational thinking concepts of representing data through abstractions, such as models and simulation, and logically organizing and analyzing data. They are also exploring ways of transferring these skills to other contexts.

Ms. Lee's seventh grade class is looking at a series of diagrams her students have created to portray floor plans of their school and homes. In the diagrams, each room is labeled as a node and each pathway out of the building is labeled as a route. Students are discussing the options for escape routes in the event of a fire. As the students and Ms. Lee look over the diagrams, you hear a conversation among the students describing how the diagrams are an abstraction of the actual rooms in a home or school building that enables them to represent all the possible escape routes. The students are preparing to create an algorithm to calculate the safest and fastest routes from the buildings.

Mr. Butler's fifth grade music class has been studying the diatonic scale and the concept of pitch. Now the students are using Scratch to create a virtual xylophone that will correctly reproduce the scale. Through observation, the students recognize that each bar of the xylophone behaves in the same manner, but the pitch varies for each bar. These students are learning the CT concepts of representing data through abstractions as well as identifying, analyzing, and implementing possible solutions. Additionally, they are experiencing the CT disposition of persistence in working with difficult problems.

Mr. Davis' ninth grade language arts class is studying various literary elements, such as plot, point of view, irony, and voice. They have read a number of short stories and are wrapping up the unit. They are preparing to write essays that explore how a particular literary device plays a part in the essence and workings of the chosen stories. These students must state their theses clearly and include at least three pieces of evidence to support the theses. The skills of logically organizing and analyzing data necessary for proving a thesis with citations of strong and thorough textual evidence are also essential elements of computational thinking. The CT concept of representing data through abstractions of literary elements, such as plot structure, setting, figurative language, tone, and point of view, is also necessary to writing a coherent essay of literary analysis with a clear thesis statement. The CT ability to communicate and work with others to achieve a common goal or solution facilitates active participation in class discussions, especially those guided by a seminar question. As the students reflect on their unit and the skills that enable them to be effective writers, they begin making connections between the skills they are using in language arts and their application to other subject areas.

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- It is a unique combination of thinking skills that, when used together, provide the basis of a new and powerful form of problem solving.
- It is more tool oriented.
- It makes use of familiar problem-solving skills such as trial and error, iteration, and even guessing in contexts where they were previously impractical but which are now possible because they can be automated and implemented at much higher speeds.

Why Is CT Important?

The application of computer technology to virtually every field of study has changed the way work is done today. While the human mind is by far the most powerful problem-solving tool we have, the ability to extend the power of human thought with computers and other digital tools has become an essential part of our everyday lives and work. We all need to understand how, when, and where computers and other digital tools can help us solve problems, and we all need to know how to communicate with others who can assist us with computer-supported solutions.

Students already learn many elements of the set of computational thinking skills in a variety of disciplines, but we need to ensure that all students have the opportunity to learn the complete set of skills so their combined power is available to them. The NSF/ISTE/CSTA project has explored how students learn computational thinking at all grade levels and in all disciplines. The long-term goal is to recommend ways that all students have the opportunity to learn these skills and to ensure that they can be transferred to different problems and used in different contexts.

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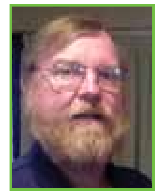

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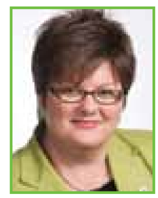

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