CIRCL Primer: Assessing Computational Thinking

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Questions, or want to add to this topic or to a new topic? Contact CIRCL.

Overview

Computational thinking (CT) is increasingly being recognized as a crucial educational literacy characteristic of 21st century learning as well as a requisite skill for the 21st century economy, which relies on computing as an essential component of commerce.   CT is broadly defined as a way of “solving problems, designing systems and understanding human behavior by drawing on the concepts fundamental to computer science” (Wing, 2006, p. 33).The term “computational thinking” can be dated back to the 1980s when Seymour Papert’s Mindstorms book brought to the mainstream the idea of using computers in K-12 schools as “objects to think with”. However, it was Jeannette Wing’s influential 2006 article on CT that helped spark CT as an educational imperative for schools. Since 2006, a total of forty (40) states have enacted--or are in the process of enacting--computer science (CS) standards and frameworks for their K-12 schools (Code.org, 2018). In high school, CS is typically a stand-alone course offering; however, on the K-8 levels, many states and districts are largely focusing on integrating computing into existing coursework, be it math, science, social studies, and/or language arts. With this curricular integration on K-8 levels, the goal is twofold: First, to foster children’s capacity to formulate and address problems systematically; and second, to direct and reinforce learning within existing academic disciplines through the refinement of such problem solving skills.

One of the primary challenges of computational thinking as an integrative, cross disciplinary competency is of **assessment**. In assessing CT, one could consider evaluating a student with regards to any or all of the three dimensions of CT:

(1) **computational concepts**: the fundamental concepts students engage with as they program or engage in CT oriented practices-such as algorithmic thinking, decomposition, abstraction, parallelism, and pattern generalization

(2) **computational practices**: the actual practices students develop as they encounter and engage with the concepts; this includes collecting and sorting data, designing and remixing computational models, debugging simulations, documenting one’s work, and collaboratively breaking down complex problems to their requisite parts

(3) **computational perspectives**: the perspectives students form about the world around them and about themselves as they comprehend these concepts and engage in such practices; perspectives here refers to learners’ own sense of agency and technology fluency, as well as a

wider appreciation as to how systems function, why they break down and how they can be improved

Given the imperative to integrate CT into existing school subjects, especially on the K-8 levels, there are questions as to how to define CT as a skill and as a knowledge. *Is CT best assessed as a series of learned concepts? How does understanding such concepts measurably inform CT practices? How does CT learning transfer across academic subject areas and how does its subject matter integration inform the dimensions of CT that can be be assessed?* Alongside these pressing questions, there are then other persistent variables to consider that are characteristic of assessing any type of learning. *How do teaching practices and purported learning styles inform the way CT is assessed, and how do these assessments relate to grade level expectations and expected competencies?*

There is general consensus from the research (Aiken et al., 2012; Dorling, 2016; Duncan, 2018; Grover, Cooper, & Pea, 2014; Grover & Pea, 2013; Snow et al., 2012; & Wentrop et al., 2015) that computational thinking represents a more robust and practical goal for K-12 schools than the more nebulous goal of “digital literacies”, which too often is driven by for-profit companies promoting particular apps and products.

Yet there is still considerable debate over the precise meaning of computational thinking, and much of this stems directly back to this question of effective and consistent assessment. Being able to effectively assess CT within different content areas allows for a greater understanding as to how it may best be implemented into a range of academic content areas. More rigorous and systematic assessment also could informs what pedagogies better facilitate learners' understanding of its various components. In the same manner, changes could be made to the wider school curricula in order to address changing student and workforce needs. Finally, gaining a stronger grasp on the ways and means CT is (and could be) assessed offers a sharpter examination of equity of access and educational experience within schools with regards to which students are encountering such content and to the degree they are comprehending it.

Key Lessons

The following lessons stem from research that has been conducted regarding defining and assessing CT concepts, CT practices, and CT perspectives:

Assessing Computational Concepts

Researchers have defined several CT concepts that are highly useful when students/designers understand them and are able to apply them in various academic and non-academic contexts:

- iterative, recursive, and parallel thinking; sequences; loops; events; conditionals; operators; data; abstraction; evaluation; algorithmic thinking/design; decomposition;

automation; pattern generalization; pattern recognition; systematic processing of information; symbol systems and representations; conditional logic; efficiency and performance constraints; debugging; and systematic error detection (Basu, Mustafaraj, & Rich, 2016; Brennan & Resnick, 2012; Grover & Pea, 2013)

Methods for Measuring CT Concepts. Guided by their design of the Three-Dimensional Integrated Assessment (TDIA) framework, Zhong, Wang, and Chen (2016) developed assessment tasks that aimed to comprehensively assess the three dimensions of CT: computational concepts, practices, and perspectives. There have been several methods proposed for measuring CT concepts. These include:

- Designed based assessments and/or software engineering metrics:

    - Dr. Scratch, a free, open source software assessment tool for Scratch; Fairy Performance Assessment as an Alice program to analyze thinking algorithmically and making effective use of abstraction and modeling (Werner, Denner, Campe, & Kawamoto, 2012); REACT-Real Time Evaluation and Assessment of Computational Thinking (Koh, Basawapatna, Nickerson, & Repenning, 2010); Bebras tasks-aimed at choosing interesting tasks, which motivate learners to deal with informatics and to think deeper about technology (Román-González, Moreno-León, & Robles, 2017)

- Accumulative content knowledge based assessments:

    - Computational Thinking Test (CTt): designed for primary and middle school; aligned with the CSTA Computer Science Standards for the 7th and 8th grade; multiple choice; each item measures one or more of seven computational concepts; this has been used in content area research (i.e. language arts) (Román-González, 2015; Román-González, Pérez-González, & Jiménez-Fernández, 2016; Román-González, Pérez-González, & Jiménez-Fernández, 2017)

    - Commutative Assessment Test: evaluate “if and how programming modality affects learnability”. (Weintrop & Wilensky, 2015, p.4)

- Assessment of computational language/vocabulary as a measurement of CT conceptual knowledge

- Surveys/Interviews/Feedback forms:
    - Artifact-Based interviews (Brennan and Rosnick, 2012); questionnaires, journal entries, and semi-structured interviews (Chalmers, 2018); Relational Screening Model: “Personal Information Form” (Durak & Saritepeci, 2017); The CTP

Video-Prompt Survey (Marsall, 2011); and teacher feedback through online forms (Duncan, 2018)

Assessing Computational Practices

CT skills can be applicable across disciplines. For example, a student studying Spanish could identify patterns in word and sentence structure, compare these patterns to ones that could be found in English, and then explain the similarities and differences in these patterns to a classmate. These are skills that can be classified as 'systems thinking' CT practices.

By transferring CT skills and practices across school subjects, students ought to be able to use different approaches and perspectives in order create more innovative solutions in other fields, including language arts, science, mathematics, social science, and humanities. Researchers have organized CT Practices into the following areas:

- ○ Data practices (collecting data, creating data, manipulating data, logically organizing and analyzing data, visualizing data)

- ○ Modeling and simulation practices (using computational models to understand a concept, using computational models to find and test solutions, assessing computational models, designing and drafting computational models)

- ○ Computational problem solving practices (formulating problems in a way that enables us to use a computer and other tools to help solve them, choosing effective computational tools, approaching the problem using programmatic thinking techniques, assessing different approaches/solutions to a problem, breaking down problems into manageable components, generalizing this problem-solving process to a wide variety of problems, developing modular computational solutions, creating computational abstractions, troubleshooting and debugging)

- ○ Systems thinking practices (investigating a complex system as a whole, understanding the relationship within a system, thinking in levels, communicating information about a system, generalizing and transferring this problem solving process to a wide variety of problems, defining systems and managing complexity)

Methods for Measuring CT Practices. There have been several methods proposed for measuring CT practices. These include:

- ○ CT skill-transfer: aimed at assessing the students' transfer of their CT skills to different types of problems

  - Bebras Task measures transfer to ‘real life’ problems (Dagiene & Futschek, 2008)
  - CTP-Quiz: analyzes the transfer of CT to the context of scientific simulations (Basawapatna, Koh, Repenning, Webb, & Marshall, 2011)

- Student-generated portfolios & rubrics
  - Project portfolio analysis (Brennan & Rosnick, 2012)
  - Rubrics designed to evaluate student work across five dimensions: general factors, design mechanics, user experience, basic coding constructs, and advanced coding constructs (Grover, Basu, & Schank, 2018)

- Audio and video capture/observation of Students engaged in CT practices

- Direct observation of student performances using field notes to document progress

- Assessments based on real-time manual input (i.e. keystroke/ time spent on task)

Assessing Computational Perspectives

As students interact and participate with CT tools and artifacts, their relationships to others as well as the world around them purportedly evolves. CT attitudes and perspectives involve elements related to that evolving understanding of self that students experience. Basically, it is how a student sees themselves, their relationship with others, and the computational thinking world around them.

Engaging students in computational thinking practices could help develop their perspectives/ dispositions, which can then potentially enhance their academic and career success. The Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) (2011) identify “confidence in dealing with complexity, persistence in working with difficult problems, tolerance for ambiguity, the ability to deal with open-ended problems, and the ability to communicate and work with others to achieve a common goal or solution” as dispositions or attitudes that are essential dimensions of CT.

Method for Measuring CT Perceptions. Examples of methods proposed for measuring CT perceptions include:

- CT Perceptions-Attitudes scales/tests/rubrics

  - Computational Thinking Scales (CTS): five-point Likert scale; examines creativity, algorithmic thinking, cooperativity; critical thinking; and problem solving (Korkmaz, Çakir, & Özden, 2017). Though this study was done in a turkish post-secondary setting, it did show validity.

        - The Computational Thinking Test (CTt) as a means to predict if 'computationally talented' students can be detected prior to learning a CT task (can levels of success be predicted prior to learning and how can this contribute to the development of more individualized lesson plans) (Román-González, Pérez-González, Moreno-León, & Robles, 2018)

        - Rubric on learning dispositions (Dorling, 2016)

        - Self-efficacy survey five point Likert scale: assesses problem solving skills and ability to think computationally (Weese & Feldhausen, 2017)

    - Computational Thinking Pattern Analysis (CTPA): implements computational thinking patterns in a student-created game and uses the game's tutorial "norm" as a gauge of creativity. (Bennett, Koh, & Repenning, 2013)

Issues

While computational thinking is increasingly being recognized as a crucial skill for K-12 students, there are a number of challenges associated with its integration into schools and effectively assessing it.

CT Definitions. First, as noted earlier, there is still a lack of consensus with regards to how to define CT knowledge and skill acquisition. Do students have to demonstrate knowledge and abilities in all dimensions of CT (concepts, practices, and perspectives), or are we able to ascertain that they have CT knowledge/skills if they only obtain/express partial knowledge in one domain? For example, if a student is able to analyze data but has not displayed knowledge of systems-thinking practices (investigating a complex system as a whole, understanding the relationship within a system, and managing complexity), can we still say this student has CT knowledge even though they have only displayed knowledge/skills in data practice? More research needs to occur in order to develop a shared understanding and vocabulary of what computational thinking encompasses.

Multiple CT Dimensions. Second, while an exact definition of CT is still a matter of debate, as the prior section details, there has been wider consensus that CT entails concepts, practices, and perspectives. Accordingly, to assess a student or program with regards to only one of these dimensions provides an incomplete picture of CT. In developing and articulating a computational thinking framework, all three of the dimensions of CT ought to be addressed. In this regard, multiple means of assessments (i.e., artifact analysis, surveys, field note observations) may very well be necessary in order to fully evaluate a student's nascent CT knowledge and abilities. Without this, there is a risk of missing key pieces of information and contributing factors, which could affect CT development and implementation (i.e. cognitive and personality traits, learning styles, age and gender specific factors, environmental effects, and curriculum contributions).

Correlations between CT Dimensions. Third, studies evaluating the acquisition of CT increasingly need to consider correlation between conceptual knowledge, practical application, and wider shifts in personal perspectives. If a student successfully completes an activity, does this simultaneously demonstrate understanding of the CT concept as well as the achievement of a particular CT practice and a broader understanding of computing's role in society? At this point, with assessing CT still in a fledgling stage, researchers have a responsibility for developing metrics for each of these dimensions and examining to what degree conceptual gains correspond to documented changes in practice and personal perspectives. Arguably the second dimension related to CT practices is the most difficult to document and ascertain. Conceptual understanding can be often be gauged by the analysis of student projects as well as through simple quizzes and puzzles related to particular CT concepts. Pre-and post surveys coupled with participant interviews meanwhile capture shifts in perspectives. Assessing actual practice however relies heavily on direct observation and field note documentation, which is especially labor-intensive and time-consuming. Real-time digital assessments, such as documenting participants' keystrokes and the time spent online on a particular task, offer more immediate sources of data around practices, but these require considerable analyses on the back-end and are rarely telling metrics without corresponding measures, such as artifact analysis and participant survey responses.

Integrating CT into Curriculum. Finally, while the question of skills transfer is not a new one, it has renewed significance as schools are increasingly attempting to integrate CT across a range of academic subject areas. While there are numerous studies documenting CT's integration into math, science, ELA, and social sciences coursework, we still altogether lack substantial research how to optimally integrate CT into the curriculum and how to assess it in terms of the content area with which it is aligned. Additional questions could include asking to what degree CT can or should be assessed as a distinct skill set, as a series of goal-directed activities or regulatory processes, and/or as part of the normal formative and summative assessment processes that are already occurring within an academic content area.

Projects & People

Examples of NSF Cyberlearning projects that overlap with topics discussed in this primer.

Computational Thinking

- Synthesis and Design Workshop: Distributed Collaboration in STEM-Rich Project-Based Learning
- Synthesis and Design Workshop: Digital Science and Data Analytic Learning Environments at Small Liberal Arts Institutions

- EXP: Readily Available Learning Experiences: Turning the Entire Web into Progressive Examples to Bridge Conceptual Knowledge Gaps for Novice Web Developers
- EXP: Automatically Synthesizing Valid, Personalized, Formative Assessments of CS1 Concepts
- The cognitive and neural mechanisms of computer programming in young children: storytelling or solving puzzles?

Other related projects :

- CIRCL Spotlight: Principled Assessment of Computational Thinking (PACT) - NSF-funded project that applies evidence centered design (ECD) to create assessments that support valid inferences about computational thinking practices; see also Assessment Design Patterns for Computational Thinking Practices in Secondary Computer Science: A First Look, a technical report from the PACT project.
- CIRCL Spotlight: Computational Thinking & The Game Zoombinis - an NSF-funded project to study the development of CT for upper elementary and middle grades students.
- Real Time Assessment of Computational Thinking (REACT) - an NSF-funded assessment tool that allows teachers to determine level of student CT skill acquisition as they code in real time

Related CIRCL Perspectives:

- Marie Bienkowski - NSF Project: Principled Assessment of Computational Thinking; Investigators: Eric Snow, Marie Bienkowski
- Deborah Fields - NSF Project: EXP: Macro Data for Micro Learning: Developing FUN! for Automated Assessment of Computational Thinking in Scratch; Investigators: Deborah Fields, Sarah Brasiel, Taylor Martin
- Mark Guzdial - Course and tool development for CS1 Course: Media Computation; FCS1 (with student, Allison Elliott Tew), the first validated test of introductory CS knowledge designed to be multilingual; replicated by SCS1 (with student, Miranda Parker)
- Yasmin Kafai - NSF Project: Collaborative Research: ET-ECS: Electronic Textiles for Exploring Computer Science with High School Students and Teachers to Promote Computational Thinking and Participation for All; Investigators: Yasmin Kafai, Jane Margolis, Joanna Goode
- Pati Ruiz - 2016 NSF Video Showcase: Broadening Participation
- Aman Yadav - NSF Project: PD4CS (Professional Development for Computer Science); CPATH-2: Computer Science Pathways for Educators

Resources

Related CIRCL Primers:

- CIRCL Primer: Computational Thinking - an overview of computational thinking definitions, frameworks, and research by the Cyberlearning 2016 working group.
- CIRCL PRimer: Evidence-Centered Design (ECD) - an approach to designing educational assessments, which measure their intended constructs and yield to evidential arguments.

Conferences & Organizations:

- AERA SIG/ATL and SIG/LS - Special Interest Groups in Advanced Technologies for
- Learning and Learning Sciences
- CSforAll - Resources for districts, schools, and classrooms to help provide all K-12 students with an effective computer science education.
- CSTA - Computer Science Teachers Association
- Code.org - Online resource for learning and teaching coding practices (aim: increase access to computer science in schools)
- ICLS - International Conference of the Learning Sciences
- ISTE - The International Society for Technology in Education
- K12CS - K–12 Computer Science Framework
- RESPECT - Research on Equity and Sustained Participation in Engineering, Computing, and Technology
- SIGCSE - Special Interest Group on Computer Science Education

Videos:

- Integrating Computational Thinking into Mathematics Instruction in Rural and Urban Preschools - Brief overview of project with: CT learning blueprint; CT/math alignment document (preschool math Building Blocks curriculum); hands-on activity prototypes that focus on the CT concepts (sequencing, debugging, and modularity); and brief discussion on ways to assess preschool students' CT learning and preschool teachers' CT understanding
- Principled Assessment of Computational Thinking (PACT): Assessing Computational Thinking in High School - An overview of what PACT has accomplished and future plans. Two ECS teachers also discuss their use of the ECS assessments developed by the PACT team.
- ScratchEd Webinar-Assessing Computational Thinking: May 2012 -- ScratchEd Team discusses different approaches to assessing students' understandings of computational thinking

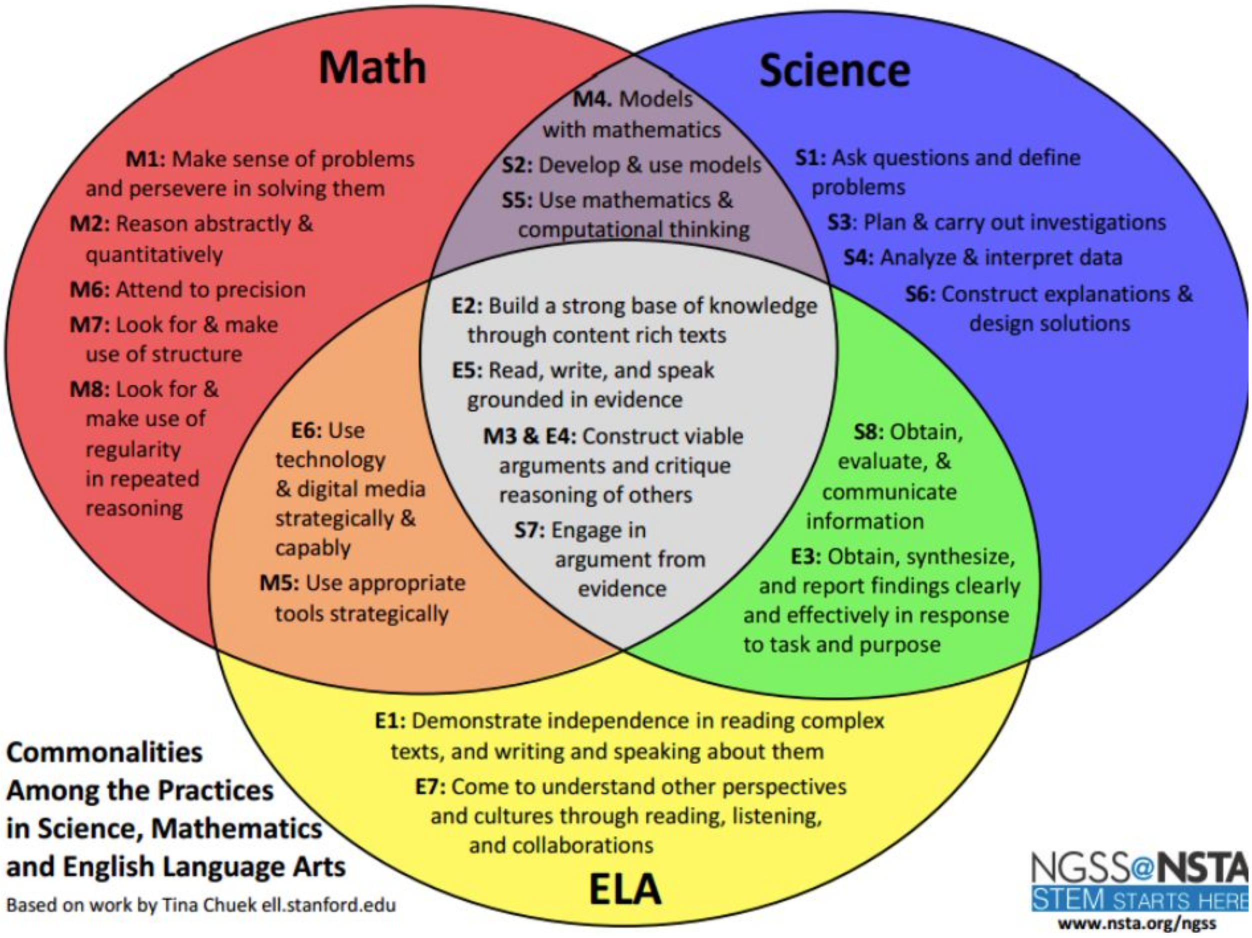
Digital Media:

- 7 Computational Strategies - e-school news provides seven computational thinking strategies to equip students with problem-solving abilities
- Computational Thinking Concepts Guide - concepts, definitions, and teaching tips
- Computational Thinking in Cyberlearning in K-12 - an accumulation of digital articles on CT and cyberlearning
- Cyberlearning Community Report: The State of Cyberlearning and the Future of Learning With Technology: describes six design themes emerging across multiple NSF-funded cyberlearning projects: Community Mapping: Moving and Discovering Across Contexts; Expressive Construction: Enabling Learners to Represent Powerful Ideas; Enhancing Collaboration and Learning through Touch Screen Interface; Virtual Peers and Coaches: Social and Cognitive Support for Learning; Classrooms as Digital Performance Spaces; and Remote Scientific Labs: Authenticity at Distance
- Fairy Performance Assessment: Measuring Computational Thinking in Middle School - preliminary results of a performance assessment tool for measuring CT in middle school (game-based design)
- Operational Definition of Computational Thinking for K–12 - The Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE)

Tools:

- AgentSheets
- Alice
- App Lab
- Arduino
- ARIS
- Blocky Talky
- Dr. Scratch
- EarSketch
- Hummingbird Robotics
- MIT App Inventor
- Modkit
- Ready, Steady, Code
- Scratch
- Tree House

Computational Thinking Frameworks:



Math

M1: Make sense of problems and persevere in solving them

M2: Reason abstractly & quantitatively

M6: Attend to precision

M7: Look for & make use of structure

M8: Look for & make use of regularity in repeated reasoning

Science

S1: Ask questions and define problems

S3: Plan & carry out investigations

S4: Analyze & interpret data

S6: Construct explanations & design solutions

M4. Models with mathematics

S2: Develop & use models

S5: Use mathematics & computational thinking

E2: Build a strong base of knowledge through content rich texts

E5: Read, write, and speak grounded in evidence

M3 & E4: Construct viable arguments and critique reasoning of others

S7: Engage in argument from evidence

E6: Use technology & digital media strategically & capably

M5: Use appropriate tools strategically

S8: Obtain, evaluate, & communicate information

E3: Obtain, synthesize, and report findings clearly and effectively in response to task and purpose

E1: Demonstrate independence in reading complex texts, and writing and speaking about them

E7: Come to understand other perspectives and cultures through reading, listening, and collaborations

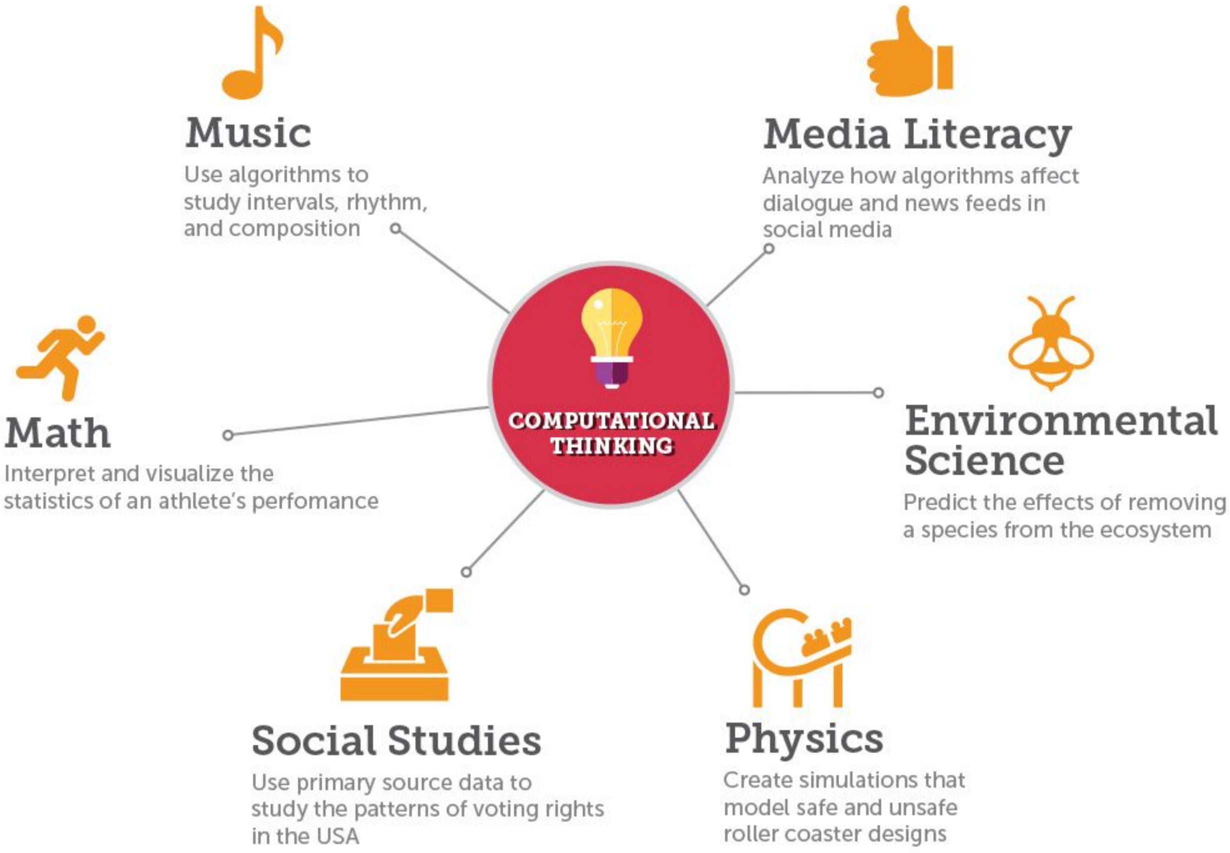
ELA

Commonalities Among the Practices in Science, Mathematics and English Language Arts

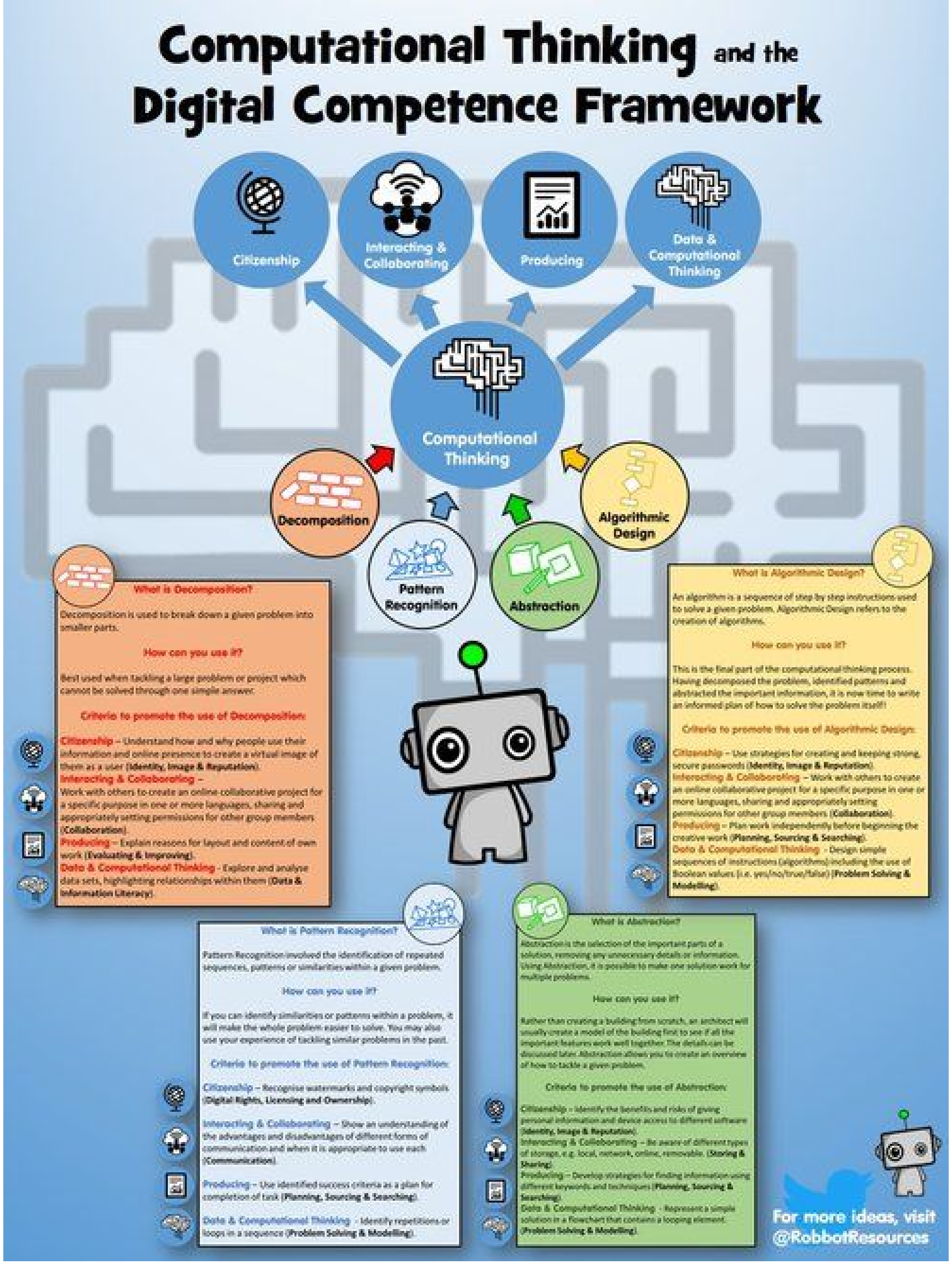
Based on work by Tina Chuek ell.stanford.edu

NGSS@NSTA
STEM STARTS HERE
www.nsta.org/ngss

From presentation by P. McLaren & J. Solek


Music
Use algorithms to study intervals, rhythm, and composition
Media Literacy
Analyze how algorithms affect dialogue and news feeds in social media
Math
Interpret and visualize the statistics of an athlete's perfomance
COMPUTATIONAL THINKING
Environmental Science
Predict the effects of removing a species from the ecosystem
Social Studies
Use primary source data to study the patterns of voting rights in the USA
Physics
Create simulations that model safe and unsafe roller coaster designs

From Angevine, C. (2017). Advancing computational thinking across K-12 disciplines.



Computational Thinking and the Digital Competence Framework

What is Decomposition?

Decomposition is used to break down a given problem into smaller parts.

How can you use it?

Best used when tackling a large problem or project which cannot be solved through one simple answer.

Criteria to promote the use of Decomposition:

Citizenship – Understand how and why people use their information and online presence to create a virtual image of them as a user (**Identity, Image & Reputation**).
Interacting & Collaborating – Work with others to create an online collaborative project for a specific purpose in one or more languages, sharing and appropriately setting permissions for other group members (**Collaboration**).
Producing – Explain reasons for layout and content of own work (**Evaluating & Improving**).
Data & Computational Thinking – Explore and analyse data sets, highlighting relationships within them (**Data & Information Literacy**).

What is Algorithmic Design?

An algorithm is a sequence of step by step instructions used to solve a given problem. Algorithmic Design refers to the creation of algorithms.

How can you use it?

This is the final part of the computational thinking process. Having decomposed the problem, identified patterns and abstracted the important information, it is now time to write an informed plan of how to solve the problem itself!

Criteria to promote the use of Algorithmic Design:

Citizenship – Use strategies for creating and keeping strong, secure passwords (**Identity, Image & Reputation**).
Interacting & Collaborating – Work with others to create an online collaborative project for a specific purpose in one or more languages, sharing and appropriately setting permissions for other group members (**Collaboration**).
Producing – Plan work independently before beginning the creative work (**Planning, Sourcing & Searching**).
Data & Computational Thinking – Design simple sequences of instructions (algorithms) including the use of Boolean values (i.e. yes/no/true/false) (**Problem Solving & Modelling**).

What is Pattern Recognition?

Pattern Recognition involved the identification of repeated sequences, patterns or similarities within a given problem.

How can you use it?

If you can identify similarities or patterns within a problem, it will make the whole problem easier to solve. You may also use your experience of tackling similar problems in the past.

Criteria to promote the use of Pattern Recognition:

Citizenship – Recognise watermarks and copyright symbols (**Digital Rights, Licensing and Ownership**).

Interacting & Collaborating – Show an understanding of the advantages and disadvantages of different forms of communication and when it is appropriate to use each (**Communication**).

Producing – Use identified success criteria as a plan for completion of task (**Planning, Sourcing & Searching**).

Data & Computational Thinking – Identify repetitions or loops in a sequence (**Problem Solving & Modelling**).

What is Abstraction?

Abstraction is the selection of the important parts of a solution, removing any unnecessary details or information. Using Abstraction, it is possible to make one solution work for multiple problems.

How can you use it?

Rather than creating a building from scratch, an architect will usually create a model of the building first to see if all the important features work well together. The details can be discussed later. Abstraction allows you to create an overview of how to tackle a given problem.

Criteria to promote the use of Abstraction:

Citizenship – Identify the benefits and risks of giving personal information and device access to different software (**Identity, Image & Reputation**).
Interacting & Collaborating – Be aware of different types of storage, e.g. local, network, online, removable. (**Storing & Sharing**).
Producing – Develop strategies for finding information using different keywords and techniques (**Planning, Sourcing & Searching**).
Data & Computational Thinking – Represent a simple solution in a flowchart that contains a looping element. (**Problem Solving & Modelling**).

From Rob-Bot Resources

Readings

References and key readings used in this primer on the dimensions of CT thinking (concepts, perspectives, and practices) as well as research on assessment in these areas are listed below.

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Citation

Suggested citation:

Burke, Q., Bailey, C. S., & Ruiz, P. (2019). CIRCL Primer: Assessing Computational Thinking. In CIRCL Primer Series. Retrieved from http://circlcenter.org/assessing-computational-thinking

Special thanks to Kerri-Anne O’Donnell and Patricia Schank for reviewing and suggesting edits to this primer.