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Assessing computational thinking: an overview of the field

The last decade has seen rapid growth in the presence of computational thinking (CT) in educational contexts. Those working to advance CT argue that the concepts and skills associated with CT are essential to succeed in an increasingly computational world. As a result of these efforts, CT has a growing presence in K-12 classrooms and beyond. This can be seen in the inclusion of CT in disciplinary standards (e.g. the Next Generation Science Standards and Common Core Math identifying CT as a core practice), as well as national curricular efforts (e.g. the United Kingdom's national computing curriculum seeks to have students "develop and apply their analytic, problem-solving, design, and computational thinking skills"). Just as CT has a growing presence in formal education, it can also be seen in informal contexts through the growth of computing camps, after-school and library CT programming, and a growing array of toys designed to engage youth with CT.

The contemporary discussion around CT began with Wing's (2006) article, where she argued "to reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability" (p. 33). However, the conceptual origins have a much longer history, dating back to early work on the Logo programming language and Papert's insights on the potential of computing as a powerful context for learning (1980). In response to Wing's article, much effort has been dedicated to trying to define what constitutes CT and where the boundaries of the construct lie. While the community has yet to settle on a single unified definition, there is general consensus that CT includes foundational computing concepts such as abstraction and algorithms, as well as computing practices such as problem decomposition and debugging (Grover & Pea, 2013; Shute et al., 2017). As the dust started to settle from early debates around the scope and nature of CT, a growing number of research projects sought to design CT learning experiences. Spurred in part by an increase in funding for educational projects at the intersection of computing and other disciplines, a space in which CT is particularly well-suited to contribute, the last decade has seen tremendous growth in curricula, learning environments, and innovations around CT education (Tang et al., 2020). In the wake of this growth, this special issue seeks to respond to a question of growing importance: *How do we assess computational thinking*?

This is not a straightforward question to answer as several aspects of CT make it challenging to assess. For example, there is a wide variety of methods by which CT is taught and contexts in which students learn CT. While some schools offer stand-alone CT learning experiences, other schools may try to integrate CT within current subject matters. Further, as discussed above, CT is a relatively ill-defined construct, thus, different assessments may focus on slightly different dimensions of CT. Collectively, this produces a landscape where a variety of assessments are needed to reflect the different conceptual, contextual, and motivational aspects of CT instruction.

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In selecting work for this special issue, a concerted effort was made to capture the plurality of ways in which CT is being assessed, while at the same time demonstrating the importance of building upon the fundamentals of assessment design. Towards this end, submissions were categorized based on several dimensions, including learning context (e.g. kindergarten classroom), age/grade of learners, CT definition, relation to other disciplines (e.g. integrated vs. stand-alone), methodological approach, and assessment type. The result is a set of seven papers that span these categories. We briefly summarize this work below, providing a picture of the breadth of research on assessing CT, beginning with work focused on young learners.

As the presence of CT in early elementary classrooms grows, so too does the need to have effective assessments for such early learning contexts. Towards this end, Clarke-Midura and colleagues document the development of an empirically grounded assessment in their paper entitled *Developing a kindergarten computational thinking assessment using evidence-centered design: the case of algorithmic thinking*. This work is novel both in the context (CT in kindergarten) as well as in the approach to assessing CT in a screen-free context, relying on paper-based activities to evaluate young learners' emerging algorithmic thinking skills. This work expands the landscape of CT assessment to consider the assessment of CT in unplugged contexts with young children.

Continuing to slightly older learners, Gane and colleagues draw on learning trajectories to develop an assessment for CT situated in a mathematics context. Their paper, entitled *Design and validation of learning trajectory-based assessments for computational thinking in upper elementary grades*, focuses on assessing learners in grades 3 and 4 on the constructs of sequence, repetition, conditionals, decomposition, variables, and debugging. This work demonstrates how learning, instruction, and assessment can be coordinated based on a model of what it means to learn and know CT.

Not all learning objectives can be measured using the same type of tasks or assessment approach, a fact that must be taken into account during the design process. This is especially true in the context of CT given its various facets, which can make designing CT assessments particularly difficult. Basu and colleagues speak directly to this challenge in their paper titled *A principled approach to designing computational thinking concepts and practice for upper elementary grades*. They show how an evidence-centered design approach can be used to develop separate assessments for measuring concepts and practices using easily-scorable tasks. The paper discusses how a set of focal knowledge, skills, and abilities were developed that matched the purpose and requirements of the assessment. The paper further discusses the design process and provides results of the administration of the two assessments as part of a large-scale evaluation project.

Shifting away from written assessment, Metcalf and colleagues investigate assessments that ask learners to enact CT practices, employing their CT knowledge and skills to generate computational artifacts. In their paper *Assessing computational thinking through the lenses of functionality and computational fluency*, Metcalf and colleagues present two rubrics that can be applied to assess student-created artifacts, one that focused on the functionality of the resulting program and the other that focused on the stages of development. These two rubrics reflect the desire to assess both declarative and procedural CT competency.

In response to a recognition of the multifaceted nature of CT, Fields and colleagues report on research using portfolio analysis to identify and assess students' ability to communicate about computational practices in their paper titled *Communicating about Computational Thinking: Understanding Affordances of Portfolios for Assessing High School Students' Computational Thinking and Participation Practices*. This work focuses on a high-school unit in which students work on e-textile projects and create portfolios containing the artifacts they create alongside a description of their process and the challenges they encountered along the way. This work contributes along several novel dimensions to the picture of CT assessment painted by this special issue, namely another methodological approach (portfolio review), a novel CT learning context (e-textiles in high school classrooms), and additional dimensions of CT (communication).

One feature of many CT learning experiences situated in computational contexts is the ability to collect fine-grained data on student performance by logging student interactions. In their paper entitled *How Do Students Develop Computational Thinking? Challenges and Difficulties Assessing Early Programmers in a Maze-Based Online Game*, Guenaga and colleagues look at data from young students (ages 8–14) who used an instrumented coding platform to solve coding puzzles. Drawing on best practices from learning analytics research, this work provides useful tools and techniques that can be used to create a more well-rounded picture of student's knowledge. Such assessments provide insight into students' understanding of CT concepts as well as ways the assessment itself, in this case the maze-based puzzles, can be improved.

Acknowledging the plurality of context where CT learning occurs, this special issue also includes work by Weintrop and colleagues exploring how CT is assessed in library contexts. In their paper, entitled *Assessing Computational Thinking in Libraries*, Weintrop and colleagues interviewed 37 library staff members from across the United States to identify the motivations library staff members have for bringing CT into their buildings, the challenges they face in trying to assess CT, and what library would like to assess about their CT programming. This work contributes new insights into the motivations, challenges, and aspirations of those providing CT learning experiences beyond the walls of the classroom.

Looking across the research compiled for this special issue, this collection provides insight into the different ways in which CT is being assessed and the methods used for creating innovative CT assessments. As the field of CT continues to grow, so to must the landscape of CT assessments. While we know there are many other projects and assessments beyond what is captured here, we hope that these articles will inspire new tools, methods, and insights that advance the goal of creating assessments that live up to the lofty aspirations of CT.

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