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Teacher Practices for Formatively Assessing Computational Thinking with Early Elementary Learners

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Abstract: Few studies of computational thinking (CT) integration in elementary curricula have yet focused on supporting early elementary educators with implementing and assessing their young students' application of these practices to content area work. This paper summarizes a collaborative research project that engaged researchers, K-second grade teachers, and professional development (PD) providers in implementing a hybrid PD model to answer the following research questions: (1) What kind of PD and guidance do teachers need to identify and support emergent computational thinking development in young students' language and work process? (2) What kind of PD and guidance do teachers need to identify emergent computational thinking development in young students' work products? This project employed a mixed-methods research design that included pre- and post-surveys and interviews with teachers to measure and understand how growth in teachers' confidence, knowledge, and self-efficacy with CT prepared them to identify and support these concepts with young learners. Additionally, analysis was able to identify the key formative assessment strategies these teachers employed to generate insight into students' understanding and application of CT during problem-solving.

Keywords: computational thinking; early elementary education; computational thinking assessment

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1. Introduction

Computational thinking (CT) has been part of computer science for numerous decades but its applications to K-12 STEM teaching and learning is something that has been explored more recently. Seymour Papert, a founding member of the faculty at MIT's world-renowned Media Lab, is widely credited with being the first person to use the term computational thinking in the 1980s (Papert, 1980) [1]. It was not until 2006 when Jeannette Wing, a computer scientist who directs Columbia University's Data Science Institute, published a paper that not only popularized the term but also established a foundation for using computational thinking strategies to support learning more broadly (Wing, 2006) [2]. Ms. Wing described computational thinking as a learning toolkit that every student should have to support critical thinking and problem solving across various STEM domains (Wing, 2006, 2008; Fletcher & Lu, 2009) [2–4]. Computational thinking helps students become active and efficient problem-solvers by drawing on fundamental computer science concepts and practices.

There are still various versions of how CT is defined but a common theme is that computational thinking is a problem-solving strategy that is derived from computer science but is also applicable in any domain. This strategy includes the following core constructs: Decomposition, which is the skill of breaking a problem into smaller, more manageable parts; Pattern Recognition, which is one's ability to use prior knowledge to find patterns within the smaller problem that will help solve the complex problem more efficiently;

Abstraction, which is the skill of removing unnecessary information and focusing on what is truly important in a given situation; and Algorithm/Debugging, which are usually paired together, and is the skill of developing a series of instructions to solve the original problem, and evaluating the solution to address any errors.

Although additional core constructs are sometimes included in definitions of computational thinking, we view these concepts as problem-solving strategies that could be applied towards any subject matter with or without the use of technology. It is also important to note that these core constructs are not always implemented in a linear or step by step process; rather, they can be drawn on to respond to the needs of the problem at hand.

While computational thinking (CT) in early elementary education continues to gain traction as a necessary and beneficial aspect of learning, measuring CT skills among young learners is an emergent and evolving practice. Teachers navigating this nascent field need resources that will support their assessment of students' understanding of and application of CT, both as a problem-solving strategy and a metacognitive strategy in the classroom. To further CT education as a field of practice, it is crucial to invest in teacher preparation and to develop effective professional development (PD) strategies and assessment resources to help teachers plan for and carry out assessments of their young students' learning in CT.

Across three years, researchers partnered with a professional development provider to deliver and study a PD program to help kindergarten through second-grade teachers identify and support their students' emergent CT. This work was conducted in response to the need for teacher training to incorporate CT in classroom practices with very young children, and it highlights the need for teachers to be supported in assessment practices amid a field that is still being established.

Findings from this work allowed us to gain insight into changes in educator perceptions of CT, through measures that captured evolving attitudes, beliefs, and self-efficacy regarding teacher knowledge, comfort, and frequency with integrating CT into lesson plans. Findings also illuminate how educators deployed formative assessment practices to measure their K-2 students' emerging CT skills in the context of their content-area work. Elementary grade teachers who are integrating CT into their existing curricula often adopt formative assessment practices to identify students' emergent CT skills by observing evidence of their application of CT in student work and analyzing the language used by students to describe their thought processes [5], and these teachers' practices were consistent with these prior findings. These teachers' efforts also helped the project team to better understand the kinds of support that are needed for early elementary teachers who are new to CT to help increase their understanding of CT and to help them learn to identify how CT concepts are being deployed by the earliest learners [6].

This project aligns itself with Shute, Chen, and Asbell-Clark (2017), who define CT as "the conceptual foundation required to solve problems effectively and efficiently (i.e., algorithmically, with or without the assistance of computers) with solutions that are reusable in different contexts" [7] (pp. 142–158). This definition frames CT as a mindset and a set of behaviors, demonstrated through specific, observable skills that can then be assessed through performance-based evaluations of CT abilities [7]. However, although this premise is theoretically justified, teachers have reported difficulty assessing CT, perhaps precisely because it is a set of thinking strategies that may be expressed in a variety of contexts or modes of expression, rather than a body of content knowledge. Prior research suggests that teachers associate assessment of CT practices with moments of informal or formative assessment, rather than formal assessments that are likely to be more uniform and more aligned with specific content [8,9].

Early grade teachers rarely have access to sustained, quality PD about CT. These teachers also often have a lower level of knowledge and confidence when it comes to instructing CT compared to their expertise and confidence in teaching other subjects, such as English [10]. It was also report that CT was challenging to integrate into their classrooms without appropriate teacher PD [11]. Thus, the field needs more solid research and practice to help teachers implement CT integration.

Teachers' limited opportunities to build their own mastery with CT also plays a substantial role in shaping how it is (and is not) being adopted in classrooms. A survey study of preservice teachers, which was conducted to understand their perceived definitions of CT and how they intended to integrate it into their future classrooms, suggested that many of these teachers believed that simply using computers alone without teacher guidance would suffice for students to learn CT [12]. Elementary teachers who have participated in initial CT PD and coaching often understand its importance for their students. However, they often struggle with recognizing or interpreting the emergent CT skills in their students' discussions or activities, which makes it challenging to adjust their teaching methods to integrate CT [13].

Existing Assessment Tools for Early Grade CT

There has been some momentum in the development of performance-based assessments aligned with project work in coding or "plugged CT experiences". These include computerized, adaptive, and game-based tools, including but not limited to Computerized Adaptive Programming Concepts Test (CAPCT), TechCheck, and other rubrics developed for block-based performance-based assessments [14,15]. For instance, in 2021 researchers developed and validated the Computerized Adaptive Programming Concepts Test (CAPCT). The CAPCT is a web-based, adaptive assessment consisting of 4489 questions that measures the understanding of basic sequences, loops, conditions, debugging, and the ability to generalize to a new syntax, among other CT concepts and practices. While this tool was developed for CT learners ages 4 to 13 [14], researchers have suggested that some of the included concepts that are a part of CAPCT, such as complex conditionals, may present developmental challenges for younger children [15].

TechCheck [15] is another recently developed CT assessment tool designed for early elementary learners. It includes 15 unplugged, developmentally appropriate tasks representing six CT domains. A validation study of 768 children ages 5 to 9 suggests that the initial version of TechCheck demonstrated strong validity and was easy to administer and score. However, the same study's research limitations emphasized that the multiple choice format of the assessment conflicts with the creative nature of CT and leaves room for respondents to guess the answers without understanding the concepts [15].

Process-based assessments have also contributed to the growth of the development of performance-based assessments, including strategies that seek to define and measure Game Computational Sophistication. Researchers analyzed the coding that students integrated into their programming to gain insight into the quality of young learners' CT practices. Research findings suggested that differences in the learners' use and mix of coding constructs, the patterns they use, and the systems they develop that determine how their game works can provide evidence of computational learning [16].

Performance-based CT assessments also include established rubrics for block-based programming in Scratch and Scratch Jr. Some implementations of these rubrics provide automatic, individualized, and consistent feedback, intended to help CT learners adjust and improve their programming designs [17]. Lessons learned from the implementation of these tools have not yet led to the development of more broadly applicable assessment tools that could be used in a broader array of CT applications and contexts [8,18].

None of the tools described above are fully adaptable to meet the needs of early grade teachers who are seeking to assess their students' ability to draw on and apply CT skills in the context of other curricular content and activities. This was the kind of CT work that this project sought to support, and consequently helping teachers to recognize and assess CT in action among their students, across a variety of curricular contexts, was challenging. We found Brennan and Resnick's (2012) [19] CT framework to be a useful resource that helped to organize teachers' thinking about assessing their students' CT. This framework includes three dimensions that describe the computational concepts, practices, and perspectives involved in developing competence with CT problem-solving strategies. Computational concepts refers to the CT-related ideas, such as iteration and parallelism, that designers utilize. Computational practices encompasses the specific skills and strategies developed through engaging with these concepts, such as debugging and remixing work. Computational perspectives relates to the viewpoints young learners develop about the world and their own roles within it as they use these strategies to analyze and solve problems [19]. This project draws on Brennan and Resnick's work to consider how CT assessments might be tailored to the distinctive developmental readiness of young learners and their teachers' need for flexible, formative assessment strategies [20–25].

2. Study Overview

This project sought to explore how different kinds of PD resources could best be deployed to support K-2 teachers in learning about CT, integrating it into their regular curricular content, and assessing their students' ability to draw on CT skills to support their problem-solving efforts. This work was grounded in the PD providers ongoing collaborations with K-2 teachers in Queens, NY, USA. Researchers collaborated with the PD providers to conduct mixed method research that explored whether and how the PD helped teachers to integrate CT instruction into their classroom praxis, and to better understand how teachers assess their students' CT skills and the types of support they need to do so. Over the course of three years the research team used interviews and surveys to find out more about teachers' backgrounds, beliefs about CT, their current assessment practices, and their perceptions about how to find evidence of students applying CT to their content-area classwork. The research team also reviewed the PD resources used by the PD provider, teacher lesson plans, and interactions among teachers on PD resources.

2.1. About the Professional Development Program

As Ball (2017) [26] explains, building new, ambitious teaching practices requires addressing two interconnected challenges that we have seen K-2 teachers face as they seek to integrate CT into their classrooms. First, K-2 teachers need opportunities to become fluent in uncovering and interpreting student thinking, not only its outcomes, but its underlying processes. Second, they need opportunities to experience and recognize the scope and scale of individual students' ability to use CT strategies in distinctive, creative ways. The PD providers whose work is described here were prepared to address these challenges with K-2 teachers, and their ability to engage and support these teachers was critical to the success of this study.

The PD provided for the purposes of this study built on several years of collaborative work with other schools and teachers in Queens, New York, who were also developing their CT programs as part of New York City's comprehensive CSNYC initiative, part of the national CS for All effort to infuse computer science and computational thinking much more broadly into K-12 schools. The PD model was grounded in an "I do, we do, you do" approach to professional development that emphasizes the gradual transfer of authority from the PD provider to the teacher and leaves significant room for exploration and iteration on the teacher's part as they determine how to align new practices and existing classroom requirements and constraints.

A recent review of the literature on professional learning [27] lays out a clear set of key features that have been demonstrated to be shared among professional learning experiences that have an impact on teachers' instructional practice and on student learning. We have found this structure to be a useful way to organize and describe the key features of this project's PD and have aligned our presentation of research findings to this structure as well. In Table 1, below, we briefly demonstrate how this program's PD model aligns with this framework.

Table 1. Aligning Project PD with Hill and Papay's key features.

Hill and Papay: Key Features of Quality PD	Implemented PD Program
Prioritize instructional practices over content knowledge	CT was presented by PD providers as a set of problem-solving strategies that teachers could integrate into existing curricula to support their students' success. CT was tied explicitly to a problem of practice (helping students tackle complex problems) that teachers cared about.
Use concrete materials for practice over general principles	Lesson planning was at the core of the overall PD experience and grounded all other learning activities.
Follow up meetings and coaching	PD providers visited teachers' classrooms repeatedly, coaching teachers in CT implementation.
Help build relationships with students	PD providers framed CT as a set of tools that could increase student agency and independence as problem-solvers, giving teachers new strategies to help their students develop both socially and intellectually.

During the first phase of this project (September 2021–June 2022), the PD instructors focused on collaborating with a cohort of K-2 teachers from Queens, N.Y., who had already participated in the PD provider's CT PD program. As a group, we reviewed, observed, and reflected on the design and implementation of various CT-integrated lessons to better understand how these lessons are intended to provide opportunities for K-2 students to develop CT abilities, and to demonstrate what they know and can do through classroom discussion and work products.

During the second phase (July 2022–August 2022), the PD instructors focused on implementing two, one-week long CT summer camps for a total of 40 K-2 students (one camp for kindergarten students and one camp for first- to second-grade students). The PD provider concurrently hosted a teacher CT boot camp for 22 teachers from NYC DOE District 24 located in Queens, N.Y. This new cohort of educators also observed the children's camps in person during their preliminary CT boot camp. We were able to collect recordings of the students' discussions as they engaged in CT activities and projects and used some of those artifacts as additional resources for the teachers to learn from during the 2022–2023 school year.

The third phase (September 2022–June 2023) of the project focused on providing the 22 teachers who participated in the Summer Boot Camp with extended PD experiences in the form of asynchronous and synchronous sessions to improve their ability to design, implement, and revise their own CT-integrated, unplugged and plugged-based lessons. This was conducted through the use of an online Community of Practice platform. Teachers were also being supported through facilitated, reflective discussions as they attended to and interpreted students' use of CT strategies during those lessons, and adapted those lessons to ensure that they support diverse, creative approaches to computational problem-solving.

2.2. Research and Analysis Methods

This mixed methods study used Convergent Mixed Methods [28] by using qualitative data collected through interviews with teachers and using the quantitative data gathered from surveys. The data collected from interviews and surveys were analyzed separately, and then the analysis was reviewed jointly to interpret data findings. This work was guided by two research questions: (1) What kind of PD and guidance do teachers need to identify and support emergent computational thinking development in young students' language and work process? (2) What kind of PD and guidance do teachers need to identify emergent computational thinking development in young students' work products. The first research question focuses on understanding how teachers support and identify the application of CT strategies while students are engaged in problem-solving and how the strategies support their work process. The second research question focuses on the assessment strategies teachers employed when identifying CT concepts in students' work products

In fall 2021, the research team began developing research instruments and received an approval for conducting the study in New York City from the Institutional Review Board in the New York City Department of Education (NYC DOE). In January and February 2022, researchers conducted interviews and observations with a first cohort of six pilot teachers who developed both unplugged (lessons that do not include the use of technology) and plugged (lessons that use technology lessons). These six teachers served as "expert" teachers, having participated in multiple years of PD on integrating CT with the PD provider. The findings from this pilot phase were focused on learning the formative assessment strategies these teachers used when identifying and supporting emergent CT with young students. These data were used then to inform the revisions to the PD model and revisions to data collection instruments that would be employed the subsequent academic year with a second cohort of teachers.

In the summer of the next year (2022), a second cohort of 22 teachers participated in a weeklong Summer Boot Camp PD and completed a pre-survey following their attendance. Teachers were then asked to implement two CT-integrated lessons in their classroom over the school year. The first lesson implemented was the unplugged CT-integrated lesson. The second lesson implemented was the plugged CT-integrated lesson. Teachers were then asked to complete the post-survey upon completion implementing their second CT lesson. Both the pre- and post-surveys contained items that were pre-coded using a five-point Likert scale that asked teachers to indicate how strongly they agreed with items, ranging from strongly disagree to strongly agree. The items in the survey asked teachers to rate their self-efficacy in regard to CT integration by responding to items that address perceived challenges in undertaking integration efforts, how frequently they implement CT in lesson plans, their beliefs toward the benefits of integrating CT, and their beliefs around their knowledge and ability to integrate and assess CT in content-area work. The teacher self-efficacy scale consisted of 11 items. The self-efficacy scale for the pre-survey had a Cronbach's alpha of 0.885. The post-survey self-efficacy scale had a Cronbach's alpha of 0.848.

During that academic year, teachers focused on developing and implementing both one an unplugged and one plugged lesson in their classroom. The unplug lesson was implemented during the fall or early winter months of the school year. The plugged lesson was implemented during the spring months of the school year. The research team conducted a semi-structured interview with participants after each implemented lesson (one unplugged and one plugged lesson) and distributed a post-survey at the end of the academic year. The interview questions were designed to allow teachers to openly describe their experience with integrating CT into each lesson—describing their comfort level with integrating CT and describing challenges that arose, detailing their lesson planning process and rationale as to what specific concept(s) they embedded into the lesson—and to provide examples as to how they were able to identify emergent CT in their students' work process. Interview responses were analyzed using Dedoose software V 9.2.22 and employing an inductive coding system that was refined over time, followed by using a constant comparative approach [29]. Four members of the research team developed a coding scheme that included code name and code examples and included relevant child codes. All interviews were coded by at least two members of the research team, with data being analyzed individually and then checked for agreement by researchers. The survey included 12 items that were either multiple choice or on a Likert scale that probed for frequency implementation, challenges to implementation efforts, teacher's comfort with and knowledge of CT, and assessment strategies utilized during lessons. Analysis of these items involved frequency counts to identify what responses were most prevalent among each item. Finally, analyses from the teacher interviews and pre- and post-survey data were compared.

2.3. Setting and Participants

The sample of 22 teachers was drawn from a cluster of schools in one NYC DOE school district in Queens, N.Y. (see Table 1). These teachers were invited to participate in the study because they (1) had little to no prior experience with integrating CT; (2) taught in one of the target grade levels (pre-K to second grade); and (3) taught at a school that had a high percentage of economically disadvantaged students enrolled. All 22 teachers completed the pre-survey, and six of those 22 teachers completed the post-survey. Nine of the 22 teachers completed interviews after implementing CT lessons. The reduction in number of participants between the pre-surveys and the post-surveys and interviews was due to teachers dropping out of the study due to competing priorities for their time.

3. Results

3.1. Identifying CT in Early Elementary Students' Work Process and Work Products: Growth in Educator Knowledge, Confidence, and Self-Efficacy of CT in Early Elementary Education

One of the primary goals of this research was to gain an understanding of the support teachers need to help them identify, encourage, and assess emergent CT development in young students' language and work process. During the CT summer camp, PD providers discussed CT with teachers as a set of problem-solving strategies that students can use during their work process in core content areas. This PD process was designed to help teachers identify strategies for integrating CT into their existing curricula and tie CT as a problem-solving strategy students can use to help them successfully complete work products. Over the course of the year, teachers were also supported by the PD providers in how to integrate CT by first focusing on unplugged lessons that utilize CT strategies during student's work process in core content lesson plans, followed by focusing next on integrating CT into plugged activities. By focusing on how growth in teachers' confidence, knowledge, and self-efficacy with CT prepared them to identify and support young learners' use of these concepts and assess the application of CT in student's completed work products, we were also able to identify the strategies these teachers employ when formatively assessing CT, and how their skills in formative assessment might grow and deepen over time.

Analysis of pre- and post-survey and the interviews showed growth in three key areas: (1) an increase in teachers' fundamental understanding of what CT is and the types of PD activities that supported this growth; (2) an increase in teachers' ability to support students in utilizing CT concepts during in their work process; and (3) an increase in teachers' knowledge and comfort with identifying and formatively assessing students' application of CT in their work products.

3.1.1. Teachers' Growth in Understanding CT and Relation to Supporting Students' Work Process

Teachers consistently reported that the PD program had supported them in teaching CT effectively, and that they had gained a deeper understanding of CT concepts and how CT could be integrated into their lesson plans. One teacher described that though they were new to CT, what they learned through the PD helped them to see it as something that could be useful in her classroom. Another teacher echoed these sentiments by stating: "It really helped me—so going to the PD over the summer and then . . . just being in that community really helped me to see how this could be used . . . as a strategy in my classroom". In surveys, the number of teachers reporting that they understand CT concepts well enough to teach them effectively nearly doubled from 8 out of 22 teachers in the pre-survey to 4 out of 6 teachers in the post-survey.

Teachers directly linked their enhanced understanding of CT to activities completed during the summer boot camp PD, as understanding the role CT can play in the classroom and integrating CT into lesson planning was one of the core activities during the PD program. After implementing the first plugged CT lesson, one teacher reflected on how she successfully developed and executed her instructional plan. The teacher stated, "Well, basically I thought about what we were doing in the class over the summer, like how we were taught the CT and what it is". Another teacher described how one PD instructor's explanation of assessment helped her to understand how they could apply it in a lesson. The teacher explained, "I think once she explained how she was going to do it and . . . once she said how she would use it, I was like, 'Oh, okay. I get it now'. Like the process kind of clicked then".

Teachers valued opportunities to learn about how CT can be used in a young student's work process by hearing from peers sharing their own experiences. The PD model included ongoing support and discussion with teachers through an online Community of Practice. The Community of Practice allowed for teachers to continue developing their knowledge of how CT can be utilized as a problem-solving process by young students by being able to visualize integration of CT into lesson plans by seeing examples from their peers. Following the implementation of a plugged lesson, one teacher poignantly described the way peer sharing supported their learning. The teacher noted, "We've gotten to see examples of each other's lessons and sometimes looking at that can spark an idea like, 'Wow, I can use it in this way. I never thought of that before'. But then I saw how they used it, and I really was able to bring it to the forefront more and drive that way of teaching". Another teacher also highlighted that their peers' ideas helped to inspire their own thinking about specific ways to integrate CT into their instruction, saying, "It was useful, because when I wasn't sure, I was able to go back in and say, 'Oh yeah, this person did it. Maybe this will work for mine'". These anecdotes illustrate how the PD effectively deepened teachers' understanding of CT integration in their lessons by fostering a collaborative environment where they could draw on inspiration and ideas from their peers.

Teachers expressed a willingness to challenge themselves by incorporating CT into lessons in novel ways. When asked by researchers about their perceptions of the PD and the concept of CT, a teacher remarked, "It was an eyeopener. This is a different way of thinking". Another teacher expressed their desire to try to integrate CT into subjects that they had not worked with during the summer PD session under the guidance of PD instructors. The teacher explained that although they envisioned how they could integrate CT into their math course, they could not quite picture how they might integrate CT into another subject in a way that authentically supports students in utilizing CT during their work process. The teacher said:

> "*I found that I really wanted to try and do it with some [subject like] literacy or social studies just for my own sake, to try and see if I could do it and wrap my mind around using it for something that wasn't so, for me, straightforward. When we went over it, over the summer, I instantly was like, 'Oh, I can do it with math and having the students break down word problems and figure out what steps they need to take,' and I wanted to try and challenge myself to figure out a way to use it in other than what I thought was the obvious way of using the CT process.*"

The PD not only expanded teachers' understanding of CT but also inspired them to apply it in innovative and interdisciplinary ways that support students in solving complex problems during their work process. As teachers began to see the value of CT across various subjects, they embraced the challenge of integrating it into diverse areas of instruction.

3.1.2. Increase in Teachers' Ability to Engage Students in Utilizing CT as a Problem-Solving Strategy During Their Work Process

When asked about the effectiveness of their CT-integrated lessons in being able to engage students utilizing CT during their work process, one teacher explained that their main objectives were straightforward and that their students were able to achieve them, noting that students were highly engaged in their work while completing CT-integrated lessons. For example, one teacher explained their surprise and satisfaction with how quickly and deeply students understood and were able to apply the CT concept pattern recognition. The teacher elucidated:

> *"[Students] caught on very quickly. One of the things that they did was with the patterns. They really, really dove into that rather deep and I was really excited about that, because I wasn't sure what I would get out of them for that . . . I was pleased with that and hearing them discuss that shows me that they can and do identify patterns more readily than I probably would have expected."*

Another example of student engagement in CT is students developing multiple perspectives in their approach to problem-solving during their work process. In one lesson, a participating teacher described that students would "revise and remix" their ideas while working to create a better solution to a problem. The teacher said of one activity where students were asked to pose a question to solve a defined problem:

> *"Even though we went over a question that we all thought was a good question, some of [the students] went back and changed their question, if they ended up getting paired with someone who they already knew kind of well already. And they went back and asked a different question so that they had a new fact to learn, which I thought was very interesting."*

Survey responses further point to strong evidence of CT integration increasing student engagement during lessons that provided opportunities for students to use CT in their work process. For example, in the post-survey all 6 teachers felt that students were typically more engaged in lessons with CT versus without, and 4 out of the 6 teachers felt that students typically learn more when engaged in a CT lesson.

3.1.3. Growth in Teachers' Knowledge and Comfort in Assessing CT in Young Childrens' Work Products

In interviews after the plugged and unplugged lessons, teachers reported that they felt knowledgeable about and comfortable with assessing their students' ability to recognize evidence of student's employing CT strategies in their work products and their work process while they conducted their lessons. Being as the participating teachers were all novices with CT at the start of the project, we sought to understand how the PD model implemented by PD providers supported teacher growth in this area. They identified two key ways through which they developed the knowledge and confidence needed to assess their students. First, they explained that they employed CT assessment strategies acquired during the summer PD sessions with the PD provider. One teacher described a strategy the PD instructor had demonstrated called a "gallery walk", during which students could showcase their expression and understanding of their work, as well as the critical thinking skills they practiced, through presentations and explanations. Second, another teacher talked about how attending the PD with a teacher colleague from their school allowed them to collaboratively reflect on what they learned during the summer and develop CT assessment strategies that they could integrate into their lessons. The teacher stated:

> *"So one of my coworkers. . .we went together to the program over the summer. And so when we were talking about this, we kind of bounced ideas back and forth off of each other to try and figure out which way we thought would be the best way to assess our students and some of them do have, you know, our students with disabilities and some have—are multilingual learners, so we really were just trying to figure out what the best way that we could see what they were—how they were following the process since, as adults, we were just learning the process."*

Despite this, however, one teacher did recommend utilizing more formalized assessment tools that could have helped to prepare them to assess their students' application of CT in their work products. The teacher explained, "So I think the planning and implementing was okay, but I think . . . maybe having some sort of rubric . . . would be more beneficial. It would have been helpful to have an example of a rubric and more guidance on how to assess".

3.2. Identifying CT in Early Elementary Students' Work Process and Work Products: Understanding Teacher Practices for Identifying and Assessing Evidence of CT Application by Young Students

Our second goal for this research was to learn the strategies teachers employed when formatively assessing the emergent CT development in young students' work process and work products. Interviews and survey data indicate that participating teachers employed a diverse array of formative assessment strategies to identify and evaluate their students' emergent CT knowledge. These assessments were generally informal and intended to generate formative data regarding students' understanding and application of CT during problem-solving.

3.2.1. Applying General Formative Assessment Practices for CT-Specific Work

When asked how they determined the way they would assess students when creating lesson plans, teachers stated that they did not employ new assessment practices or utilize formal assessment measures, and instead formatively assessed CT application to course work by using the same kinds of strategies they use during other content-area work. Teachers are well-versed in educational standards and continually engage in formatively assessing student learning during instruction. This allows them to pivot and scaffold their teaching as needed to ensure that students remain actively engaged in the learning process. Participating teachers indicated in their interviews that they assessed students' CT skills the same way they would typically conduct a formative assessment for more traditional assessment of content-area understanding or practices. For example, one teacher emphasized the importance of the "speaking and listening" standard in kindergarten, noting that "turn and talk" activities are crucial, especially at the beginning of the year. They explained further, "It's so important for us to listen to the students and how they're explaining the process. So that standard sticks out in my mind and that's something I was trying to assess. Are they able to verbally talk about the process?"

Another teacher described their approach as "just a basic, like kid watching, informal assessment would be like asking a lot of questions and having them debrief". This response suggests that such practices are already integrated into their classroom routines, making assessment of CT skills as part of their ongoing instructional methods more accessible to them.

When asked in the survey and during interviews how they assess the use of CT strategies in their students' work process, teachers referenced using only informal assessment strategies, such as asking questions while students were working or listening to student talk during collaborative work, that provided them with formative data about students' understanding and application of CT concepts. Teachers indicated in the survey that they did not use summative assessments to measure growth in CT knowledge and did not utilize more formal assessment measures such as quizzes, classwork, polling, or having students detail their problem-solving process in reflection journals. When analyzing all survey and interview responses, we can deduce that teachers relied on four main informal assessment strategies:

1. Observing students during their work process. Once they were explicitly integrating CT into existing curricular topics, these teachers reported few challenges to recognizing, observing, and reflecting on students' use of CT practices. As one teacher said, "The assessment was based on what we saw and it was something very comfortable for them to do again". Another teacher made clear that this kind of observation was something they did routinely: "Usually what I do is just by observation, I'm observing, seeing what they're doing. How are they communicating? Then at the end, I start saying, 'Oh, wow, this child is still having difficulty, so my next lesson let me focus on that" These explanations suggest the strengths that experienced teachers can bring to a new topic like CT once they have had an opportunity to learn about it and plan for introducing it into their existing curricula and classroom routines. At the same time, it also raises questions worthy of further study about whether they are actually

identifying an accurate and representative range of examples of CT behavior among their students.

2. Questioning students during their work process. Teachers stated that one assessment strategy they used was to ask questions to individual students while they were completing classwork to listen for evidence of the student applying a CT strategy during their work process. As one teacher explained, "I was looking to see if they were breaking down the problem . . . if they were following the steps that we kind of created together, and then if they went back and fixed anything that they thought was incorrect. I felt like those were the things that I could explicitly see from them based on what they were doing and kind of get in their minds by just even watching what they were doing or listening to them talking more". Again, once teachers were comfortable with the language and practices of CT, they seemed to have little probing for evidence of it being applied into the range of topics that they discussed with students during work periods.
3. Listening to student discussions during collaborative work times, such as groups or pairs. Teachers reported that they were able to extend their comfort with CT into their observations of students' group work and discussions. "We were definitely assessing the fact that they know there's a problem with what they were trying to build and the purpose of the building and that didn't work and they had to fix it. So I would say the assessment was definitely in that same pair share and that verbal explanation". This was consistent with classroom observations in which student discussions included students' use of CT strategies that teachers were able to recognize and reinforce even in the context of group work, a setting that can be challenging for students in grades K-2.
4. Having students present their work products and explain their work process to classmates. After listening to students' use of CT during their work process, teachers reported that they included CT in their assessment of student's final work products. Teachers probed for students' reflections on how they had solved problems, and they listened for references to the distinctive aspects of CT problem-solving strategies, such as breaking down problems. "It was basically informal, like we did take photos of the finished structures. We had them do a verbal explanation. Could they explain what our expectation was?"

Another example of the assessment strategies used by teachers during their instruction in CT included technical informal assessment. Teachers used the student's time on task and understanding of basic terminology related to their activities as a form of assessment. For some teachers, a significant portion of informal assessment during routine student work time was dedicated to verifying that students are engaged in the required work to grasp the concepts and that they can effectively articulate what they are learning. When we asked teachers how they were assessing their students' CT practice, one teacher said, "I was walking around . . . making sure they were doing what we were supposed to be doing and following the steps that we had done". Another teacher stated that they provide students with a checklist of the tasks they needed to complete when completing a CT-integrated lesson. For each task, the teacher asked the student to rate their experience, inferring that completing a task meant that the student had understood the task well enough to tackle and complete it independently. The teacher explained, "*So it was like a self-assessment for the students to fill out. Then they'd put a check next to the smiley face or the—so smiley face for actually doing the task. The sad one was not doing it. Then the middle one was like 'I'm confused and not sure what to do.' So, the students filled out that checklist*". This approach encourages students to reflect on their own learning process (matching what they did to what was asked of them), providing valuable insights for both the teacher and the students into their understanding and engagement with the tasks.

Most teachers reported using a combination of assessment strategies, including but not limited to technical informal assessment. In one example a teacher stated of their informal assessment strategy, "*I did it in some parts of the lesson, because I was able to observe, 'Oh, they* *got the part where they're able to decompose, circle the numbers,' so I was able to do it. And then I also did it at the whole lesson if they were able to follow the steps. So, I did a combo of both*". This highlights the multifaceted approach teachers take in assessing CT skills, combining technical informal assessments during student's work process with ongoing assessment strategies when assessing student's work products to ensure students are comprehending and effectively engaging with the material.

3.2.2. Assessment Strategies Focused on Understanding the Application of CT, Not Hearing CT Vocabulary

During CT-integrated lessons and activities, teachers did not often rely on observing or hearing students state the name of the specific CT concept they used in their work process„ and instead focused on assessing evidence of the concept based on their understanding of specific CT skills that was taught to them during the summer bootcamp PD and further developed during in-class coaching with PD providers. When asked to describe their assessment strategies in interviews, teachers often stated that they would listen for students describing evidence of a specific CT concept, rather than expecting students to label their actions using specific CT vocabulary. Teachers elaborated that they often had students in their classrooms who were very young, who were English language learners, and who might have learning disabilities that hindered their ability to label the concept they utilized. For all of these reasons, they de-emphasized the importance of specific terminology, and believed that they could still accurately identify when a particular child was appropriately using a CT concept:

> "*We know our kids really well in here. We just get to know them really well from the beginning of the year, you know, whether they have paperwork that they have a disability or not and the strengths and weaknesses. Once you know that—like we have a kid who is an artist, like off the charts, and he's so creative and he's very much into all the CT activities and he's into plugged and unplugged everything. So I could watch him build something and know he got it, but he will not think, pair, share, and explain his process.*"

Teachers also stated that when teaching CT concepts to their students, while they would label the skills they were using during the modeling, emphasizing this terminology was not a primary concern. This strategy was based on their experience in the summer bootcamp PD that framed CT as a set of tools and processes that students can use to increase their independence as problem-solvers rather than memorization of terminology. Similarly, their expectations and assessment strategies for recognizing how students were applying CT concepts focused on their ability to properly use the skill rather than labeling or defining the term. For example, one teacher stated that she was able to recognize that students were engaged in the CT strategy debugging by listening to students describe a problem in their work process and their attempts to fix it: "*You didn't hear, 'Oh, I'm debugging,' but you did hear things like, 'Oh, this is not working,' or 'My structure is collapsing. It's not supporting'*".

Another teacher explained, "*There's the verbal challenge, because some of the kids don't have the language in order to [describe] the process. And then there's the visual part. Did they achieve the goal? Did they build a structure together? Are they talking to their partner? Are they engaging in a team conversation on how to make this work?*" While these teachers did not explicitly focus on CT vocabulary as a primary formative assessment measure, some asserted that moving children toward learning the terms and being able to properly label them is important: "*That's the part where we can definitely work on with them moving forward. I didn't hear them actually using the word decomposing or recognizing a pattern. They did use problem and solution, not necessarily using the word algorithm*".

In summary, teachers used a variety of assessment strategies—from observations to listening to student talk—to evaluate their students' CT skills during their work process. More specifically, teachers looked for evidence of student use of the CT strategies in their work process and in their work products rather than focusing on hearing stude1nts use CT vocabulary. The PD they received was crucial in building their confidence and knowledge of CT concepts, which allowed for them to informally and formatively assess evidence of young children applying CT during problem-solving rather than relying on more formal, structured assessments as a data source.

4. Discussion

4.1. The Intersection of CT and Formative Assessment

The project on which this study is based is part of a broader national effort to ensure that all students have the opportunity to rehearse and master the metacognitive strategies of CT in order to support their development as ambitious, creative problem-solvers. Historically, in K-12 environments computer science has been the preserve of upper grade students with access to advanced course work. A range of public and private investments have encouraged researchers and teachers to expand access to the metacognitive strategies that are characteristic of computer science as a field through CT initiatives, and this project is intended to contribute to that body of knowledge by exploring how best to support K-2 teachers to accomplish these goals.

In the context of this broader effort, what is the purpose of assessing K-2 students' CT skills? Our colleagues have developed several promising measures, described above, that capture students' understanding of specific CT concepts or measure the complexity of their application of CT skills in the context of programming tasks. This project began from a slightly different set of priorities, grounded in the expectation that K-2 classroom teachers would rarely be in need of formal measures of students' CT achievement. Rather, formative assessment practices would be an important element in the successful integration of CT into their content-area teaching and one that could be integrated into PD about CT itself.

Teachers who are comfortable with formative assessment are recognizing, interpreting, and responding to evidence of their students' thinking processes, not only the content of their work products. This focus on students as active, creative thinkers is central both to meaningful application of CT component skills, and to equitable, ambitious instruction that recognizes all students' ability to learn. If the purpose of introducing CT is not only to make students aware of CT concepts but to encourage their application to expand and enrich students' repertoire of problem-solving strategies, then it becomes important to examine whether teachers are able to make these kinds of formative observations and adjust their instruction accordingly.

4.2. K-2 Teachers as Learners

This study sought to understand how a group of K-2 classroom teachers responded to PD opportunities that sought to help them to integrate CT practices into their existing curricular content areas. We entered into this study with a keen awareness of the multiple layers of challenges that could make this PD effort difficult for teachers to leverage or fully assimilate into their instructional repertoires. This study was conducted between 2021 and 2024, a period when schools were experiencing and recovering from the traumas of the COVID-19 pandemic. Like teachers across the country, the teachers involved in this project were dealing with both the short- and the long-term impact of the pandemic, responding to stressors in both their own and their students' lives. It was a difficult time to ask teachers to devote extra time to their development, and to take creative risks in their classrooms. It was also a difficult, and at times impossible, time for researchers to observe classrooms or spend extended time with teachers. Therefore, future studies might aim to observe students during their work process to further uncover their thought-process for determining which CT strategy they intend to use to help them solve problems.

Despite these challenges, this study consistently found that, even under challenging circumstances, teachers were motivated by the PD itself; were eager to explore new challenges in lesson planning; were comfortable trying out new lessons and problem-solving strategies with their students; and, most importantly, were consistently generous and positive in their views of their students as learners and creative problem-solvers. As this article seeks to demonstrate, once these teachers had developed CT-integrated lessons with the support of their peers and PD providers, they were consistently willing and able to observe and support their students' efforts to deploy those strategies in the context of a range of lessons, projects, and group activities.

At the same time, we did not find that teachers' new-found understanding of CT as a set of problem-solving strategies that could be used by students in a wide variety of curricular contexts led to dramatic changes in their formative assessment practices. These teachers describe drawing on established practices to elicit and attend to student behaviors and ideas in the course of instruction. Overall, these teachers appeared not to change their assessment practices substantially, but to integrate existing approaches to monitoring student learning into their understanding of CT, which did evolve rapidly. These teachers consistently displayed an understanding of CT as a set of problem-solving strategies and were able to recognize and validate students' rehearsal and application of those strategies.

This focus on incremental change is well-suited to the deep commitment and, often, limited spheres of action available to many teachers today, including those involved in this PD program. These teachers' experiences demonstrate a deep belief in their students' abilities and a cautious willingness to integrate new ideas into their practices that are well-suited to the complex and challenging policy and material contexts in which they are working.

4.3. Conclusions

The PD experiences these teachers participated in facilitated their willingness to experiment with CT, and their growing ability to plan for, recognize, monitor, describe, and value their students' application of CT across multiple curricular contexts.

The research findings described above demonstrate how one group of teachers working under challenging circumstances were able to develop and implement these new instructional practices, with the support of PD that was consistent with Hill and Papay's [27] framework discussed above. The framework emphasizes the importance of tightly tying new and challenging ideas (such as CT) to teachers' current practices and priorities. This project's PD did this primarily by making lesson planning the centerpiece of the PD process, making CT a resource to support ambitious student learning goals, rather than a content area to be explored for its own sake. During the PD provided through this project, teachers typically were quick to recognize the potential relevance of the topic for their students, but they took more time to become confident in identifying or interpreting the development of emergent CT in their students' talk or work in ways that allowed them to adapt their instruction appropriately [5]. As the findings above demonstrate, over time these teachers did build confidence in these more ambitious practices.

This study allowed us to focus on understanding how K-2 teachers CT into multiple curricular contexts as a problem-solving strategy and how they extend existing practices, or develop new ones, to support these innovations in their classrooms. This approach prioritized working with and for teachers as a preferred mechanism for understanding and supporting instructional change and centered all students as competent learners who need access to a broad range of problem-solving tools that they can deploy as needed to address problems that matter to them.

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