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Teachers' Perceived Value, Challenges, and Advice for Implementing Computational Thinking in Elementary Classrooms

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Nurturing computational thinking (CT) in students is necessary for problem solving and important for bridging the current STEM gap, such as the American K–12 students' lagging behind in math and science standardized testing. To facilitate the integration of CT in students' and teachers' experience and insights on implementing CT into K–12 classrooms, particularly elementary school classrooms, need to be investigated. We interviewed 12 teachers who had participated in a larger National Science Foundation funded STEM+C (computing) study that integrates CT in informal STEM learning guided by a project-based learning (PBL) approach. The teachers had facilitated a STEM+CT (computational thinking) curriculum as part of their professional development that introduced fourth- to sixth-grade students to CT in an after-school community center's program over an eight-week period. We conducted a comprehensive analysis of the interviews regarding the implementation of CT into formal elementary classrooms including teachers' perceived value of CT, the challenges for classroom implementation, and their advice on how to resolve those challenges. Half of the teachers interviewed have adapted the informal STEM+CT curriculum they had facilitated in the after-school program in their own classrooms and the other half have not. We found that, while both groups of teachers cited similar challenges, teachers who have adapted the STEM+CT curriculum valued CT more specifically as a strategy for complex problem-solving. Teachers who have adapted the STEM+CT curriculum and integrated it as part of their own curriculum were more vocal and descriptive regarding the need and justifications for more teacher professional development regarding CT integration.

Keywords: computational thinking (CT), CT integration, STEM+CT, project-based learning, teacher professor development

Computational thinking (CT) is a thought process designed to help students solve problems using mental tools such as decomposition, abstraction, heuristics, data collection, algorithms, modeling, and communication (Wing, 2006). The recent increased interest of CT is due to researchers and educators recognizing the stake in today's technology-savvy world (Hubwieser et al., 2015). It is no longer viable to wait and introduce CT concepts to students in higher education. Students must now learn how to work with algorithmic problem solving and computational methods as early as possible. Despite the importance of integrating CT into K–12 schools, CT is still largely missing in K–12 STEM education (College Park, MD Conference Report, 2020; Lee et al., 2020). Educators and researchers need to push for a drastic change and aim at providing teachers with resources that would help them implement CT into their curriculum.

The limited research on teacher's professional development (PD) for CT integration mostly focused on student-centered learning in informal after-school programs, or formal classrooms with limited teacher facilitation (e.g., Calandra et al., 2021; Dasgupta et al., 2017; Yadav et al., 2017). Studies on teacher interviews also tend to involve teachers who have not attempted to implement CT into formal classrooms after PD (e.g., Rich et al., 2019). This study contributes to the literature by immersing teachers in a project-based learning (PBL) environment with subject matter experts, as well as researchers, present on site for help over a relatively long period of time before teachers attempted to integrate CT in formal classrooms. The subject matter experts and researchers had also provided the teachers the necessary training on CT and PBL prior to the teachers' facilitation of the STEM+CT curriculum in the after-school program. The PBL approach could engage teachers in deep learning, which also assists teachers in developing their conceptual understanding of CT, as well as their own CT curriculum. A teacher PD utilizing a teacher-facilitated PBL after-school program with on-site experts standing-by would provide teachers with necessary support for their teaching, addressing their concerns, and building on their earlier learning of CT and PBL (Guo & Yang, 2012). The collaboration during the PBL-guided after-school program between teachers, subject content experts, and educational researchers provided a unique and intensive experience for teachers in preparing them to integrate CT into formal classrooms. Therefore, insights and experience from these teachers who had gone through such an intensive program is valuable to understanding how to integrate CT into elementary school classrooms.

Integrating Computational Thinking into K–12 Learning

Integrating CT into K–12 education is perceived as being the forefront of engaging students in authentic STEM practices (Lee et al., 2020). Since CT involves critical thinking skills such as complex problem solving and abstract thinking, fostering CT as early as possible in elementary students can greatly assist students in later years such as high school or college (Kennedy et al., 1991). Currently, CT is most often integrated into the teaching of coding and programming (Zhang & Nouri, 2019). The K–12 Computer Science Framework (2016) views CT in terms of abstraction, pattern recognition, and reasoning abstractly and quantitatively. The practical use of CT extends to problem representation, verification, and prediction, which lead to modeling, reasoning, and problem solving in numerous scientific and mathematical disciplines (National Research Council, 2011).

In order to successfully integrate CT into K–12 classrooms, educators must first and foremost have a good understanding of CT. Unfortunately, there is no consensus on a definition of CT for K–12 education (Lee & Malyn-Smith, 2020). Nevertheless, attempts have been made to develop a working definition or framework for CT that can be used in teaching practices. Mayln-Smith et al. (2018) listed five CT integration elements for K–12 education. These are: 1) understanding complex systems, 2) innovating with computational representations, 3) designing solutions that leverage computational power and resources, 4) engaging in data collection, and 5) understanding potential consequences of actions. From the above five integrated elements, CT can be integrated via problem-solving activities and CT components such as abstraction, algorithms, programming and software development, data collection and analysis, modeling and simulation (Yang et al., 2021). Likewise, Yang and colleagues (2018, 2021) have identified eleven components of CT such as abstraction, algorithm, communication, conditional logic, data collection, data structures and analysis, heuristics, and simulation and modeling with examples for upper-level elementary students, which can serve as a guide to help teachers understand the CT components and apply them in STEM learning.

Some researchers have also begun to promote adoptions of CT in formal classrooms. For example, Waterman et al. (2020) developed a CT-integrated activity module called iMOD for third-grade students to learn ecosystem science. and found their CT-integrated curriculum promising, and students demonstrated a grasp on both CT concepts and deeper scientific understanding after using the curriculum. Yadav et al. (2019) recommended using abstraction, decomposition, pattern recognition, and debugging for elementary classrooms for CT integration. Another recent effort to situate CT in elementary level learning is PBL which engages students in authentic hands-on learning (Yang et al., 2021; NRC, 2011). Students in PBL are active investigators and knowledge seekers rather than regurgitating information handed down by instructors. Therefore, PBL can be used to embed CT components such as abstraction, algorithms, conditional logic, data analysis, decomposition, and heuristics in hands-on problem-solving activities (Yang et al., 2018). For example, a STEM+CT (computational thinking) curriculum can include learning activities grounded in problem solving or relevant topics (e.g., detecting life on Mars, building a bridge, building an airplane etc.), which provide students an opportunity to formulate and test their plan, as well as evaluate their solutions with necessary support (Yang et al., 2021; Blumenfeld et al., 1991). Students in PBL are also directed to have sustained inquiry, learner reflection, testing and revisions in problem solutions applying CT components (Yang et al., 2018).

Teachers must also actively engage in teacher-facilitated activities in order to effectively integrate CT into formal classrooms (Mason & Rich, 2019). Teacher-facilitated activities involve teachers playing the role of introducing and mentoring CT development in students, such as in the context of PBL (Yang et al., 2021). Past research suggests that by using a PBL-guided curriculum, teachers can learn how to take a direct role in both introducing the content, as well as fostering students' problem-solving ability and critical thinking skills during the learning process (Kokotsak et al., 2016). A PBL-guided CT curriculum allows teachers to assume multiple roles such as coach, mentor, learner, and facilitator as needed, rather than a lecturer (Yang et al., 2018; 2021). The teachers mentoring the process such as trial-and-error (i.e., heuristics), breaking a problem into simpler steps (i.e., decomposition), helping with planning the overall design (i.e., abstraction) etc. will eventually gain them experience to integrate CT into classrooms.

Teacher's Perception of Computational Thinking

Morreale et al. (2012) conducted a survey amongst high school teachers and found that the majority of the teachers perceive CT to be important for thinking critically and solving problems and as an important tool to help enhance students' problem-solving skills. On the other hand, depending on the operational definition of CT, teachers' perception of CT may differ. For example, Sands et al. (2018) found that while teachers agreed CT was important for problem solving, logical thinking, and algorithmic thinking, they also tended to view CT as mathematics, using a computer, and playing online games. This latter view of CT could render many elementary school teachers unmotivated to teach CT to their students. A literature review on teachers' conceptualization of CT found that the majority of the participating teachers reported that they did not conceptualize CT as mental process categories of algorithmic thinking, automation, debugging, and creating. This suggests that there is a knowledge gap between the operational definition of CT and teachers' perceptions of how CT should be used in practice (Corradini et al., 2017).

While teacher's positive perceptions of CT do not necessarily transfer to teachers' confidence or knowledge in integrating CT in their teaching practices (Bower & Falkner, 2015; Giannakos et al., 2015), research shows that after teachers have gained experience with CT integration, their perception and understanding of the value of CT became more aligned with using CT as a problem-solving mental tool. For example, Yadav et al. (2018) engaged elementary school teachers in teaching CT with unplugged activities and found that teachers' perception of CT shifted from viewing it as a general problem-solving process to more specific understanding of CT such as using algorithms, sequences, and pattern recognition from data collection and structures. Consequently, not only did teachers' perceived value in CT increase positively after they had accumulated experience with CT, but they also acquired knowledge on how to teach CT in terms of making predictions based on data and finding solutions for tasks more efficiently and quickly (Yadav et al., 2018). The lesson learned from past research is that teachers' attitude and perceived value could change if they had the opportunity to learn about CT.

Challenges in CT Integration

While integrating CT into K–12 classrooms shows great promise, there is still limited research that could provide an in-depth understanding of the challenges teachers encounter while attempting to integrate CT into formal classrooms. A major challenge is the lack of an agreed upon definition of CT, particularly in the context of K–12 contexts (Voogt et al., 2015) because introducing CT into practice means teachers need to understand what CT looks like in students' learning activities. CT is often defined as a form of "peripheral" thinking or problem solving (Barr & Stephenson, 2011) which may be too vague for teachers to put into practice (Voogt et al., 2015). A solution has been to define CT by breaking CT into components such as abstraction, decomposition, algorithm, etc. (Yang et al., 2021). But the components of CT are often portrayed in the context of programming and coding, which may deter teachers who lack training in programming and coding from integrating CT for elementary level subjects (Lu & Fletcher, 2009).

Teachers also lack specific examples of CT for their instruction. Finding materials and resources for practical examples of CT for elementary students has been one of the main challenges for teachers (Ketelhut et al., 2020). Furthermore, even with practical examples of CT, teachers need to actively reflect on their experience of using CT to integrate it into their curriculum (Sands et al., 2018). A critical part of this reflective process is for teachers to actively recognize which features of their implementation of CT would lead to productive outcomes for students (Santagata & Yeh, 2016). Teachers' interactions with students and responding to students' ideas can further help teachers understand the causal reasoning of the CT components in the curriculum and connect it to student thinking based on how students respond to the features (Dyer & Kaliski, 2016). Thus, teachers' reflective practice based on concrete examples of CT and student's interaction is an important mechanism that would greatly assist teachers to fully integrate CT into their curriculum. However, this reflective process of CT integration often lacks in teachers due to their busy teaching schedule. Therefore, instructional strategies such as the PBL-guided approach that facilitate teachers' reflective practice and teachers' interaction with students is necessary.

Another major challenge regarding classroom implementation of CT is to properly position CT into the curriculum (Voogt et al., 2015). Mapping CT components to different content areas, problem-solving abilities and grade levels remains a challenge (Denning, 2017). Some researchers believe that CT should be taught separately in a subject such as in computer science that directly incorporates CT (Basu et al., 2016), while others believe that

CT can be taught universally across all subjects with a thoroughly revised curriculum (Mishra et al., 2013). However, adding a new curriculum for the purpose of teaching CT in a heavy-scheduled school day is not an option for many teachers (Hacker, 2018; Rich et al., 2019). Ketelhut et al. (2020) found that systemic barriers such as the lack of time and school districts' placing lower priorities on STEM courses remain as the main challenges for teachers to properly integrate CT into classrooms. Teachers reported their schools' focusing on reading and math and little on science makes it difficult to implement CT-related activities. In addition, teachers also reported needing time to modify and carry out long CT-infused activities where students work through challenging problems relevant to the topics in the curriculum (Ketelhut et al., 2020).

Teacher Professional Development for Integrating Computational Thinking

Preparing teachers for teaching CT is pivotal for the success of integrating CT into K–12 education. The Computer Science Teachers Association (CSTA, 2009) and the International Society for Technology in Education (ISTE, 2017) have issued standards on how teachers ought to fill the roles of leaders, collaborators, designers, and facilitators in CT integration. However, there is a shortage of qualified K–12 teachers to teach CT, as many teachers lack the necessary knowledge and background (Yadav et al., 2016). Research has shown that teacher PD programs help teachers not only gain the necessary knowledge for implementing a CT curriculum but also gain the confidence and change their attitudes about CT in general. For example, Morreale and Joiner (2011) found that high school teachers had a 50% increase in recommendation for more PD on computational concepts and ideas after being introduced to such concepts and ideas. Those teachers also reported as becoming more confident with programming tasks and using visuals to explain concepts to their students. More recently, Ketelhut et al. (2020) found that supporting elementary school teachers to integrate CT into science resulted in teachers' valuing the CT activities as both motivating and helping their students develop persistence and confidence to solve difficult problems. Likewise, Simmonds et al. (2021) designed a PD program for elementary school teachers engaging them in coding activities and learning how CT can help teach different subjects and later found that those teachers' attitudes toward CT became more positive. Collectively, these studies suggest that teacher PD will not only help teachers gain necessary knowledge but also change their perception and confidence of teaching

CT and facilitate in keeping the positive attitude of integrating CT into their curriculum.

Theoretical Framework

Yadav et al. (2017) have argued that K–12 teachers need to gain a deep understanding of not only the content of the subject they are teaching but also a systemic framework to integrate CT that aligns with both content and pedagogical knowledge. In a larger STEM+C project, our teacher PD in an after-school program prepares teachers to teach CT and provides them with content, technological and pedagogical knowledge (Yang et al., 2021). Thus, the technological pedagogical content knowledge (TPACK) framework (Mishra & Koehler, 2006) for the purpose of integrating technology into teaching and learning can also guide teacher PD on CT integration. The TPACK framework indicates that the teacher's knowledge domains (content knowledge, pedagogical knowledge, and technological knowledge) are interfaced into pedagogical content knowledge, technological content knowledge, technological pedagogical knowledge, and technological pedagogical content knowledge. The TPACK framework specifies the need for teachers to intuitively understand the interactions between technology, pedagogy and content while integrating this knowledge into their planned coursework. Thus, for teachers to effectively integrate CT in their classrooms, they need to understand what CT (content and technological knowledge) is and then how to adopt it into their curriculum (pedagogical content knowledge and technological pedagogical knowledge).

Kong et al. (2020) designed a CT curriculum with emphasis on linking CT concepts, practices, and perspectives utilizing the TPACK framework for training teachers (Mishra & Koehler, 2006). Kong et al.'s (2020) curriculum focused on introducing CT concepts and developing a pedagogy for teaching CT in relation to programming. In the assessment for teachers' training, the teachers were asked to put their pedagogical and content learning into practice and reflect on their teaching experience for CT. Kong et al. (2020) found that as a result of the integration of pedagogy, technology, and content knowledge, the teachers became more confident at linking the content knowledge of programming for CT development, technological content knowledge of the programming tool for programming, and use of the environment to teach programming with the appropriate pedagogy.

Context of the Study

Although there has been promising research on how to properly integrate CT into K–12 education, pivotal knowledge regarding teachers' integrating CT into formal classrooms after they have received relevant PD has been largely absent in the literature. The study investigates how in-service elementary school teachers, who had received an informal afterschool PD program while facilitating students in practicing CT in STEM-related learning, perceive the value of CT, the challenges regarding implementing CT into formal classrooms, and the advice they would give for formal classroom CT integration. We are also interested in the experiences of the teachers who have not adopted an informal STEM+CT (computational thinking) curriculum (but who may still be using CT in their practices to various extents). This study is part of a larger STEM+C (computing) study that involves collaboration between teachers, on-site subject content experts, and educational researchers. The research team had designed and implemented a STEM+ CT curriculum that was guided by PBL in an after-school program for upper-level elementary students (Yang et al., 2021). In the after-school program, 24 elementary school teachers facilitated the STEM+CT curriculum with subject content experts and educational researchers present for support after the teachers had been introduced to PBL, CT, as well as the STEM content of the curriculum. The 4th to 6th grade students collected data, communicated with the teachers and their peers, and solved problems in the after-school program. At the end of the after-school program, the students would showcase their products in a final challenge. Teachers then had first-hand experience in integrating CT and using hands-on approaches to integrate CT into their own classroom. The current study was carried out after the 24 teachers had participated in facilitating the STEM+CT curriculum in the after-school program. The research questions guiding this study are:

1. What are the teachers' perceived value of implementing CT into formal classrooms?
2. What are the challenges the teachers perceived in implementing CT into elementary school classrooms?
3. What advice do teachers give for implementing CT into elementary school classrooms?

METHOD

A qualitative study was conducted consisting of one-to-one interviews with elementary school teachers who had participated and facilitated an informal STEM+CT curriculum in an after-school setting. The teacher PD program was designed and conducted by the research team that included content experts, education researchers and the content supervisor for science and social studies from the school district. The PD program included the introduction of CT and PBL to the teachers as well as the teachers' facilitation of an eight-week implementation of the STEM+CT curriculum in community center's after-school programs with the stand-by support from the research team (Yang et al., 2021). The participating teachers in the current study are therefore considered to be knowledgeable about CT and therefore can provide invaluable insights to help us better understand and address the research question.

Study Design

We chose a qualitative case study methodology to gain in-depth insight into each of the teachers' experience from the details of their responses to our semi-structured interview questions. The qualitative approach would allow us to answer the research questions that general survey or quantitative multiple-choices methodology would not be able to address. The interviews were conducted after the teachers had had both the PD for CT in the informal after-school setting and had had attempts to integrate CT into their formal classrooms. For the current study, we purposefully recruited the teachers from both the group that had adopted the curriculum and the group that had not adopted the curriculum in their classrooms. Thus, we were able to compare the difference of responses between the two groups of teachers. We were also able to identify the teachers who have adapted the STEM+CT curriculum and the teachers who haven't based on their post-program responses.

Participant

Twelve of the 24 teachers who had participated in the after-school program volunteered to be interviewed for 30 to 40 minutes. Due to the COVID-19 pandemic all the interviews were conducted virtually via Zoom. The interviews were recorded for data analyses. The average age of the interviewed teachers is 43 (*SD* = 11.69), and the average years of teaching is 15.17 (*SD* = 7.63; see Table 1). Majority of the teachers (92%) are female and White/Caucasian. The grade levels taught by the teachers were 2nd to 6th grades, with 33% teaching the 6th grade. Half (6) of the teachers interviewed have adapted the informal after-school STEM+CT curriculum and formally implemented it into their own curriculum and the other half (6) of teachers have not formally adapted the STEM+CT curriculum. In addition, when asked regarding their knowledge of CT prior to participating in the after-school program, five out of the twelve teachers interviewed reported that they had only known about CT prior to participating in the after-school program, whereas the other seven teachers had not had any knowledge about CT previously. Among the five teachers who reported knowing about CT, two teachers mentioned that they had lacked training and resources about CT, and two reported that they only "somewhat" knew about CT as a tool for problem solving.

Table 1
Teachers' background

Teachers (Pseudonym)	Gender	Age	Ethnicity	Years of Teaching	Grade Level Taught	Curriculum Adoption
Olivia	F	34	Caucasian	10	5th	Yes
Chris	M	34	Caucasian	8	6th	Yes
Emma	F	30	Latino	9	4th	Yes
Ava	F	29	Caucasian	5	2nd	Yes
Charlotte	F	53	Caucasian	18	6th	Yes
Anne	F	63	Caucasian	16	6th	Yes
Amelia	F	35	Caucasian	10	2nd	No
Isabella	F	50	Caucasian	22	2nd	No
Mia	F	34	Caucasian	11	6th	No
Evelyn	F	50	Caucasian	20	3rd	No
Camila	F	58	Caucasian	31	5th	No
Sofia	F	46	Caucasian	22	3rd	No

Data Collection and Analysis

The 12 participating teachers answered 13 semi-structured questions on implementing CT into elementary classrooms regarding their personal experiences with integrating CT into formal classrooms. The interview questions were:

1. What is your understanding of CT?
2. How do you perceive the value of CT in elementary classrooms?
3. In which course(s) have you implemented CT in your teaching?
4. If you have implemented CT in your curriculum, how did you go about in implementing CT?
5. Do you find your students more engaged when you use CT?
6. What are some of the issues and challenges with implementing CT in elementary classrooms?
7. For teachers who have not implemented CT, what do you think the reasons might be?
8. Do you think elementary students are ready for adopting CT as a mental tool?
9. Did participating in the STEM+CT afterschool program help you integrate CT into your own curriculum?
10. What is the demographic make-up of your student population?
11. Which CT components have you used in your curriculum?
12. What advice would you give to educators and researchers regarding implementing CT into elementary classrooms?
13. Anything else you might want to add? Such as resources, policy changes etc. that might help in a large-scale integration of CT into elementary classrooms?

In terms of CT, the interview questions referred to the CT components (see table 2) that were embedded in the informal STEM+CT curriculum and the teachers had facilitated the curriculum during an eight-weeks afterschool program (Yang et al., 2021). The following table lists the CT components.

Table 2
CT Components and description

CT Components	Description	Reference
CT concepts and language	CT Vocabulary, such as variables, data, modeling, testing and debugging, iterative.	Brennan & Resnick, 2012; Lu & Fletcher, 2009; Lye & Koh, 2014
Abstractions	Collecting information and developing plans to solve problems.	An & Lee, 2014; Barr et al., 2011; Wing, 2008
Decomposition	Simplifying problems or specifying solutions.	CSTA, 2009
Algorithms	Applying a specific set of tools or sequences of steps to solve problems.	Barr et al., 2011; Yadav et al., 2011
Conditional Logic	Using strategy such as an "if-then-else" construct to clarify problems and solutions.	Wing, 2006
Heuristics	Applying experience-based strategy that facilitates problem solving, such as "trial and error."	Scucuglia et al., 2020
Data Collection	Gather data to define or solve a problem.	CSTA, 2009; Grover & Pea, 2013
Data Structures	Exploring data to find patterns, causes, trends or results to facilitate the knowledge construction and problem solving	CSTA, 2009; Grover & Pea, 2013
Simulation and Modeling	Manipulating data or concepts through controlled programs or exercises or creating such programs for data manipulation	CSTA, 2009
Communication	Written and oral description supported by graphs, visualizations, and computational analysis.	Astrachan & Briggs, 2012

The interviews were transcribed and prepared for analysis by one graduate research assistant and one postdoctoral fellow. The postdoctoral fellow and another research assistant conducted a thematic analysis of all interviews independently by "identifying, analyzing and reporting patterns within data" (Braun & Clarke, 2006, p. 79). The inter-rater reliability was calculated with the agreement and disagreement on the whole data set, which resulted in a 95% agreement. This agreement is higher than the minimum acceptable threshold of 75% (Graham et al., 2012). All frequency analysis were calculated based on the number of times each theme occurred in each of the interviews. For each thematic category, each teacher's response that has that specific theme would only be counted once. The thematic categories were based on common ideas or subjects that the teachers reported in the interview. For example, if a teacher says: "*time is an issue*" when discussing challenges and issues in the interview, this would be counted into the category "*lacking time*" as a challenge for implementing CT.

RESULTS

Teachers' Perceived Value of CT Integration

All teachers interviewed chose to implement some CT elements into their teaching, even if they have not adapted the informal STEM+CT curriculum as part of their curriculum. This suggests that all teachers have valued CT integration into formal classrooms. The majority (67%) of the teachers perceived CT to be valuable for problem solving. Amongst the teachers who have reported using the most popular CT components, 17% of the teachers also mentioned that CT is valuable for answering questions, using trial and error or some form of modeling as a mental tool, and an additional 8% of the teachers also specified that CT is a higher thinking level process that can be used for real life situations, learning the scientific methods, and collecting data. On the other hand, relatively few teachers (33%) have reported using simulation and modeling.

The teachers' responses suggest that after participating in the afterschool program, they valued CT as an integral part of their teaching, particularly for helping their students learn how to problem solve. Examples of typical responses regarding valuing CT for problem solving are as follows:

> *"Computational thinking, to me, is the process of thinking and solving problems like how you would think through the process of thinking though the ways to solve a problem and the ways that you would apply that"* (Olivia).

> *The biggest value I have [is] at the elementary level, where they start[ed] developing kids as problem-solver. And for me, I use the term critical thinkers–to be able to think critically about a problem and not just have somebody else solve it for them, that they need to think through the solution and that sometimes takes some trial and error and not always the right thing the first time. But for them to really to be able to see a problem and attack it for themselves.* (Sofia)

> *I do think it is very valuable. I–you know of course–to a third-grade level and yes I do implement problem solving and critical thinking. I work with [a] high refugee population. So just learning how to communicate in English and teaching kids how to read also –it's… I feel that it's quite a challenge to have a class comprised of kids that are so low level and then kids… that are medium and high level in the same core group–that is a challenge…You know, I think it's valuable to teach the structure and to teach the process of problem solving.* (Evelyn)

Majority (83%) of the teachers also voiced value for CT being implemented into elementary school classrooms specifically regardless of age. For example:

> *I think that's how we are teaching math, and that's how we are teaching science. That's like… let's break it down really small…and how can we apply it the next time we solve it– the same thing [like] the first time they solve the math problem. It takes a while and then they can apply the pattern later and quicker and quicker that's automatic. I think they are doing it all the time even as little guys*. (Evelyn)

> *I get my students [who] are highly engaged because the work is authentic, it's hands-on. They are not just reading about what a scientist does, what a mathematician does– they are working as such*. (Camila)

> *At all grade levels, even from kindergarten. Because if they don't, they kind of get that learned helplessness, that they don't know how to attack problems and to be able to…learn to see the problem. But even when they see a problem, they don't see it having a solution. But for them to be able to see a problem and then to think well okay I can solve this. And at the early level, at the early grades is when you really need [to] instill these habits–that's problem solving. Even the kids I get in third grade, if they haven't had these CT strategies and habits…then they really struggle with even the simplest problems*. (Sofia)

When comparing the teachers who have adapted the informal STEM+CT into their curriculum and those who have not, the teachers who have adapted the informal curriculum tend to perceive the value in CT as helping students become better solvers of complex problems and lending itself to students thinking like scientists. The teachers who have not adapted the informal curriculum leaned more towards equivocating CT as a general critical thinking process and giving students more hands-on experience. Table 3 displays the frequency of how teachers value CT and the comparison between the teachers who have implemented the STEM+CT curriculum and the teachers who have not.

Table 3
Perceived Value in CT

Perceived Value in CT	Adapted Informal Curriculum	Not Adapted Informal Curriculum	Total
Helps students become better problem solver for daily life situations	3	1	4
Facilitates the process of learning STEM	2	1	3
Good for higher level thinking process/developing critical thinking skills	0	3	3
Helps students find patterns or connections	1	2	3
Helps students work through complex problems	2	0	2
Helps students break complex problems down into simpler steps in their coursework	2	0	2
Gives students more hands-on experience	0	2	2
Helps students through trial and error	1	1	2
Helps Students identify problem, explain, and support their thinking through research	1	0	1
Help students solve problems in multiple ways	1	0	1
Helps with a future career in technology	0	1	1

For example, an example response of a teacher who has implemented CT is:

> *I think CT allows a lot of critical thinking for students. So I think that's really valuable in that way. I think it also helps students to take something that's really big and complex and break it apart into manageable pieces that can be really hard for students to grasp a larger complex issue or idea. Just a student might have a hard time with many steps in a problem. But breaking it down into little pieces can help students understand piece by piece and build towards a better understanding. I'm thinking especially in sciences–a lot of things that we study can be really daunting to students like big concepts that seem hard to pull apart or understand the pieces. So I think computational thinking has a real strength in breaking the ideas down for students. For example, when I taught in 4th grade, we did a water unit and one of the bigger ideas with the water unit was how the ground purifies water. And so we did a series of experiments with different materials…we have this complex idea how to purify water and we [broke] it down into pieces*

by setting different materials that water goes through and allowing students to experimenting with those materials like for example we ran water through sand and we ran water through different materials and filters in order for students to build their own understanding of how water purify. (Chris)

On the other hand, a common response of a teacher who has not implemented CT is, "*Yes, there is some value in it. It takes a lot more time on the teacher's end to come up with projects that can lend themselves to this type of thinking process. But it's good for students to do higher level thinking*." (Amelia)

Teachers' Perceived Challenges of Implementing CT

Eleven themes on the challenges the teachers reported on implementing CT into elementary school classrooms (see Table 4) were identified. The result shows that the majority of the teachers reported "lacking time" as the main challenge in implementing CT. The teachers who have not adapted the informal STEM+ CT curriculum raised three more challenges than the teachers who have adapted the curriculum, which were lacking resources, teachers having too much to do, and students' issues such as language and poverty issues.

Table 4
Frequency of the challenges reported by teachers

Challenges of Implementing CT	Adapted Informal Curriculum	Not Adapted Informal Curriculum	Total
Lacking time in general	5	5	10
lack of training, knowledge, or experience	5	4	9
Schedule issues	2	2	4
aligning with curriculum	1	2	3
Teachers' misconceptions of definitions on CT	2	1	3
Lack of resources or materials	0	3	3
Funding or budget issues	1	2	3
Teachers have too many things on their plate	0	2	2
Confidence	1	1	2

Challenges of Implementing CT	Adapted Informal Curriculum	Not Adapted Informal Curriculum	Total
CT is viewed as impractical and not worth learning	2	0	2
Kids with grade level, language, poverty etc. issues	0	2	2
Students' misconceptions of definitions on CT	1	0	1

For example, one of the teachers who have adapted the informal STEM+CT curriculum expressed the issue of lacking time:

> *The researchers gave us way too much information or way too many tasks. And so it was kind [of like] finding a balance of what elementary students were capable of and what was more important, but again we had the support so we could sit down and be like–okay, in this lesson you gave us 15 different things to do and we are going to be able to do 5. What are the most important out of these 5 or out of 15?* (Ava)

The second most reported challenge for both groups is "lacking teacher development or knowledge." For example, a teacher who has adapted and implemented the STEM+CT curriculum expressed:

> *It's the experience [that] might be a big one. This is my fourth-year teaching so I feel very comfortable with the materials that allow me probably a little bit more flexibility than I can bury myself into when I was a first year teacher. So I think having a really good grasp of the material makes it easier [to] hold things apart. Because then we know how we'll put them back together. So I think experience with your subject materials makes a big difference*. (Chris)

A teacher who has not implemented the STEM+CT curriculum also reported:

> *I think for a lot of teachers would be their knowledge in the subjects and not feeling like they had the resources to have whatever in their classroom to teach it and not knowing...I think overall teachers would be hesitant to dive in unless their knowledge base was pretty large on it I think a lot of cases the kids might know more about computers and stuff than they do depending on the age of the teachers so.* (Mia)

Both groups of teachers equally cited the lack of time/scheduling conflict, teacher development, and knowledge of CT as the most pressing issues. However, the teachers who have not adapted the STEM+CT curriculum tend to also cite the issue of the lack of resources, and focus on more peripheral issues, such as students' backgrounds, teacher communication, community support etc. For example:

> *I would say, generally speaking, it's because of the levels of poverty and everything that goes with poverty. The majority of the kids at our school are very low level and were trying to retract and teach very low-level things, so that they can even get to the point of doing some of this high-level stuff. They are just not all of them now and that is the rub–that you know it's just a very diverse group within a classroom. So it is hard to, you know, when this one can't add 4 + 3 to get the energy to move forward with this high level stuff. Well that is the challenge with my classroom and that is the reality.* (Evelyn)

Teacher's Advice on How to Integrate CT

Unsurprisingly, almost all the teachers explicitly voiced wanting some form of teacher PD (see Table 5).

Table 5

Frequency of the advice given by teachers.

Teacher's Advice on Integrating CT	Adapted Informal Curriculum	Not Adapted Informal Curriculum	Total
More professional development afterschool Program	6	5	11
Having stand-by Support	3	3	6
"Go for it"/Fight for it in general	2	2	4
Having ready-made materials for teachers	3	1	4
Focus more on Hands-on	3	0	3
Communication/collaborating with teachers who have done it	0	3	3
Work with school district/community partnerships	1	2	3
Integration with course curriculum	0	3	3
Clearly define what CT is	0	3	3
Be considerate of teachers' time	0	2	2
Be mindful of individual differences in students	0	1	1

On the other hand, the teachers who had adapted the curriculum tend to be more vocal about not only a need for more teacher PD programs but gave more descriptive justifications regarding why the PD would benefit teachers. For example:

> *I have a strong belief that if you want teachers to do something in their classroom you need to give them something for their classroom. So I think that for example, the afterschool program we did with the bridge building and then there was another of airplanes, there was another they did with robotics after school programs were super helpful. And one of the big reasons that I wanted to teach and engage and to participate in those programs was because I knew that … I was going to [be] able to implement these same skills in my classroom and I have. So because I was able to keep those materials that were good quality materials that I could never get otherwise. I would not be able to afford them for my classroom because I was going to be able to keep them and continue using those same skills and those same lessons. I modified the curriculum that we used to create a unit for my classroom. So because I knew that I was going to [be] able to have materials and have an easy to implement unit into my classroom I was in. I think that's all it really takes. I think the afterschool ideas were great to provide teachers with guidance to do this afterschool to gain familiarity with it and I also think professional development. People who have knowledge in computational thinking skills and want it to be more prevalent connecting to the district wanted it, to provide professional development for credit since teachers are looking for credit*. (Emma)

Whereas the teachers who have not adapted the STEM+CT curriculum gave more advice on asking researchers to be more understanding of their situation, such as difficulty working with low-income students, or pushing to get teachers involved. An example from a teacher who has not adapted the STEM+CT curriculum:

> *I would go so far to say for most of the teachers at Whitney, we are struggling with kids that are not on grade level and are very far below grade level in many instances. And so having a core group of kids that are not all ready for that you know and to go into these very analytical processes…No some of them are, but I think that the motivation would be that these kids they…you know are not ready for that. They can't. They aren't ready for the higher-level stuff and not to say they shouldn't*

> *be exposed to it. But really truly I have kids that cannot read okay yet… So being able to function at the higher levels is not ugh the true picture. I think probably for other schools that are more affluent and are grade level I think it would be very valuable. I find it very valuable. But I don't find it to be a good fit when we got such low-level kids*. (Evelyn)

DISCUSSION

The aim of this study is to investigate how teachers who had participated in an intensive after-school CT integration program perceive the value of CT, the challenges, and advice regarding implementing CT into elementary school classrooms. We found that all the participating teachers interviewed perceived the value of CT as helping students become better problem solvers. They tended to use the CT components of decomposition, communication, and data collection when formally implementing CT in formal classrooms, tended to cite time as the most pressing challenge for adopting a CT-integrated curriculum, and wanted more PD for teaching CT. Regarding the challenges and issues, there is no difference among the teachers who have adapted the informal STEM+CT curriculum and the teachers who have not. Our finding on challenges and issues for implementing CT is consistent with previous research (Ketelhut et al., 2020; Rich et al., 2019). Other than the lack of knowledge, our results support past research that suggests teachers perceive the lack of time to be one of the most pressing issues for implementing CT in their curriculum (Ketelhut et al., 2020; Rich et al., 2019). The participating teachers also expressed concerns regarding researchers not understanding how many things the teachers have on their plate, as well as not being mindful of the teachers' lack of scheduling flexibility. Several teachers also voiced wanting the school district to collaborate with researchers and teachers so that there is constant stand-by support and resources available to resolve the challenge of lacking time for implementing CT into formal classrooms. However, past research found that teachers expressed concerns regarding CT being age inappropriate for younger students to grasp (Rich et al., 2017). In our study we found that teachers who have adapted the STEM+CT curriculum expressed mostly enthusiasm about teaching CT to students of all age groups (from 2nd to 6th grades - see Table 1). This suggests that not only is it important for teachers to have professional training for teaching CT but adapting the curriculum into their own classroom based on their own students' needs motivates teachers to better integrate CT into elementary classrooms.

Amongst other differences between the teachers who have adapted and implemented the informal STEM+CT curriculum and the teachers who have not, we found that for the teachers who have adapted the STEM+CT curriculum tended to value CT as a mental tool for problem solving rather than CT being synonymous with critical thinking in general. This is likely because adapting the informal STEM+CT curriculum gave the teachers the necessary experience and an organized approach to purposefully use CT for helping students solve complex problems. Yadav et al. (2018) found that teachers' conceptions of CT evolved from a generalized idea of broadly defining CT as problem-solving to referencing CT components such as conditional logic during the course of their PD. In this study, we found that teachers who have not adapted the informal STEM+CT curriculum tended to value CT as a general critical thinking skill, whereas the teachers who have adapted the STEM+CT curriculum were able to better express how CT was valuable for problem solving. For example, one teacher who has adapted and implemented the informal CT curriculum was able to extensively discuss the changes in his attitude and pedagogy that would help students solve complex mathematical and scientific problems. In addition, Rich et al. (2019) found that elementary school teachers tend to associate CT with mathematics and not science. In our study we found that teachers realized that CT could be used for a variety of subject disciplines. The teachers who have adapted the STEM+CT curriculum tended to be less likely to cite the lack of resources as a challenge. This is also likely because these teachers are knowledgeable enough to not need additional resources for implementation. The teachers who have adapted the STEM+CT curriculum tended to be more vocal about the need for more teacher PD as well as being more descriptive regarding why PD would benefit teachers. This finding makes sense as the experience of adapting the informal STEM+CT curriculum would give teachers the insight into what specific training the teachers need for a successful implementation. For instance, we found that the teachers who have adapted the informal STEM+CT curriculum were also able to recall specific examples on how they used CT in their teaching. On the other hand, the teachers who have not adapted the informal STEM+CT curriculum tend to want more ready-made resources, and focus more on peripheral issues, such as students' backgrounds, teacher communication, community support etc. This finding suggests that some teachers may have unique individual circumstances that become obstacles for implementing CT which researchers should be mindful of.

Consistent with previous research (Bower & Falkner, 2015; Giannakos et al., 2015), the teachers in this study who gained experience from adapting the informal STEM+CT curriculum and implementing it into their formal classroom valued CT more as a mental tool as specifically for solving complex problems. The high demand from the teachers for ready to use materials demonstrates that after PD the teachers perceived greater value for implementing CT as part of their formal curriculum. Our findings are consistent with Giannakos et al.'s (2015) study in that we also found the lack of knowledge to be a challenge for CT integration for teachers. However, our participating teachers also voiced that more teacher PD would fill the gap in CT knowledge. The participating teachers who have adapted the informal STEM+CT curriculum were more thoughtful on how PD would benefit both teachers and students alike. Two of the teachers also insisted that just by showing other teachers how to integrate CT in an informal classroom setting can motivate the others to want to join in implementing CT in their own classrooms. This argues for the importance of having a CT related program available for teachers that would support the implementation of CT into classrooms. In the current study we used the TPACK (Mishra & Koehler, 2006) Framework for teacher's PD on CT integration. Our results show that teachers participating in the afterschool program grasped the interactivity between content knowledge, technological knowledge, and pedagogy. Our teachers expressed valuing CT as a critical mental tool for complex problem solving, therefore they learned to adapt and integrate CT into their expertise on the subject content. During the process of this integration, the teachers not only were immersed with the technology usage in the PBL setting, they learned to adopt technology during the integration of CT into formal classrooms, such as experimenting with different materials on how water purifies (as explained by the teacher Chris). This suggests that the teachers have learned through PD to combine content knowledge with technological knowledge as well as pedagogy. Our teachers also expressed the benefit of having readily available materials of the CT curriculum so they can integrate CT more effectively in formal classrooms. This suggests that the teachers also learned how to integrate CT curriculum into their own pedagogical practices.

Our recommendations regarding how to integrate CT into elementary classrooms (and by an extension to K–12 education in general) are as follows: 1) PD provided for teachers on CT should consider the interactions of content knowledge, technology knowledge and pedagogy outlined in the TPACK framework, 2) teachers need to be trained on CT via adopting the role of both a facilitator and learner preferably within a PBL setting, and 3) form collaborations between the school district, teachers, and researchers on introducing CT curriculum into elementary school classrooms. A teacher

PD program in a PBL setting with a CT curriculum can successfully immerse teachers into learning how to teach CT and facilitate the teachers' changing attitudes and valuing CT as a problem-solving process (Yadav et al., 2018). Past research shows that CT is commonly associated with computer programming, such as using the VPE of Scratch (Zhang & Nouri, 2019). However, we have found that whether the teachers have adapted the informal STEM+CT curriculum or not, they can use CT in a variety of subjects from mathematics to reading, to social studies.

The current study has several limitations. Firstly, in line with the nature of qualitative research, the small sample size and the fact that the teachers who participated in the after-school program were all volunteers limit the generalizability of the results. Secondly, since the teachers who participated in our interview study were more likely to be the teachers who are enthusiastic about integrating CT in their classrooms and voice their opinions. This can further limit the generalizability of the findings. Nevertheless, we consider that the teachers' insights from this study can pave the way for future research on this important topic. Finally, because of the small sample size, the frequency differences observed in the groups of teachers, who have adopted the STEM+CT curriculum and those who have not, may not be significant.

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