Teachers' Perspective on Implementing Computational Thinking in Elementary Classrooms

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***Abstract*—Computational thinking (CT) is a thought process designed to help students better solve complex problems using mental tools such as decomposition, abstraction, heuristics, data collection, algorithms, modeling, and communication (Wing, 2006). This study is part of a larger National Science Foundation funded STEM+C (computing) study that integrates CT in informal STEM learning. The informal STEM+CT curriculum resulted from the large study was guided by project-based learning (PBL) to help 4th to 6th grade students practice CT in the context of problem solving. Twenty-four teachers have worked with small groups of students in an afterschool community center program over an 8-weeks period. The larger STEM+C study also encouraged teachers in adapting the informal STEM+CT curriculum in their own classrooms, which eight of the 24 teachers have done so. This study investigates the participating teacher's perspective on implementing CT into elementary classrooms after they had facilitated the STEM+CT curriculum in community centers' after-school programs via interviewing 12 of the 24 teachers. The current study focuses on the challenges and issues regarding implementing CT in elementary classrooms. The results show that teachers collectively place the lack of time and the lack of professional development as the major obstacles in integrating CT into elementary classrooms.**

Keywords—computational thinking, STEM+C, Project Based Learning, teacher perspectives

I. Introduction

CT is a critical thinking process designed to help students tackle complex problems by breaking them down into simpler steps, such as using heuristics, decomposition, and abstraction, as well as engaging in the scientific method of data collection and analysis [1]. In the 21st century, critical thinking skills that enable students to learn science, technology, engineering, and mathematics (STEM) concepts are in dire need for the future large technology-based workforce. Integrating CT into K-12 STEM curriculum helps prepare students by fostering creative and self-reliant problem solving [2]. The unique contribution of a CT embedded curriculum is such that it couples with some form of project-based learning (PBL), which is centered on hands-on learning that allows students to engage in constructive, goal-setting, collaborative, communicative, and reflective investigations for problem solving [3]. CT is then fostered in students via PBL with teacher facilitation such as asking questions and mentoring steps that leads to the solution. Although CT has been studied in the educational setting, there remains many questions regarding the challenges and issues with implementing CT in classrooms [4]. Therefore, it is essential to gain a better understanding of how teachers can integrate CT into elementary school curriculum in a formal setting. Thus, this study investigates the challenges and issues regarding teachers' integrating CT in their classrooms with the aim to shed insight into effective classroom CT integration and fostering CT in students.

Despite the importance of integrating CT into K-12 schools, CT is still largely missing in K-12 STEM education [5]. Nevertheless, major governmental efforts have been made to recognize CT as a key scientific practice and have supported its practice in K-12 education, such as the Next Generation Science Standards (NGSS) and the National Science Board [6][7]. Majority of recent attempts to integrate CT into K-12 education tend to rely on a series of "coding" activities that offer little support for subject concept learning such as science learning [8][9]. Weintrop and colleagues described implementing CT as a composite of practices that include data collection, modeling and simulation, problem-solving, and systems thinking [10]. More recently, Yang and colleagues further described CT in an upper elementary curriculum as eleven components that included vocabulary, abstraction, decomposition, communication, heuristics, conditional logic etc [2]. However, more research is needed to examine how teachers can embed various CT components into their curriculum, especially in the context of elementary classrooms.

Although CT is widely studied in education, very few studies investigated the challenges, issues, and recommendations regarding CT integration in STEM learning in a formal classroom setting from the teachers' perspective. A major challenge in CT integration is the lack of an agreed upon and consistent definition of CT [4]. CT is often vaguely defined as a "peripheral" type of thinking. The Computer Science Teacher Association (CSTA) for example listed several dimensions of CT as dealing and working with complex and difficult problems, having a tolerance with open-ended problems, and the ability to work collaboratively [11]. These CSTA's CT definitions would be too vague for teachers to put into actual practice [4]. Yang and colleagues broke down CT as a list of useful components including abstraction, heuristics, and conditional logic [2]. However, these definitions may be too broad and abstract for teachers who would like to get a general understanding of what CT is in subject disciplinary practice. Most often, CT components are in the context of higher level programming and coding which may deter teachers from integrate CT for elementary school level STEM subjects [12]. Another major challenge is how to properly position CT into the curriculum [4]. There remain questions regarding what kind of CT concepts should be taught in a standardized, wide-scaled way and how to teach those concepts [13]. Some researchers believe that CT should be taught separately in a subject such as in computer science that directly incorporates CT [14], whereas others believe that CT can be taught universally across all subjects, in which case the curriculum would need to be thoroughly revised to for teaching CT adequately [15].

Researchers have studied the integration of CT via a PBL guided curriculum that engages students in "authentic" hands-on learning where students are the active investigators to knowledge seeking rather than regurgitating information handed down by instructors [16]. Notably, Yang and colleagues' STEM+C project designed a curriculum in which teachers were guided to assume multiple roles such as coach, mentor, learner, and facilitator as needed rather than only a lecturer as in the case for traditional classroom learning [17] [18] [19]. The design of the learning activities is grounded in real-world problem solving or topics (e.g., detecting water on Mars, building a bridge, building an airplane etc.) that are closely related to students' surroundings, which provides students an opportunity to formulate a plan, test their plan, and evaluate their solutions with necessary support [20] [19]. A central guiding principle for a PBL curriculum design is that learning activities are driven by a guiding question (e.g., how can we detect life on Mars?). The project embedded CT by using the eleven components described in the paper by Yang and colleagues [2]. The eleven components are: *CT vocabulary*, *abstraction*, *algorithm*, *communication*, *conditional logic*, *data collection*, *data structures and analysis*, *heuristics*, *pattern recognition*, and *simulation and modeling*. These components act as a guide for defining the overreaching concept of CT. Each component was not only defined but also an example was given to the teachers as guidance. For example, for the component "abstraction," the example given in the bridges project described in the study is to "identify each of the characteristics that would make a strong bridge." Students then are directed to have sustained inquiry, learner reflection, testing and revisions in problem solutions applying CT components. The majority of the 11 CT components highlighted by Yang and her colleagues in their STEM+CT curriculum focus on students' abilities to communicate and solve problems, as well as collect data [19]. Oral and written communications are supported by visuals, graphics, simulations. At the end of a PBL curriculum, the students would showcase their final products often through a competition or an exhibition. These structuredness of PBL enhances students' learning as well as collaboration that can be facilitated based on the student needs [21]. Overall Yang and colleagues found that both the teachers and the students responded positively to their STEM+CT curriculum in terms of learning experience and teacher facilitation.

The current study is part of the larger STEM+C study and within the same curriculum by Yang and colleagues, in which the research team had designed and implemented a STEM+ CT curriculum that was guided by PBL in an informal after-school program [19]. In the program the researchers trained teachers in PBL and CT. Informal programs that are not part of the regular school classrooms that have an advantage in being highly adaptable to offer structured environments for hands-on, immersive, and authentic learning [22]. There is of course a continuous need to bridge informal learning with formal classroom coursework. Having teachers participate in PBL with an integrated goal to instill CT in students is an important step to integrate CT in formal learning settings. Teachers then can have first-person experience in how to integrate CT into their curriculum and change their way of thinking about teaching in terms of using more hands-on approach rather than regurgitation for students. The experiences of these teachers are valuable in that they not only have training on CT but also have attempted to integrate CT into their own classrooms. Thus, the teachers can have valuable insights of the issues and challenges of integrating CT. The main research question for the current study is:

What are the challenges the teachers perceived in implementing CT into elementary classrooms?

II. Method

A. Study Design

This is a qualitative study consisted of in-person interview with elementary school teachers who have participated and facilitated an informal STEM+CT curriculum. All teachers had an eight-week apprenticeship in an informal afterschool learning environment for facilitating the STEM+CT curriculum after they were trained in CT and PBL described in the paper by Yang and colleagues [19]. We interviewed the teachers who had participated in the afterschool program and facilitated the informal STEM+CT curriculum to gain further insight into how they could effectively integrate CT into their own classrooms.

B. Participants

A total of 12 of the 24 teachers volunteered to be interviewed for 30 to 40 minutes on average. Due to the current COVID-19 pandemic all the interviews were conducted remotely online via Zoom. The average age of the teachers is 43 (*SD* = 11.69). The teachers' average years of teaching is 15.17 (*SD* = 7.63). The majority of the teachers are female (92%) and White/Caucasian race/ethnicity (92%). The grade levels taught by the teachers range from 2nd grade to 6th grade, with 33% of the teachers reported currently teaching 6th grade, 25% reporting currently teaching 2nd grade, 17% currently teaching 3rd grade, 17% currently teaching 5th grade, and 8% currently teaching 4th grade (see Table 1). Half (i.e., 6) of the teachers have formally implemented CT and adapted the after-school STEM+CT curriculum into their curriculum and the other half have not formally implemented CT into their course curriculum. The six teachers who have adapted the informal STEM+CT curriculum into a unit lesson plan for specific subjects, math, science, language, and social studies.

Table 1. Teachers demographics.

Teachers	Gender	Age	Ethnicity	Yrs of Teaching	Grade
Olivia	F	34	Caucasian	10	5th
Chris	M	34	Caucasian	8	6th
Emma	F	30	Latino	9	4th
Ava	F	29	Caucasian	5	2nd
Charlotte	F	53	Caucasian	18	6th
Sophia	F	63	Caucasian	16	6th
Amelia	F	35	Caucasian	10	2nd
Isabella	F	50	Caucasian	22	2nd
Mia	F	34	Caucasian	11	6th
Evelyn	F	50	Caucasian	20	3rd
Camila	F	58	Caucasian	31	5th
Sofia	F	46	Caucasian	22	3rd

C. Procedure and Data Analysis

The interviewed teachers answered a total of 13 questions on the topic of implementing CT into elementary classrooms including the perceived value, challenges and issues, and their personal experiences with using CT in their curriculum. The interviews were audio-recorded for data analyses. For the purpose of the current study, only the responses to interview questions pertaining to the research question were analyzed. Specifically, the questions analyzed were: "*What are some reasons why teachers haven't implemented CT*," "*what are some issues and challenges you see with integrating CT into elementary school classrooms*," and "*what advice would you give for researchers and educators for implementing CT into elementary classrooms?*" For the data analysis, we used a coding theme based on the commonalities in the teachers' interviews for challenges and issues in implementing CT, as well as suggestions given for how to better integrate CT into elementary school classrooms. The coding themes are based on the teachers' reported issues and challenges to the interview question "what are the issues and challenges you perceive with integrating CT into elementary school classrooms?" One researcher coded these based on the content of what the teachers relayed during the interview. For example, if the teacher said: "we do not have enough time on our hands," this would be coded as an issue with lacking the time. If a teacher said: "I feel that teachers don't have enough knowledge or experience with CT," this would be coded as "lack of training or experience." The resulting themes total to 11 issues (see Table 2). The frequency is based on how often the mentioned themes occurred in the teachers' responds. The frequency indicates how many teachers brought up each issue. In other words, for each category if a teacher brought up the issue it would only be counted once. The likelihood is calculated based on the occurrence of each theme divided by the total number of mentioned issues (totals to 44).

III. Result

The frequency analysis shows that "lacking time" and "lack of teacher training or knowledge" accounting for 43% of all mentioned issues and challenges. And unsurprisingly, the teachers voiced wanting some form of teacher training/development program 40% of the time in the total course of the interview. The other common issues and challenges mentioned by the teachers are "lack of clear definition of what CT actually is," "scheduling issues with their daily courses," and "lack of resources to teach CT."

Table 2. Teachers mentioned issues/challenges of integrating CT by frequency and likelihood.

Issues/Challenges	Frequency	Likelihood
Lacking the Time	10	0.23
Lack of Training/Knowledge/Experience	9	0.20
Scheduling Issues	4	0.09
Definition/Misconceptions on CT	4	0.09
Hard to Align with Curriculum	3	0.07
Lack of Resources/Materials	3	0.07
Funding/Budget Issues	3	0.07
Lack of Space/Too Much to Do	2	0.05
Lacking Confidence	2	0.05
Impractical/Not Worth Learning	2	0.05
Kids Having Grade level/Language/poverty Issues	2	0.05

A typical response from the teachers regarding the lack of time is the following:

"*In title I schools we spend a good 30 to hour, a good 30-60 minutes a day playing catch up and doing intervention helping kids get to grade level material plus teaching them all of the basics of math, reading, and science, and social studies that I can't see anything else being perceived as extra going to the wayside.*"—Emma

Of the teachers who mentioned lack of training, one of the teachers described the issues such as:

"*I think again the big challenge is the training….I mean I have 30 years to figure this all out. But I think that there'd value in having a course at the college level for teacher's training that would be the highest value because I think that having a really good instructor that can explain the rationale of why we instruct in this way and why it's good for kids and then how to go about designing units and giving baby teachers a chance to actually practice this.*"—Camila

A typical response for issues with defining CT went like this:

"*The terminology was difficult for the students that I work with to understand. And so, there was a, I don't want to say a disconnect, but I had to teach what is computational thinking, and the vocabulary and those words, then had to teach the curriculum of the airplane, in with teaching the words and the definitions of computational thinking. So, I think with the students, there was a disconnect in what they're trying to learn. Are we learning about computational thinking or are we learning about airplanes? Without them able to understand: it's both and the computational thinking is the structure that's going to help guide you through learning about airplanes. And I don't know, part of the problem why that could have been difficult was that I'm new at teaching it so, I didn't have a real fluid understanding of how it worked. And so, I might have been piecemealing things together but I really think the vocabulary was difficult for the students I work with to understand.*"—Charlotte

Charlotte also emphasized that other than for teachers, the students' understanding of what CT is can be just as important, she said:

"*The terminology was difficult for the students that I work with to understand. And so, there was a, I don't want to say a disconnect, but I had to teach what is computational thinking, and the vocabulary and those words, then had to teach the curriculum of the airplane, in with teaching the words and the definitions of computational thinking. So, I think with the students, there was a disconnect in what they're trying to learn. Are we learning about computational thinking or are we learning about airplanes? Without them able to understand, it's both and the computational thinking is the structure that's going to help guide you through learning about airplanes. And I don't know, part of the problem why that could have been difficult was that I'm new at teaching it so, I didn't have a real fluid understanding of how it worked.*"

Another teacher also emphasized that revisiting the way of teaching students how to think is important, she said:

"*We spend a lot of time identifying children's deficits and then we take them out of engaging activities and we focus on their deficits. And we use canned, boring programs, in theory to help them close the gap. So, if they have a reading fluency deficit, they're pulled out of the class and helped to read faster, or if they have a math fact fluency deficit, they're pulled out and given drills. And in my opinion, that time would be much better spent focusing on the deeper thinking levels and giving kids a way to excel at more, not necessarily advanced, I can't find the right word but…you know, the taxonomy of…there's basic and there's application…I can't think of that taxonomy, but opportunity to focus more on those skills than the basic route remediation skills*."—Sophia

The results were both consistent with the previous research but also shed additional insight. Although the teachers have expressed frustration with the lack of standard definitions, and a few of them expressed that they did not know that what they were teaching was CT until they thought about it, the definition was not the biggest issues for these teachers who have participated in the afterschool program for PBL. Almost all teachers expressed that time was the biggest issue, with the second being teacher experience and knowledge. This shows that the issue with definition became minor when teachers have enough knowledge about what CT entails in a PBL setting, as well as having the time to think about how to integrate it into their own courses and the time to actually do it. This is similar to the issue of integration. The teachers expressed that having learned CT it helps them to switch from lecture format to hands-on or thinking about how to rearrange the teaching style to fit CT, and that itself can be done if given enough time or having resources readily available. For example, one of the teachers who integrated CT into his math coursework said:

"*Before we solve problems I introduce all those ideas and give them example of those in problems so they have a vocabulary page that also has math examples in them and I do all that before any student solve any problems. That way when they are ready to start solving problems we already have those pieces and we are able to put them together as appropriate to solve problems. Before when I taught it would be much more like: here's a problem and see what shows up in this problem so it was kind of constant introducing new ideas and new terms which was harder for students I believe because they didn't have all the tools in place to solve those so every problem was kind of like a gotcha problem almost like oh so we haven't learned this yet so now we have to do this. Whereas now, we have something to reference something to look at so when they see the piece they know what to apply to the piece.*."—Chris

IV. Discussion and Conclusion

The current study investigated the issues and challenges with integrating CT into elementary school classrooms. The results from the teachers interview from those teachers who had gone through a professional development program for facilitating a STEM+CT curriculum and adapting the curriculum show that the most commonly CT integration issues are lack of time and a lack of training or knowledge to teach CT. This is both consistent and inconsistent with the previous research. The previous research suggests that the major issue with implementing CT is the lack of a standard practical definition of CT for teachers [4]. Our findings show that although the teachers did mention the definitions of CT as being one of the issues, it is not as frequently mentioned as time and training. In fact, collectively, the teachers suggested that given enough time and training, educators will interpret what CT is based on the curriculum needed. Indeed, many of the teachers have said that they did not know what they were teaching is CT until they had gone through the professional development in the STEM+C program in the after-school program. The professional development not only shaped their understanding of what CT is, the teachers also had realizations of what previous pedagogies they had used previously actually involves teaching CT, as well as the pedagogies that would need to be revised in order to fit into a CT curriculum better.

The teachers also gave the following suggestions regarding how to proceed in the future for integrating CT into elementary school curriculum: 1) have more teacher professional development for implementing CT in the curriculum, 2) have stand-by support available for teachers for questions during the course of CT implementation, and 3) have ready-made materials that teachers can access to reduce the time from teachers' hands to generate content for their courses. Other than more teacher professional development in CT integration, the teachers also would like to communicate and collaborate with other teachers who have already implemented CT. They would also like to collaborate with the school district in general and have easy access to hands-on materials available that are readily integrated into their curriculum. These suggestions are important additions to the positive reactions the teachers had regarding facilitating the curriculum, which they deem as highly beneficial despite of some challenges presented herein regarding the design and implementation of such a complex curriculum [19]. In fact, virtually all the teachers during the interview have voiced that they enjoyed the afterschool program and would like to be involved in similar projects in the future, especially with more support and more collaboration amongst researchers and teachers in the field of education.

Another issue that are often overlooked is whether elementary school students would be motivated or engaged with a CT curriculum and whether CT would be age appropriate. Majority of the teachers interviewed considered that compared with the older students (i.e., 5^{th} grade and above) the younger students ($2^{nd} – 4^{th}$ graders) tend to be more motivated with a CT curriculum as it is hands-on and active which younger children tend to like. On the other hand, the younger students are less likely to adapt to the core feature in the CT curriculum which is using self-regulated learning and understanding meaning that it is okay to be wrong when they are playing an active role in learning. The younger students tend to want the correct answer given to them by the teachers rather than doing the trial-and-error, of which the older students better understand the merit of the trial-and-error approach. However, the majority of the teachers have voiced that they believe CT is right for students of all ages because it was important for them to acquire critical thinking as early as possible for meeting the current demands of society.

A limitation of the current study is that due to time constraints, only one researcher coded the data, and we did not conduct an interrater reliability analysis. We aim to analyze the responses to all 13 questions pertaining to all aspects of implementing CT into elementary school classrooms and using at least two coders for an interrater reliability analysis for future publications.

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