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# K-2nd Grade Teachers' Perceptions of Computational Thinking: Research Findings and Implications for Integrating Engineering and Computational Thinking in Elementary Education (Fundamental)

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## Abstract

As engineering has been incorporated in elementary education over the past two decades, a primary focus has been on engineering design. This approach has been productive, particularly in integrating engineering with math, science, and language arts. However, design is only one aspect of engineering. Engineering as a field of study and a profession also involves mathematical modeling, teamwork, ethical reasoning, and computational modeling. In this paper we are interested in computational thinking as a way of thinking and a set of skills relevant for computational modeling and synergistic with engineering problem solving. Computational Thinking (CT) has been described as a set of essential skills that are relevant for computer science but also can be integrated across STEM disciplines. These skills have the potential to advance children's problem-solving skills and foster their ability to think in new ways. However, for children to reap the benefits of CT, there is a critical need to prepare teachers who are well-equipped to teach CT. This qualitative study explores kindergarten through second grade teachers' perceptions of CT after they have implemented a STEM+C+literacy curriculum in their classrooms. A thematic analysis of the data revealed that teachers associated computational thinking with specific coding activities, an interdisciplinary subject, and a problem-solving process.


## Introduction

Over the years the presence of engineering as well as computer science (CS) education in K-12 classrooms in the U.S. has increased. In essence, numerous programs and curricula have been developed to support pre-college engineering and computer science education for formal and informal learning settings [1-3]. This presence and integration of engineering/CS in K-12 is an important phenomenon due to the implications it has for the future of STEM education [4]. In fact, a variety of positive outcomes have resulted from engineering integration in pre-college education, including improved performance in STEM subjects ([5, 6], a better understanding of what engineers do [7], and increase in the number of students pursuing careers in engineering [8]. Similarly, integration of CT can add to children's intellectual ability in reading, writing, and arithmetic [9], in addition to science [10].

Moreover, research corroborates the importance of computation in the formation of engineers [11-14] since these skills are necessary for solving complex technological problems for all engineering professionals. In fact, these skills support the various student outcomes described by ABET and are fundamental for developing a competitive engineering workforce. Furthermore, the relationship between engineering and computational thinking is formalized in 'The Taxonomy of Engineering Education Research' in which these skills are included in the student outcome category [14,15]. In a recent study, Diaz et al., 2020, employed the Engineering Computational Thinking Diagnostic to assess the development of computational thinking skills in one course for first year engineering students that included computational thinking topics. The authors found that the first-year engineering course did result in engineering students significantly increasing their computational thinking skills. This study suggests the importance of computational thinking in undergraduate engineering education. Therefore, we also argue that the integration of CT is relevant for pre-college engineering education (including in elementary grades), as early experiences with CT can help prepare youth for undergraduate engineering education. Research continues to explore engineering and CS learning of children, especially early childhood aged children, with integrated STEM curricula [1-2]; nonetheless, for engineering and CS education to become a "mainstream component" [4, 16] of pre-college education, more research needs to be conducted, not just exploring children's learning but also teachers' perceptions of and implementation of engineering and CS. In this study, we explored elementary teachers' perception of computational thinking after they implemented a STEM+C+literacy curriculum in their classrooms.

**Background & Literature Review**

***Computational Thinking***

Computational thinking (CT) has gained momentum in pre-college education as these skills are necessary for solving problems and developing a more competitive 21st century engineering workforce [16]. Though many CT definitions exist, Wing defines CT as "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" [9]. CT has become a prerequisite for many undertakings in the 21st century and is acknowledged as a foundational competency that supports the potential for creative problem solving and innovation across disciplines [9,17]. The benefits of CT integration in core subjects have led countries globally to incorporate CT in their academic standards (e.g., ISTE & CSTA 2011) while many more are committed to making it compulsory by 2020 [18]. This shift in education is intended to ensure that the general populace is technologically literate [18, 19]. Nonetheless, one major issue with implementing CT in the classroom is educators' lack of knowledge and familiarity with CT practices. Thus, examining educators' perceptions of CT is necessary because their perceptions can impact their teaching and lead students to develop accurate understanding of CT – or potentially incomplete or inaccurate understandings and perceptions of CT.

Additionally, it is important to consider how we prepare pre-college educators to explicitly integrate and teach CT. A report by the National Research Council [19], suggests that students can learn about CT by observing teachers as they model related thinking strategies and guide students to use these strategies independently. However, most of the current efforts to educate teachers about CT have been limited to computer science teachers [20]. For CT to become an integral part of the school curricula, exploring teachers' understanding and perception of CT is important, especially since CT is often equated with skills not reserved just for computer scientists [9, 21]. Teachers play an integral role in student learning and achievement, and therefore any misconception regarding CT or lack of knowledge pertaining to CT among teachers can greatly influence children's academic achievement, subject selection, and future career choices [22]. Although teachers' perceptions about disciplines have been a subject of research for decades [21, 23-28] understanding and exploring perceptions continues to be the first step to reform efforts in education. Accordingly, in this research study we explored early childhood teachers' perceptions of CT based on their experiences. Since assessing perceptions held by individuals can be invaluable in terms of tailoring interventions to meet the needs of people, especially teachers' because their perception and beliefs can directly affect practices [25, 29, 30, 31].

### *Teachers Belief and Perceptions*

The concept of "belief" has several implications and copious definitions, although the term is often used to describe perceptions [30]. Perceptions in literature are described as thoughts, actions, preferences, decisions, and judgments [32]. These perceptions develop through direct experience, observation, interaction, and communication with the social and physical worlds [30]. Perceptions influence one's subsequent actions that direct cognitive, motivational, affective, and decision-making processes [33]. Whereas teachers' perceptions can shape children's learning, experiences and stimulate children's interest [32].

In education several studies have investigated teachers' perceptions and the impact of their perceptions on students' learning and academic achievement in science, mathematics, engineering, and technology (e.g., [34 -36]). Cunningham et al. (2005) suggests that teachers' perceptions and beliefs are the key elements that can help determine their pedagogy and their ability to instruct students effectively. Teachers' beliefs and perceptions have a powerful impact on their willingness to adapt to new pedagogies and teaching strategies [37]. For example, Cotabish and colleagues (2013) highlighted that, elementary teachers have a big influence on effecting and nurturing students' interests and talents towards STEM fields. However, limited studies have explored perceptions of CT in pre-college levels, particularly in elementary grades, and most have primarily focused on teachers' perceptions in the context of pre-service teacher preparation (e.g., [20, 39-40]) and in-service teacher professional development (e.g., [41]) where understanding of CT practices is promoted through workshops and activities. Since teachers' perceptions can influence students' learning, it is critical to explore their perceptions. Examining prospective teachers' beliefs and perceptions could provide both an insight into their thinking and guide the development of teacher development programs to help transform their perceptions or misconceptions about computational thinking.

## Research Purpose and Question

To support the inclusion of CT in elementary school classrooms, exploring teachers' understanding and perception of CT is important. It is important to understand how teachers make sense of CT to generally support their teaching of CT, but also to understand how teachers might include both CT and engineering (either as two separate topics or in an integrated way). Thus, this study explores kindergarten through second grade teachers' perceptions about computational thinking (CT) after they implemented a STEM+C+literacy curriculum in their classrooms. The research question addressed in this work is: *How do K-2 grade teachers perceive CT based on their experiences?* Addressing this question can also allow us some insight into ways that teachers' understanding, and perceptions of CT connect with engineering.

## Methods

### *Research Design*

A descriptive qualitative study was employed [42] to investigate how teachers perceived CT based on their experiences. Qualitative descriptive studies draw from the general tenets of naturalistic inquiry which allows investigations of a phenomenon in its natural state. This methodology is a good fit for studies "when straight descriptions of phenomena are desired" [42, p. 339]. The target phenomenon in this study is teachers' perceptions towards computational thinking after they experienced STEM+CT activities in a professional development.

### *Participants & Settings*

The participants included six K-2 grade teachers that were purposively selected since they all participated in our Professional Development workshop prior to the study and then implemented the STEM+C literacy curriculum during the academic year. All of the teachers were female and White. The teachers' demographics and grade levels are presented in Table 1. To protect the privacy of the participants, pseudonyms have been assigned.

**Table 1**.

Teachers' Demographic Information

| Teacher ID | Grade | Gender | Ethnicity |
|---|---|---|---|
| Kelly | Kindergarten | Female | White |
| Laura | First | Female | White |
| Jessica | Second | Female | White |
| Samantha | Second | Female | White |
| Alice | First | Female | White |
| Julie | First | Female | White |

The study took place at public schools located in the Midwest, specifically in teachers' respective schools and classrooms. Teachers (K-2$^{nd}$) implemented the STEM+C+literacy curriculum, specific for their grade level, in their classroom as a regular series of lessons. The lesson implementation was approximately one week-long. After the implementation, teachers were interviewed.

### *Context: Teacher Professional Development*

The summer prior to implementation of the curriculum in their classrooms, teachers participated in a three-day professional development (PD) and were introduced to different CT competencies. The PD provided teachers an opportunity to engage with the curriculum and receive training on the curriculum units specific to their grade level. The nature of the curriculum allowed teachers to see how science, engineering, mathematics, computational thinking, and literacy could be taught together through integrated STEM+C+literacy lessons and it also emphasized the interdisciplinary nature of computational thinking. The curricula for each grade level began with an engineering design challenge, where paired literacy and mathematics/science lessons also brough in science, engineering, and computational thinking. For example, in the kindergarten unit, a literacy lesson emphasized pattern recognition through the reading of a book that also emphasized patterns, and in the science lesson children tested the material properties of different types of paper that were used to create patterns

They also watched videos of teachers who had implemented the curriculum in a previous year, interacted with CT toys, and discussed how they could use these activities in their classrooms. The teachers stated that they did not have any exposure to CT competencies prior to the PD. These competencies included, *Abstraction, Algorithm and Procedures, Automation. Data Collection, Data Representation, Debugging, Problem Decomposition, Pattern Recognition and Simulation.* All the CT competencies were discussed through hands-on examples.

### *Data Sources*

The data sources for this study consisted of teachers' semi-structured interviews, observation notes and video recordings of the teachers' and children's interactions including conversations [42]. Following the curriculum implementation, teachers were interviewed by multiple members of the research team. Each member was assigned to a different teacher based on teacher and researcher availability. In the interviews, we asked teachers *what* and *how questions* [43-44] regarding their experiences pertaining to CT. The questions captured how participants implemented CT, and their prior experiences with CT activities. While the interview transcripts were the primary data source we used in this analysis, we also used video recordings of the classroom during the implementation of the curriculum to capture any possible conversation that highlighted individuals' perceptions towards CT.

### *Data Analysis*

A thematic analysis was conducted on the participants interviews as it is a suggested method of analysis for descriptive qualitative studies [45] and is useful for examining the perspectives of participants [45-47]. We followed Braun and Clarke (2006)'s six-phase method for thematic analysis, which encompassed, *familiarizing yourself with data, generating initial codes*, *searching for themes, reviewing, defining, and naming the themes, and creating the report.* While the method is presented as being linear, we took an iterative and reflective process that involved a constant moving back and forth between phases. Finally, video recordings and observation notes that captured all the moments of target participants' conversations and interactions that could hold meaning of CT were reviewed. Those transcriptions of these moments underwent a similar process of thematic analysis by both the first and second author and were shared with the third author.

This study was strengthened by following the trustworthiness criteria suggested by Guba and Lincoln, 1989 [47]. We established credibility through data and researcher triangulation. Triangulation included data and researchers. Data in this case comprised of transcription of multiple teachers' interviews along with video recordings of the classroom. Although our teacher participants were not diverse in terms of gender and ethnicity, they were diverse in terms of teaching experiences, and varied from first year teachers to veteran teachers. These differences provided us with a broader perspective of CT. Triangulation in terms of researchers included multiple researchers coding data individually, then recording as a group to develop themes. Agreements and disagreements were discussed through deep conversation among multiple researchers at different stages [49].

## Findings

Teachers' perceptions of CT derived from their personal experiences, including STEM+C+literacy curriculum implementation in their classrooms. Our findings suggest that teachers perceived CT as: (1) plugged or unplugged programming activities/practices, (2) an interdisciplinary subject domain, and (3) a process for thinking.

### *Perception 1: CT includes and/or is equivalent to Plugged or Unplugged Coding Activities/Practices*

Many of the teachers considered CT as programming/coding activities that required technology or programming (plugged), as well as activities that did not require any electronic technology (unplugged). They described CT based on their experience with coding toys from and beyond the curriculum, website-based CS activities, and plugged activities embedded in the curriculum (See Figure 1), which was evident in how they taught these concepts in their classroom during curriculum implementation. The "robot mouse" was a common teacher response that referenced a specific activity that involved CT or exposed children to CT.  The Code and Go™ Robot Mouse Activity Set is a coding robot created and sold by Learning Resources for children ages 5-7.

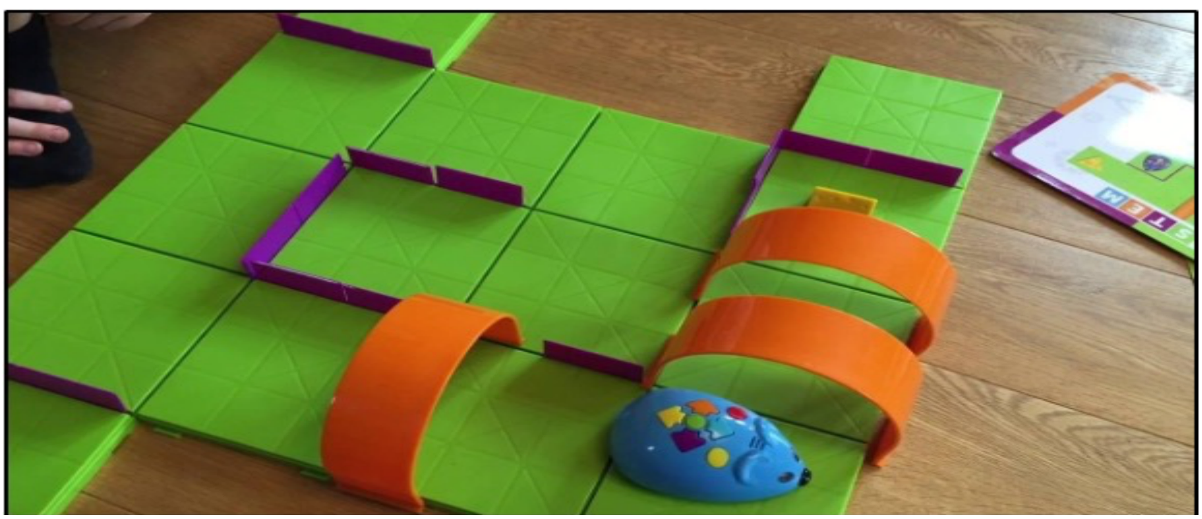

***Figure 1:*** Robot mouse coding game (Previously published in Ehsan et al. 2021).

In addition, other CT applications such as the Osmo "Coding Awbie" game were mentioned and described as CT activities. For example, one second-grade teacher described her CT experiences as, “I have a mouse robot game for this curriculum, and Osmo. On Osmo they [students] do coding and even mouse was coding” (Jessica). Similarly, another teacher suggested that her students are also exposed to CT through Osmo (Osmo, created by Tangible Play Inc., combines iPads and manipulatives). The specific game used by this class was “Coding Awbie”, which includes coding components to promote problem solving, logical thinking, and sense making.), “We have Osmo in our school and in the library, the coding one… an app” (Katie). Another teacher linked CT with the robot mouse and web-based CT activities: “we spent an hour coding [Hour of Code]. They did robot mouse that is more concrete coding, but also did 1-hour coding on screen” (Laura).

In contrast, some teachers also talked about CT by sharing about their engagement in unplugged activities. One teacher specifically pointed out that sequencing in a literacy lesson was comparable to CT, “[it was] like sequencing with Henry's map, having them sequence from left to right and right to left” (Jessica). Another teacher describes her use of CT in the classrooms as, “I feel like it’s the process we can use to our benefit… well we do patterns we do, but I think they learned the patterns and it was successful and they did it well” (Kelly). This was also evident in her instruction when introducing a weaving activity that was part of the curriculum. The teacher stated, “[we will] investigate weaving patterns” (Kelly). The teacher used two different colors of construction paper on the projector as examples so that her students could distinguish different patterns easily. “One way we are gonna [sic] make our pattern, is to make AB patterns with their weaving... I am going on over, then I am going under, then over this one...over-under, over-under OK” (Kelly). Likewise, Julie, discussed using tangrams to create algorithms and to understand patterns, “I think of Algorithms, but tangrams helped them learn patterns” (Julie). The video data for this activity revealed that the teacher introduced Algorithms as “a set of steps to follow to complete a task” (Julie). She emphasized to her students that they were “going to make and follow algorithms to make shapes with tangrams” (Julie). The teacher passed out the mats and tangrams and told the students that they were going to make shapes (Figure 2).

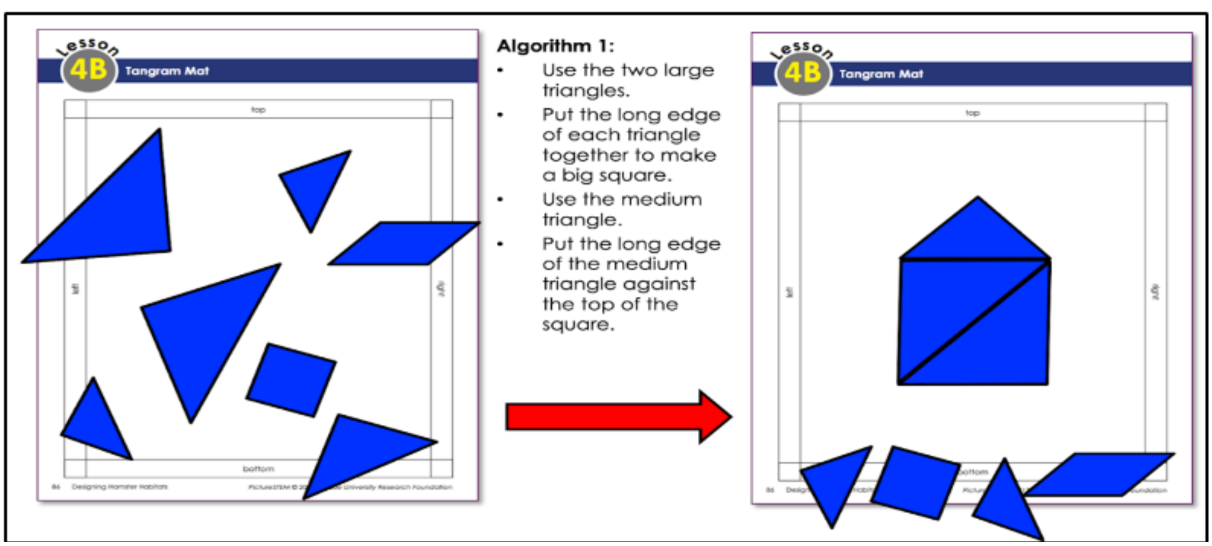


***Figure 2**:* Tangram activity from the curriculum (previously published in Ehsan et al. 2021)

**Perceptions 2: CT is an Interdisciplinary Subject**

Teachers perceived CT as an interdisciplinary subject that can be integrated into different subjects. Many teachers connected CT competencies with various subjects, such as science, math, and literacy due to their teaching of the integrated STEM+C+literacy curriculum. In one instance, a teacher discussed sequencing in literacy (See Figure 3) and connected it to CT. The teacher stated, “we do sequence in books, same thing [CT] sequencing in the story activity” (Samantha). The implementation of the lesson displayed that when the teacher (Samantha) taught the lesson, she discussed the ordering and or sequencing of the events that occurred in the story and had children place them in the correct order on the story flowchart, which was an activity in the curriculum (e.g., Jet found his ball and ran up the hill, then down the hill, then through the trees, etc.).

Another teacher connected CT to math and science: “integrating it, like we do science and math. I know there are a lot of computational phases [competencies] in there” (Jessica). Another teacher linked CT with the words such as, “flowchart”, “sequencing” & ``Algorithm which were part of the curriculum, “[CT] like doing the flowchart...we really never done like that [sic]. I feel like… one of the examples is my girl is doing a lot of LEGOs…. I kept going back to LEGOs. how she puts them together. Natural way [of] sequencing...” (Julie). This is also illustrated in her instruction, she states, “Okay we are going to learn about using flowcharts to keep track of what happens in the story. Flowcharts are like organizers that simply tell us the steps of how we are going to do something” (Julie). The teacher passed out the Joe and Jet flowchart worksheet and explained that in each box they will place the picture of the event that occurred in the story in the appropriate order. In addition, the next lesson when she was introducing Algorithms, she asked, “when you first get a box of LEGOs, what does it come with that helps you put things [LEGO Bricks] together? …Yes, instructions. So here customers should know exactly how to put together the exercise trail. We should give them the exact set of directions or Algorithms to be able to make the exercise trail” (Julie).

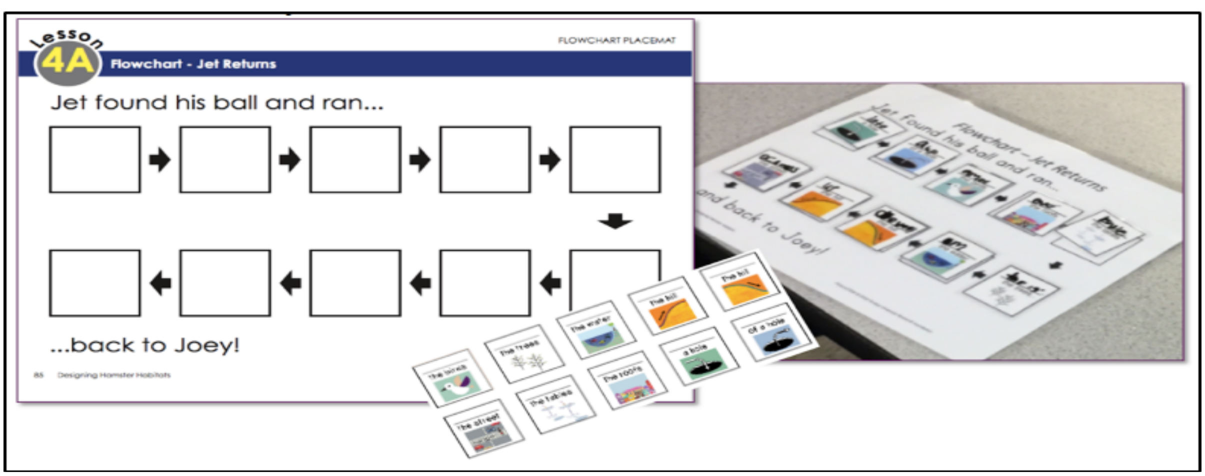


***Figure 3***: Flowchart activity from the curriculum. (Previously published in Ehsan et al. 2021)

**Perception 3: CT is a Process of Thinking or Problem Solving**

Teachers posit CT as a process of thinking to solve problems. In the words of one teacher, "The robot mouse game is super engaging, mapping and following your ideas and your thoughts that can go in multiple directions. This gave them the chance to think differently" (Jessica). In addition, several teachers included multiple ways of thinking like algorithmic thinking or problem-solving in their definitions of CT. The same teacher (Jessica) further discussed the process of thinking via problem solving, "it is different ways of solving problems. When they [students] were successful in solving the problem, they [students] wanted to improve their solution. This shows computational thinking" (Jessica). Another teacher (Samantha) suggested that CT is a process of solving problems by stating that "[through] computational thinking they [students] learned that there is more than one way to solve a problem. Even with the robot mouse thing they could solve things different than me. Even when they design things, they could solve it differently." Other teachers described CT as a means of algorithmic thinking. For example, one teacher said, "CT is a series of commands or steps to do something… like algorithmic thinking" (Laura). This teacher also presented CT as a process of following an algorithm while directing the class: "Boys and girls, remember that flowchart helps us to go through directions and helps us to be able to draw a clear picture of someone looking at [sic]" (Laura).

**Discussion**

Teachers play multiple roles in students' learning, development, and attitude. Since teacher beliefs and perceptions have the potential to impact teacher pedagogy and student learning [30, 34-36]; it is imperative to explore different perceptions held by teachers about CT. The results of this study contribute to teachers' CT knowledge base by identifying teachers' perceptions of CT because of their experiences. Several findings are clear.

First, this study illustrated that teachers' perceptions of CT overall aligned the various definitions of CT presented in the literature [9-10, 28] pertaining to CT. Specifically, teachers described CT as programming/coding (plugged) activities. This finding corroborates with Sands et al, (2018), in which 77% of secondary teachers and 85% of primary teachers identified CT as coding or programming. Likewise, Fessakis and Prantsoudi (2019) found that 81 teachers believed that CT lies within the borders of CS and consists of distinct parts, such as programming. Though, this conception may not be completely inaccurate, since one can engage in computational thinking via programing, but programming is not equivalent to CT [21, 50]. Additionally, some teachers also perceived CT as unplugged activities, capturing that CT is more than plugged activities but rather a means to solve problems [9-10].

Second, the findings of this study also highlight that many teachers perceived CT as an interdisciplinary subject domain, which is consistent with other studies (20,51]. For example, CT has been applied to language arts by having students identify patterns for different sentence types and rules for grammar [51]. In science, CT addresses the importance of computational technologies [52]. While in mathematics students' express generalizations (as algebraic representations) by identifying patterns [51]. In our finding, this integration of CT was connected to a specific lesson or activity presented in the STEM+C curriculum suggesting that teachers were able to recognize CT competencies and integration discussed in the PD and emphasized in the STEM+C curriculum. Therefore, it is important to prepare teachers in CT & CT integration as their understanding is vital for students' CT learning and engagement. Grover and Pea (2013) suggest that such educational STEM activities that involve CT practices could increase students' interests and engagements in STEM. Consequently, to develop a more competitive 21st century workforce [16] that is technologically literate [16]; it is vital to develop teachers' understanding of computational thinking across disciplines [20] as well as prepare them to integrate CT with other subject areas (e.g., math, science, literacy).

Third, teachers described CT as a problem-solving process that requires thinking, which also complements how CT has been conceptualized in the literature [16, 28, 54] as well how it was presented in the professional development and the STEM+C curriculum. Teachers also pointed out that CT is like other subjects, like science and math, comparing it to algorithmic thinking. Particularly, they were able to describe CT in terms of pattern recognition, sequence, and algorithm during the interviews demonstrating their understanding of specific CT competencies [39]. As Yadav et al., (2014) indicates using CT vocabulary across curriculum can reinforce students' understanding of the terms and help students see their applicability across the curriculum and in daily life. Hence, it is important to develop teachers' understanding of CT and its core components if it is to infuse within K-12 [28].

## Limitation

Limitations are a part of all studies. The findings of these studies are based on teachers' experiences pertaining to CT, implementation of the STEM+C literacy curriculum, and our observations of their implementation of the STEM+C curriculum in their classrooms. The first limitation is the representativeness of participants. All the participants were female and White. Future studies should attempt to include more diverse teacher populations to capture a broader set of perspectives. Additionally, the data in this paper were based on teacher experiences that may have developed due to the PD and curriculum implementation. Future studies that capture teachers' perspectives of CT prior to any engagement in CT PD or any CT-focused activities would allow us to develop a better sense of teachers' initial perceptions of CT.

## Conclusion and Implication

In conclusion, the findings demonstrate that teachers expressed highly sophisticated views of CT, one that aligns with and are discussed in the literature [9-10]. Teachers perceived CT, as coding, a set of skills that are cross-disciplinary, and a way of thinking. These perceptions were grounded in specific activities the teachers engaged in, and the experiences they had in relation to the PD, since teachers had the opportunity to experience CT in a variety of ways, and integrated in multiple disciplines (e.g., math, science, literacy, etc.). In essence, developing their understanding and awareness of CT (experience → awareness).

The findings of this study have important implications for future CT professional development to ensure that teachers, both in-service and preservice, can effectively integrate CT and CT competencies in their classrooms. To support teacher CT development, teacher education courses, in addition to CT curriculum, need to provide concrete experiences and examples to support CT integration and development that can help to develop and/or alter pre-service and in-service teachers' conceptions. The experiences teachers gained through the PD, followed by curriculum implementation which included, CT integration, plugged and unplugged activities, they were able to CT is related to programming -- but also can be a way of thinking or engaging in problem solving, and a set of skills that are fundamental and cut across math, science and literacy. Moreover, if teachers do not feel efficacious in teaching CT, this also can impact students' experiences. Therefore, programs and resources that explicitly guide and/or engage teachers in CT learning are necessary. Further research should more closely look at the impact of the PD on teachers' perceptions of CT.

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