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K-2 Students' Computational Thinking Engagement in Formal and Informal Learning Settings: A Case Study (Fundamental)

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Abstract

Given the growth of technology in the 21st century and the growing demands for computer science skills, computational thinking has been increasingly included in K-12 STEM (Science, Technology, Engineering and Mathematics) education. Computational thinking (CT) is relevant to integrated STEM and has many common practices with other STEM disciplines. Previous studies have shown synergies between CT and engineering learning. In addition, many researchers believe that the more children are exposed to CT learning experiences, the stronger their programming abilities will be. As programming is a common aspect of undergraduate engineering coursework, preparing children for programming learning should be considered in pre-college engineering education. However, in order to incorporate CT in pre-college education, it is important to know what CT learning looks like for children in different formal and informal settings and the ways children can make connections across these settings.

Previous studies have demonstrated that children as young as kindergarten are able to engage in computational thinking competencies. Building on this previous research, in this study, we look for the ways K-2 children engage in CT in school and out-of-school settings. Conducting case study research, we followed two first grade children across two learning settings and studied their enactments of CT. We first examined evidence of CT engagement of these children in a school setting where they engaged in a STEM+C curriculum and then captured their CT engagement during an engineering design task in a science center. The findings suggest that children are able to engage in several CT competencies and different levels of them. We have seen similarities in CT engagement in both settings. The competencies that we observed happening in both settings included Abstraction, Algorithm and Procedure, Debugging/Troubleshooting, Pattern Recognition, and Simulation. We also noticed that given the tasks that children were given, the level of CT competencies they engaged in was different.

Background

STEM Integration

Over the past fifteen years, engineering knowledge, practices and habits of mind have also begun receiving greater attention at the elementary school level, as these engineering practices facilitate students' skills in solving complex and real-world problems [1]–[3]. Recent studies suggest that integrating STEM provides more meaningful environments for students to foster their interest and connections to the real-world [4], [5]. In addition, engineering learning experiences enhance students' abilities to make links in science and mathematics that improve their achievement, motivation and problem-solving skills [6]. Consequently, those outcomes might facilitate preparation of highly qualified workers to fulfill the needs of the STEM workforce environment [5].

Computational Thinking

Given the growth of technology and the demands for employees with programming skills, computational thinking (CT) has gained increasing attention in pre-college education [7].

Cunningham, in an NRC report on computational thinking, states that engineering is a focus of computational thinking for elementary education [8]. Students can engage in computational thinking in the context of engineering education due to the overlap of engineering and computational thinking. Some argue that computational thinking (CT) and engineering are connected and empower each other [8]–[10]. Shute, Sun and Asbell-Clarke [9] describe CT as the umbrella term that includes engineering and design thinking. Wing [11] connects computational thinking to engineering thinking by arguing that computational thinking is the overlap between engineering thinking and mathematical thinking.

Engineering and computational thinking have both been defined as a problem-solving process [7], [9]. According to Wing [11], computational thinking draws on engineering thinking to solve problems and design systems that interact with humans and the world Shute and her colleagues refer to CT as the conceptual foundation for solving problems efficiently and effectively. When solving complex problems, CT helps with understanding complex phenomenon through combining the critical thinking skills and the fundamental concepts of computer science like abstraction, decomposition and algorithm [7], [9], [11]. Therefore, engaging students in CT through the context of engineering education can promote problem-solving skills, and may help students find innovative solutions and make good decisions [7].

Wing [11] argues that CT is a core ability for reading, writing and math and should be added to analytical ability of children. Some have studied computational thinking in elementary grades and argue that children as young as elementary grades can engage in some computational thinking competencies [12], [13]. In addition, a limited number of studies have investigated children' computational thinking in an engineering context. For example, one study explored children's CT abilities during the implementation of an integrated STEM curriculum [14]. These authors suggested that elementary students as young as kindergarten-aged can abstract patterns and use algorithms. In our previous research, we investigated kindergarten students' ability to engage in pattern recognition in a STEM+C curriculum [15]. We observed examples of pattern recognition in the artifact that students have created during their experience with the curriculum. Finally, we have also explored computational thinking in families of K-2 students when they engaged in an engineering design task in an out-of-school setting [16]. In this previous paper, we presented examples of multiple CT competencies exhibited by families, and our findings suggest that children are capable of enacting computational thinking. However, we believe that more studies are needed to further investigate what computational thinking competencies look like, as exhibited by children.

Research Purpose

The purpose of this study is to characterize the computational thinking of first grade children, We aim to uncover the computational thinking practices that first grade children can engage in during integrated engineering activities in two different learning environments. The research questions that we explore in this study are:

> What evidence of computational thinking is observed when first-grade children are engaged in an integrated literacy, STEM, and CT curriculum?

What evidence of computational thinking is observed when first-grade children are engaged in an engineering design task in a science center?

Do children make any connections across those learning environments?

Theoretical Framework: Computational Thinking Competencies

Computational thinking (CT) is a multifaceted construct that includes several cognitive processes. These processes have been defined and described by a variety of frameworks and models. These frameworks have some differences and similarities in the ways CT cognitive processes are called, categorized and defined. For example, Google education introduced CT by defining 11 mental processes including Abstraction, Algorithm Design, Automation, Data Analysis, Data Collection, Data Representation, Decomposition, Parallelization, Pattern Generalization, Pattern Recognition and Simulation. Whereas, BBC education discussed four key techniques for computational thinking which are Abstraction, Algorithm, Decomposition and Pattern Recognition [17]. The Australian Curriculum, Assessment and Reporting Authority [18] identified five competencies for CT comprising of Abstraction, Algorithm, Data Analysis, Decomposition and Simulation.

In this study, however, we use the framework developed by our research team. To develop the framework, we have compiled several models, summarized and synthesized them. We then modified the framework after conducting research in school and out of school setting with K-2 children [15], [16]. This framework includes 11 competencies which each has different progression levels (see Table 1). The progression levels can be used both in in-school curriculum and out-of-school activities. The nature of activities children will be doing in this study may provide them opportunities to engage in Abstraction, Algorithm and Procedures, Data analysis, Data Collection, Data Representation, Debugging, Parallelization, Pattern Recognition, Problem Decomposition and Simulation. However, Automation would not be observed in this study.

Table 1. Computational thinking competencies, definitions, and Progression Levels (originally published in [15])

CT Competencies	CT Connections to NGSS	Our Definitions	Progression Levels
Abstraction	*Cross-Cutting Concept:* Structure and function.	Identifying and utilizing the structure of concepts/main ideas	Identify the general make-up or underlying themes of a structure or process.
			Utilize an abstraction (the general make-up or underlying themes of a structure or process) to do a task.
Algorithms and Procedures		Following, identifying, using, and creating sequenced set of instructions (i.e., through selection, iteration and recursion)	Follow a series of ordered steps to solve a problem or achieve some end.
			Identify the sequence of steps to be taken in a specific order to solve a problem.
			Apply an ordered series of instructions to solve a similar problem the algorithm was designed for.
			Create an ordered series of instructions for solving a problem.
Automation		Assigning appropriate set of tasks to be done repetitively by computers	Assign appropriate set of tasks to be done repetitively by computers.
			Recognize different forms of automation.
Data Analysis	*Cross-Cutting Concept:* Patterns. Cause and effect.	Making sense of data by identifying trends	Describe patterns in data to come up with a solution to the problem.
Data Collection		Gathering information pertinent to solve a problem	Identify relevant variables corresponding to a given problem
			Gather data to analyze relevant variables to answer a question.
Data Representation		Organizing and depicting data in appropriate ways to demonstrate relationships among data points via	Organize data in appropriate ways to demonstrate relationships among data points.

CT Competencies	CT Connections to NGSS	Our Definitions	Progression Levels
		representations such as graphs, charts, words or images	Present data using suitable representations such as graphs, charts, words or images.
Debugging/ Troubleshooting		Identifying and addressing problems that inhibit progress toward task completion	Identify problems that inhibit progress toward task completion.
			Address problems using skills such as testing, comparison, tracing, and logical thinking.
Parallelization		Simultaneously processing smaller tasks to more efficiently reach a goal	Develop processes that can simultaneously accomplish small, repetitive tasks efficiently reach a goal.
Pattern Recognition	*Cross-Cutting Concept:* Patterns	Observing patterns, trends and regularities in data (Google)	Identify a given pattern.
			Complete a missing pattern (pattern completion).
			Show abstraction by identifying a type of pattern, but representing the pattern in a different way (e.g. identifying a set of drawn patterns, but creating the pattern using tangrams) (pattern abstraction).
			Create an original pattern.
Problem Decomposition	*Cross-Cutting Concept:* Structure and function	Breaking down data, processes or problems into smaller and more manageable components to solve a problem	Break down processes or problems into smaller and more manageable components to understand the components or issues relevant to solve a problem.
Simulation	*Cross-Cutting Concept:* Systems and system models	Developing a model or a representation to imitate natural and artificial processes	Generate a model or representation to imitate a process.

Methodology

Case Study

We utilized qualitative case study as a methodology to investigate what computational thinking might look like in two different settings, and how children might (potentially) make connections across the settings. Case study is an empirical inquiry which provides an in-depth description and analysis of a 'bounded system' called a case [19] within a specific boundary [20]. Case study helps in understanding the complexities of a case or a system [21] and can provide a holistic view of a real-life situation [20]. Case study as a methodology can be appropriate for research in engineering education [22], particularly in pre-college research, where it has been used to explore how engineering is taught in K-12 classrooms [23, 24], how students learn to engage in evidence-based reasoning [30], and the engineering learning experiences of students with learning disabilities [25].

Case study research can be conducted using one or very few cases depending on the research purposes [26]. Carefully and strategically selecting the cases plays an important role in having a generalizable case study and building a theory [27]. In addition, using several sources of data provides an in-depth and strong analysis that can contribute to scientific knowledge [26, 27]. In this study, the cases are two first grade children who both tried out an integrated STEM+C curriculum in their schools and then visited the science center with other family members and engaged in the engineering design task at the science center. In addition, to reassure a stronger analysis multiple sources of data were used such as video data of both classroom and the science center, and curriculum worksheets. Later, we discuss the data sources and data analysis in more detail.

Participants

For this paper, we focus on two boys from one first grade classroom taught by a female teacher in the Midwestern United States. The curriculum was implemented in the Fall of the school year approximately one month after experiencing the curriculum, each of the two boys along with their families visited the science center and participated in the engineering design activity. These two children were selected for inclusion in this analysis because they participated in both the school-based and the science-center activities. Background information about them is presented below.

Case #1: Sam

Sam is a child who experienced the STEM+C curriculum in his first-grade classroom. Four weeks after the curriculum was implemented, he visited the local science center with his mother and a two-year old sister. On a survey completed as part of the study, Sam's mother indicated very positive perceptions about engineering. She stated that she has enough understanding of engineering to explain it to her child, but not enough to teach it to him. She reported engaging in many engineering activities with Sam on a weekly basis. These activities included watching engineering TV shows, reading books about designing, creating and building, playing with Legos and providing problem-solving projects while cooking.

Case #2: Dan

Dan also experienced the STEM+C curriculum in his first-grade classroom. Six weeks later, he came to the local science center along with his family. His family included his parents and a second-grade sister and a five-year old brother. In the survey, Dan's parents demonstrated very positive perceptions about engineering. They believed engineering improves society and learning and understanding engineering is necessary for their children. They also indicated having some understanding of engineering, what engineers do and how it differs with science. They reported engaging in engineering activities on a weekly basis at home with their children. These engineering activities included reading about designing, creating and building and providing opportunities to play with toys and working on projects that require designing, creating and building skills. Specifically, the dad stated that his son creates patterns with movie cases, uses his imagination with toys and creates new games with his siblings.

In School Context

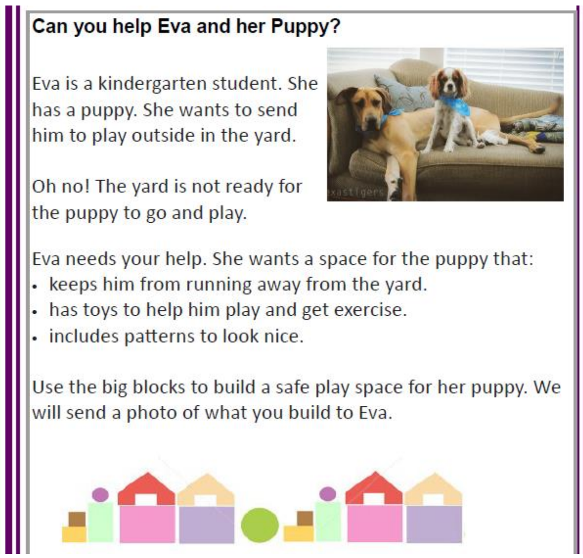
The Picture*STEM Curriculum* integrates science, technology, engineering, mathematics (STEM) as well as literacy and computational thinking components in three different units targeted at kindergarten, first, and second grade. Each unit is centered around an engineering problem where children are introduced to the problem through email interactions with their client, who needs help from the children in developing ideas. The first-grade unit centers around a pet store owner who is interested in developing exercise trails to expand a hamster habitat. Throughout the six-day engineering design activity, children have the opportunity to explore the engineering design process, ask questions of their client, help their client define the problem to be solved and identify the criteria of the problem to be solved.

The unit was developed purposefully to facilitate computational thinking, science, engineering, literacy, and mathematics connections. The children attend to an engineering design task, read several books and practice retelling the story through sequencing and identifying appropriate prepositions, classify three-dimensional shapes, learn about the needs of animals and follow and develop algorithms and procedures.

Three activities within the unit were designed explicitly to promote computational thinking: a activity where children sequence the events of the story using a flowchart; and activities where children follow and create algorithms.

Out of School Context

The second part of the study was conducted at a local science center. We contacted the families of the first-grade children who experienced the curriculum and invited them to participate in the second phase of the study at the science center. The families were given 30 minutes to read and discuss an engineering design task and build the solution using big foam blocks. Figure 1 illustrates the task.


Can you help Eva and her Puppy?

Eva is a kindergarten student. She has a puppy. She wants to send him to play outside in the yard.

Oh no! The yard is not ready for the puppy to go and play.

Eva needs your help. She wants a space for the puppy that:
- keeps him from running away from the yard.
- has toys to help him play and get exercise.
- includes patterns to look nice.

Use the big blocks to build a safe play space for her puppy. We will send a photo of what you build to Eva.

Figure 1. Engineering Design Task at the Science Center

Data Sources

Two sets of data were used in this study. The first set was the data collected in the classroom including the curriculum documents, observation of children, children's worksheets, and photographs of children's prototypes. The curriculum documents are those published and used by the teachers to implement the curriculum. The children were video-recorded during the implementation of the curriculum. In addition, children completed worksheets during each lesson and created a prototype of hamster habitat at the end of the curriculum.

The second set of data included video recordings of families at the science center, parent and child interviews, and surveys completed by the parents. The families were video recorded during the activity in the science center, and the end of the activity they were interviewed about what they did during the activity and similar tasks they have done at home, school and anywhere else out of the school. The parents were also asked to fill out a survey about their engineering background knowledge and impressions of engineering, their engineering related experiences with their children. The information provided in the survey and answers to some interview questions were used as the background information about the participants.

Data Analysis

In this study, we initially analyzed the data from in-school curriculum independently from the out-of-school activity, and at the end we compared the evidence observed in each set to make meaning of the findings. First, the curriculum was carefully examined using content analysis to identify prompts and opportunities that children may demonstrate computational thinking. Although the curriculum is designed to teach Algorithm and Procedures in certain lessons, the content analysis was done for all the lessons. To do this, we first familiarized ourselves with the content of the curriculum by reading the instruction, learning objectives and activities of each lesson, and watched some segments of videos of the curriculum being implemented. Next, we identified the activities that had the potential to support computational thinking in children. We carefully watched the videos of those activities using a video analysis process suggested by Powell, Francisco, and Maher [28].

After we captured evidences of children engaging in computational thinking competencies throughout the curriculum, we used artifact analysis [29] to analyze children's artifacts. Children's artifacts included the worksheets of the lessons which had the potential to engage children in CT and pictures of the prototypes of hamster habitats built by the children. The evidence within each form of data was compared with evidence across other forms of data to explore child learning throughout the curriculum.

Second, we analyzed the video recordings of families engaging in the engineering design activity at the science center following the process suggested by Powell, Francisco, and Maher [28]. The child and parents' interviews were also listened to and carefully interpreted for three reasons: (1) to resolve any confusions about what they have done during the activity, (2) to provide background information about the family's engineering experiences, and (3) to see any connections that children make between the curriculum in the school and the activity in the science center.

Inter-Rater Agreement

Inter-Rater agreement was reached before the videos were analyzed. First, one author discussed the codes (i.e., CT competencies and the levels) with two of the authors, and where necessary, instances from one video was shown. After this initial calibration process, four video clips were randomly chosen, and the coding team coded the videos. Then, the codes were compared, and any differences were discussed. After agreement was reached, the rest of the videos were divided amongst the coders and were coded and analyzed for the study.

Findings

After analyzing the different sources of data that we had, we observed several examples of children enacting computational thinking when they engaged in the curriculum at school and during the engineering design activity at the science center. Below we briefly report the evidence of computational thinking exhibited by the two children in both settings. Our findings are also illustrated in more details in Tables included in Appendix 2 and 3.

CT Evidence in Formal and Informal Environments

In-School

Case #1: Sam

During one of the first lessons, while working with a peer, Sam engaged in an activity that involved sorting animal characteristics and needs. Sam engaged in Pattern Recognition as he sorted animal cards and placed them into the box that indicated the right habitat for the chosen animal. On the second day, while working with a peer, Sam engaged in Pattern Recognition by identifying the relationships between animals and their habitats. Sam also engaged in the Data Representation competency by organizing animals that reside in water and placing them within the ocean habitat.

During the third day, while working independently, Sam used tangram puzzle pieces to create animals. Following the guidance from his teacher, Sam used the pieces to trace animals after identifying which shapes completed the pattern, thus engaging in Pattern Recognition and Abstraction competencies.

For the fourth day, there was no video data available for the first lesson. The worksheet developed for this lesson would suggest that Sam participated in a sequencing activity, where he potentially engaged in the Algorithm and Procedures competency by following a set of instructions. Later in that day, video recording captured Sam engaging in the Algorithm & Procedure competency as he followed a series of ordered steps from his teacher, and created animals using tangrams. After following his teacher's guidance, Sam independently created animals using tangram pieces to create his own patterns following the previous instructions.

During the fifth day, Sam worked with his peers to test methods and collect data to determine which materials would be best for his own habitat design. Sam engaged in Pattern Recognition on several occasions during the testing phase. Pattern Recognition was the most prominent computational behavior during the lesson as we observed four instances. There were two instances of the Algorithm and Procedure competency when Sam stacked blocks to determine which three-dimensional shape was most stable. In the group, Sam was responsible for recording information about how high each shape could stack and the behavior of each shape when it was flicked (i.e., rolling, sliding, falling over, etc.). Finally, there were two instances where Sam engaged in Data Collection as he used information from his group to record findings on the datasheet.

During the final lesson, Sam prototyped a habitat for hamsters. On several occasions Sam participated in the Pattern Recognition competency. Followed by bursts of building, on five occasions Sam used a hamster photograph and engaged in the Simulation competency as he moved the hamster picture through the habitat he created. Sam made four changes to his habitat, exhibiting the Debugging/Troubleshooting competency as he made sure that his design met requirements (e.g. all blocks much be touching).

Case #2: Dan

Like Sam, Dan engaged in Pattern Recognition during one of the first lessons, while working on the activity that involved sorting animal characteristics and needs. Dan also engaged in Data Representation during this activity as he placed the animal cards in the right box that indicated the correct habitat for the chosen animal. Dan used information from the animal card to determine the specific habitat, aligning with the first level of the Data Representation competency.

Dan also engaged in Pattern Recognition by identifying relationships between animals and their habitats during the lesson on the second day. Dan verbally identified the pattern between animals and habitats by verbally stating that an ocean would be a habitat for a lobster. Furthermore, Dan used the information provided to him to engage in the Data Representation competency during the second activity.

As previously noted, there was no video of the first lesson on the fourth day. As we did for Sam, we will assume that Dan also participated in a sequencing activity that would have allowed him to potentially engage in the Algorithm and Procedures competency by following a set of instructions. For the second lesson on the fourth day, the classroom was video-recorded but Dan was present in the available video data. However, given the nature of the task, we believe there is a possibility that Dan may have engaged in the Algorithm and Procedures and the Pattern Recognition competencies.

During the fifth day, Dan worked with peers to collect data about which materials would be suitable for his own habitat design. Dan engaged in Pattern Recognition on five occasions as he collected blocks from the container and organized them into groups for his team. Dan participated in the flick and stack test to collect data about the behavior of each shape. He relays the information about flicking and stacking to his team's recorder, exhibiting the Data Collection competency.

During the final lesson, Dan was not directly, so we have limited information about his CT competency engagement. However, the artifact he created during the activity suggests there is a possibility that Dan engaged in at least the Pattern Recognition competency given that the nature of the task was to create his own prototype.

Comparing Sam and Dan

In general, Sam and Dan's engagement in CT was very similar in the classroom activities, as much of their CT activity was facilitated by the curriculum that they both experienced. Some differences include one of the first lessons when both children engaged in Pattern Recognition but only Dan exhibited that Data Representation competency by illustrating animal and habitat relations. During the fourth day, we only have video evidence of Sam engaging in the Algorithm and Procedure competency by following instructions. During the fifth day, both children engaged in the same amount of the Pattern Recognition competency. Although Sam and Dan were given two different responsibilities, Sam (writer) and Dan (block collector) both carried out Pattern Recognition by identifying and creating their own patterns. Both Sam and Dan also engaged in Data Collection.
Finally, during the last day of the unit, we did not have any video documenting what Dan did during the prototyping and redesigning of hamster habitats. However, based upon the similarities in observable competencies that both Dan and Sam shared in lesson 5B, there is a possibility that Dan may have engaged in the same competencies as Sam.

At the Science Center

We observed several examples of computational thinking competencies exhibited by both children throughout the engineering design activity that they engaged in with their families at the science center. While the type and amount of support parents provided influenced children's engagement in CT, this study focuses on the CT exhibited by the target children. Below we will briefly describe the evidence of CT we observed happening by children. Narratives of what happened and detailed descriptions of CT examples are provided in Appendix A.

Case #1: Sam

During the engineering design task, we observed 12 instances where Sam engaged in a total of 4 computational thinking competencies: Abstraction, Algorithm and Procedures, Pattern Recognition, and Problem Decomposition. Pattern Recognition was the most observed CT competency with 5 instances. Sam engaged in Abstraction on 4 occasions when giving building blocks representations of real world objects (i.e., a stack of rectangular blocks referenced as a wall). The Algorithm and Procedures competency was observed during moments where Sam followed instructions from his mother to participate in building structures. We observed only 1 instance of Problem Decomposition when Sam discussed the plans for building the puppy playground at the beginning of the task.

Case #2: Dan

During the engineering design activity, we observed 9 instances where Dan engaged in a total of 5 computational thinking competencies: Abstraction, Algorithm and Procedures, Pattern Recognition, Simulation, and Troubleshooting/Debugging. Pattern and Recognition is the most common engagement observed with 3 engagements. Dan engaged in Simulation on two instances, acting as a dog during playground build. Dan engaged in Algorithm and Procedures, Abstraction, and Troubleshooting on single occasions.

Comparing Sam and Dan

Between the two children, a total of seven competencies were observed. Although Sam engaged in more instances of Pattern and Recognition than Dan, both children often enacted this CT competency when building structures for the playground. Another similarity the boys shared was the level in which Pattern Recognition occurred through abstraction. For example, both children would refer to their structures not as blocks, but as real-world representations. Another interesting finding was that both Sam and Dan engaged in the Algorithm and Procedures competency only after receiving instructions/suggestions from their parents. Sam engaged in Problem Decomposition during his engineering design task, whereas Dan did not. Dan engaged in the Troubleshooting/Debugging and Simulation competency, whereas Sam did not.

CT connections across environments: Interview Results

The interview data showed that only one child, Dan, articulated a connection between the integrated STEM+C curriculum at school and the engineering design task at the science center. Dan responded that he did "something" about engineering at school. When we asked to describe what he did, he stated that he designed a habitat for a hamster and built the habitat. However, Sam said he never participated in any engineering activity at school.

Comparing In-School to Out-of-School

In our observations of both children, we identified that the CT competencies exhibited by the children in the classroom and science center were similar. In the classroom seven competencies were observed: Abstraction, Algorithm and Procedure, Data Collection, Data Representation, Debugging/Troubleshooting, Pattern Recognition, and Simulation. In the science center we observed the children participating in Abstraction, Algorithm and Procedures, Debugging/Troubleshooting, Pattern Recognition, Problem Decomposition, and Simulation. In the classroom observation, it was observed that the teacher would scaffold and break problems into smaller manageable steps for the children, however in the science center settings parents would involve the children in the Problem Decomposition process. Data Collection and Data Representation also only occurred is the classroom, this could be attributed to the nature of the integrate STEM curriculum, where science and mathematics were explicitly included.

Discussion

In this paper, we aimed to explore the computational thinking competencies that first-grade-aged children might exhibit. Our target cases were two children who engaged in an integrated STEM+C curriculum in school and an engineering design activity at a science center. We analyzed several data sources from both settings and captured instances that these children engaged in different CT competencies. We also explored whether the children could make any connections between the STEM+C curricular activities and the design task. One child made the connection by pointing out to the similarities between the activities. While we have observed him engaging in similar CT competencies across those settings, we cannot conclude that his CT enactments in the science center was a result of his engagement in the class.

Based on our findings, both children engaged in similar CT competencies. We noticed that children's CT engagement in the classroom and science center was also quite similar. In the classroom seven competencies were observed: Abstraction, Algorithm and Procedure, Data Collection, Data Representation, Debugging/Troubleshooting, Pattern Recognition, and Simulation. In the science center we observed the children participating in Abstraction, Algorithm and Procedures, Debugging/Troubleshooting, Pattern Recognition, Problem Decomposition, and Simulation. In addition, they both showed instances of engaging in variety of progression levels of different CT competencies. Depending on the task, they were able to engage in different levels of Algorithm and Procedure, Pattern Recognition, Abstraction and Data Collection. For example, we could see that both were able to identify pattern, abstract patterns and create patterns.

The findings also suggest that depending on the nature of activities, children can engage in different CT competencies. As an example, Data Collection and Data Representation only occurred during class activities. The nature of the curricular activities provided the opportunities for children to collect data and then represent data. However, the activity in the science center did not provide this opportunity to children. In addition, the levels that children engage in CT was different depending on the tasks and the instruction they were given. For example, in most instances that children engaged in Algorithm and Procedure during the engineering design task, they followed a series of steps parents provided. However, while we observed many instances

that children engaged in Algorithm and Procedure by following the series of instruction the teacher provided, in few instances, given the curricular task and the teacher's guidance, children created series of instruction (algorithm) and applied that algorithm. This suggests that children can engage in deeper levels of CT competencies, if the activities are designed in that way.
One other differences between the two settings that we observed was the enactment of Problem Decomposition. Problem Decomposition was not observed happening in the classroom by children. Although the focus of this study was children learning, we noticed that this competency mostly happened by the teacher in the classroom. One possible reason is that the teacher would scaffold and break problems into smaller manageable steps for the children. Whereas in the science center, parents would involve their children in the Problem Decomposition process. This finding suggests further investigation of the adults' involvement and support in children's engagement in CT.

Limitations

As noted in the presentations of the findings, video recordings were missing from one of the lessons in the school environment. Additionally, the video recordings captured the classrooms as a whole, rather than focusing specifically on the two cases, Sam and Dan. In some cases, Dan was not captured in the video-recording of some class activities. Only a small number of children who participated in the classroom activities also participated in the science center activity, limiting the number of complete cases available for analysis.

Conclusion

While this study did not aim to investigate the prevalence of computational thinking amongst a large population, it provides evidence that children have the potential to engage in CT competencies in different problem-solving contexts including STEM, and particularly engineering. However, we cannot claim that all children naturally can engage in high order computational thinking. This study suggests that children can engage in different levels of CT competencies depending on the nature of tasks they are involved in and the scaffolding and supports they get from adults. Teachers, parents and also curriculum developers should consider engaging children in activities that can involve them in different levels of CT competencies. This study suggests that children can engage in several CT competencies and in different levels given appropriate circumstances. However, further studies are needed to better understand which activities and types of support are best suited for helping children develop computational thinking competencies.

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Appendix A: Tables of evidence of CT for each child in the science center setting

Table A.3.1. Sam's Engineering Design Observation in Science Center

Narrative of Child (Sam)	Computational Thinking led by the child	Evidence and Level of Progression
Mother reads the tasks to the child and asks the child: Mother: what should we do? Child: **Build**. Mother: what should we build? Child: **Puppy playground** Mother: How should we build it, then? What should it look like? Child: **to be fun**?	**Problem Decomposition**	The child is involved in breaking down the problem into smaller pieces which includes defining what they have to do (build a puppy playground) and talking about one of the criteria they have to consider (fun).
Mother: And keep the puppy to go away. What should we do first? How this would be safe? It is kind of like Sophia, we gotta keep her safe inside. How big should it be? Child [exploring the blocks]: **like Sophia. It should be medium.** **…** Mother: But how do you want to keep her inside? Child: It's **tall**. Mother: How? Child: **She cannot jump** [pointing to the little sister]. Mother: **She is the dog**? Child: **Yes**.	**Abstraction**	The child imagines that the puppy is the same size as her sister, and utilizes the size of her sister in building things for the puppy playground (**Utilize an abstraction**).

Narrative of Child (Sam)	Computational Thinking led by the child	Evidence and Level of Progression
The child then put two big **rectangular blocks in the side**, and **few curved blocks** in the **middle close to another exhibit** of the science center (ball run). Mother: what are these? Child: **play set**. She could play with slides and throw the ball here [pointing to the ball run exhibit). Mother: but we should build wall to keep her inside. Child: **That's the wall** (pointing to the two rectangular blocks).	**Pattern Recognition & Abstraction** **Pattern Recognition & Abstraction** **Pattern Recognition**	The child recognizes play set and wall as features a playground should include. This recognition might be based on the criteria of task and realizing the common and main components of all playgrounds **(Identify the general make-up of a structure and Pattern Abstraction)** The child focuses on the important details of the components he tends to build based on what he has seen in his real-life experiences. He uses a rectangular block for the wall and the curved block for the slide **(Utilize an abstraction & Pattern Abstraction).** He places the pretend slide in the middle and the pretend wall in the side. This is based on the real-life playgrounds that he has seen before (**Identify a pattern**).
Mother grabs more of the same rectangular blocks and continues building the wall following the pattern the child was making before. She then asks the child to help him in closing the wall. Child grabs blocks with **the same size, but two different shapes**, and builds the walls by putting them in **a specific order** (pattern)	**Pattern Recognition**	The child creates patterns when building the wall. He uses two different shapes of blocks and creates the pattern of AABAAB (**Create Pattern**)

Narrative of Child (Sam)	Computational Thinking led by the child	Evidence and Level of Progression
They cannot find the **same shape and size block** they have been using, so the mom **suggests using two smaller size blocks and putting them on the top of each other**, and the child follows his mom's suggestion.	**Algorithm and Procedures**	The child follows his mother's sets of instruction to build the wall (**Follow a set of instruction**).
The mother asks the child to close the corner of the playground. He **follows the moms direction in grabbing and placing a different set of blocks** that they did not use before in the corner.	**Algorithm and Procedures**	The child follows his mother's sets of instruction to find appropriate blocks and to build the wall and the corner of the playground (**Follow a set of instruction**).
The child put a **cylindrical block** and place it in the hole of one of the blocks, and calls **water fountain** that the dog can drink water from.	**Abstraction and Pattern Recognition**	The child recognizing the similarities between the cylindrical blocks and water fountain by identifying the main details of water fountain that he has observed in the real-life experiences (**Utilize an abstraction and Pattern abstraction**).

Table A.3.2. Dan's Engineering Design Observation in Science Center

Narrative and Evidence (Dan)	Computational Thinking led by the child	Description and Level of Progression
The dad begins by reading the task. Then, he restates the criteria and asks the children about what they should do. At the same time, the mother makes	**Algorithm and Procedure**	The child along with his sibling follow their mom's instruction to build the fence (**Follow a series of instruction).**

Narrative and Evidence (Dan)	**Computational Thinking led by the child**	**Description and Level of Progression**
connection to their house to make the criteria clearer. Mother: To have a safe place, what should we have—like our house? Dan: Fence? The mom begins building the fence by placing two same blocks in order. Children follow the mom and find the same blocks. Dan and Sister help placing the block following the order the mother built the fence.		
Then, the dad teaches Dan how to attach two blocks together using the cylindrical blocks. After a while, Dan finds two similar blocks and take them to the fence that they built and attaches them together.	**Pattern Recognition**	The child recognized that the two blocks were similar to the previous ones (pattern of similarities) and then uses the pattern he learned to attach them together. **(Identify a pattern).**
The dad gets a bigger block than the mom and children are using, and then he notices the size is bigger and suggests Dan find a same block as the previous ones instead. Dan and dad have a conversation on why they should change the big block with the small one, and agree that the puppy	**Troubleshooting/Debugging**	

Narrative and Evidence (Dan)	Computational Thinking led by the child	Description and Level of Progression
is not so big, so smaller blocks would still make the fence safe for the puppy		
The dad then finds a curved block and asks if this is like a slide that the dog can play with, and Dan agrees and describes how the dog can play with this. Dan finds a ball and says the dog can rolls the ball on the slide. Later, Dan and his brother continue building the slides, using the same block that the dad used.	**Abstraction & Pattern Recognition** **Simulation**	The child is able to recognize the general make-up of a slide by seeing the similarities of the block and slide in the real world (**Identify the general make-up of a structure and Pattern Abstraction).** Then, he uses that pretend slide to **simulate** how dog can play with the slides (**Utilize Abstraction & Simulation)**.
Sister finds a small round block and refers to it as a frisbee and Dan agrees. Dan then finds a block and refers to it as a windmill. The dad finds a block suggesting that it can be the mailbox, but the sister says that it can be a doggie bone box!	**Abstraction & Pattern Recognition**	The child realizes the similarities of some real-life objects (frisbee & windmill) and certain blocks **Identify the general make-up of a structure and Pattern Abstraction)**.
Dan suggests that he test the puppy playground out. And he acts like he is the dog and goes under the entrance and plays with the pretend frisbee. Dan remind everyone that the playground	**Simulation**	The child is trying out the playground he believes a dog would.

Narrative and Evidence (Dan)	Computational Thinking led by the child	Description and Level of Progression
should also be fun, and they need toys. Then he says the slide and ball are fun.		