International Journal of Computer Science Education in Schools, May 2024, Vol. 6, No. 3
ISSN 2513-8359

Investigating Sequencing as a Means to Computational Thinking in Young Learners

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DOI: 10.21585/ijcses.v6i3.192

Abstract

Within the field of K-2 computer science (CS) education, unplugged computational thinking (CT) activities have been suggested as beneficial for younger students and shown to impact young students' skills and motivation to learn about CS. This study sought to examine how children demonstrate CT competencies in unplugged sequencing tasks and how children use manipulatives to solve unplugged sequencing tasks. This case study approach examined two unplugged sequencing tasks for six children ranging from ages five to eight (pre-kindergarten to 2nd grade). Children showed evidence of several CT competencies during the sequencing tasks: (1) pattern recognition, (2) algorithms and procedures, (3) problem decomposition, and (4) debugging. The strategies and use of manipulatives to showcase CT competencies seemed to evolve in complexity based on age and developmental levels. Taking into account children's abilities to demonstrate CT competencies, this study suggests that sequencing is a developmentally appropriate entry point for young children to begin engaging in other CT competencies. In addition, these unplugged sequencing tasks can also be easily integrated into other activities commonly experienced in early childhood classrooms.

Keywords:

Computational thinking, early childhood education, unplugged activities

1. Introduction

To empower all citizens to engage with a more digitally-focused society, K-12 students will need to understand and apply basic computer science (CS) ideas and principles (Tissenbaum & Ottenbreit-Leftwich, 2020). With an emphasis on increasing CS in K-12 classrooms, it is important to note that much of the work in computing education has been focused on upper elementary and secondary students (Flannery et al., 2013; Bers & Sullivan, 2019). At the early elementary levels, research has found that early exposure to CS usually focuses on utilizing computational thinking (CT) skills (ie. Bers et al., 2014; Relkin, 2018) and has been suggested as important for a range of reasons: (1) CT itself is a foundational skill as an analytical ability (Wing, 2006), (2) CT empowers creativity by allowing children to design their own project (Resnick, 2007), (3) Learning CS and developing CT is ultimately expected to enable children to engage in this digital era actively (K-12 Computer Science Framework Steering Committee, 2016). However, even though it has been recommended that students are provided opportunities for early exposure to CT, few studies have investigated what K-2 students are capable of with regards to learning CT/CS, and how K-2 students engage with and utilize CT skills in the classroom.

Within the literature on K-2 CT/CS education, unplugged activities have been suggested as beneficial for younger students and shown to impact young students' CT skills and motivation to learn about CS (Chen et al., 2023; del Olmo-Muñoz et al., 2020; Rodriguez et al., 2017). Unplugged methods are based on the proposition of exposing children to CT without the use of computers or digital devices by implementing activities with and without tangible materials such as board games, cards, or physical movements that improve the understanding of CT concepts (Bell et al., 2009; Brackmann et al., 2017; Chevalier et al., 2022) that help to make abstract concepts more concrete (Vahrenhold et al., 2019; del Olmo-Muñoz et al., 2020). However, limited studies have investigated how children approach unplugged activities and there is still a limited understanding of unplugged activities and how those foster CT skills in K-2 CT/CS education (Chen et al., 2023; Kite et al., 2021). In order to add to the literature on unplugged activities and K-2 CT, this study utilized a descriptive case study design (Yin, 2018) to examine the engagement of children in grades K-2 and their use of manipulatives as they worked through two unplugged CT tasks. The following research questions guided this work: (1) How did the children demonstrate CT competencies in unplugged sequencing tasks? (2) How did the children use manipulatives to solve unplugged sequencing tasks?

2. Literature Review

Research on young learners CT abilities and understandings is still emerging. There are good indications from other related fields, such as mathematics and science education, that hands-on, concrete model-based learning is helpful in students understanding the concepts (diSessa, 2004; Lesh & Doerr, 2003). The concrete nature of these models allows students to physically interact with the concepts which is a good first step towards abstraction (diSessa, 2004). The use of unplugged CT activities have been suggested as a good way to introduce CT to young children through the use of concrete models (Chen et al., 2023; Chevalier et al., 2022). Since all coding—both simple and complex—requires the coder to be able to make ordering decisions, sequencing is foundational in CT (Aho, 2012, Gerosa et al., 2021). As such, this research is aimed at considering the foundational knowledge and abilities needed to understand the sequencing aspects of coding through unplugged activities. To frame this, we will explore the literature around CT—particularly in the early grades, sequencing as a foundational concept in CT, and how concrete model-based learning suggests using unplugged representations of CT may help students build understanding of the underlying concepts of CT.

2.1 Computational Thinking & Young Learners

When researching CT with young learners, it is important to note that as a field, there are nuances and struggles with clearly delineating the various CT constructs that cuts across K-12 (Dong et al., 2019). Experts have listed divergent skills encompassing CT and may use the same term or different terms in defining a specified skill/competency. For example, Brennan and Resnick (2012) presented sequences, loops, parallelism, events, conditionals, operators, and data, while Dong et al. (2019) used PRADA, an acronym for Pattern Recognition, Abstraction, Decomposition, and Algorithms, as a practical way of understanding CT skills for non-computing teachers. In fact, Dong et al. (2019) produced a representation showcasing the overlap in CT between different seminal CT publications, showing a wide range of concepts from automation to parallel thinking and conditional logic. The International Society for

Technology in Education (ISTE) and Computer Science Teachers Association (CSTA), collaboratively produced a practical definition of CT for K-12 teachers: "a problem-solving process that includes formulating problems, logically organizing data, representing data through abstraction, automating solutions, reflecting on the efficiencies of possible solutions, and generalizing and transferring this process to a variety of problems" (ISTE & CSTA, 2011, p. 1). In terms of this work, we succinctly view CT as the process of identifying a problem and creating potential solutions so that a computer (whether that be a human or machine) could potentially implement that solution. The above demonstrates the complexity of CT when looking across K-12 which begs the question: what is known specifically about young learners' CT knowledge and abilities?

The research on CT for young learners is in very early stages. Early research on CT with young learners is suggesting that they can learn and demonstrate fundamental CT skills and concepts such as pattern recognition, sorting, sequencing, and algorithm design (e.g., Bers et al., 2014; Saxena et al., 2020). Furthermore, educating young learners about CT allows them to gain knowledge, skills, and attitudes related to CT (Su & Yang, 2023) while also promoting overlapping skills and abilities important not only for cognitive development (Gerosa et al., 2021), but also for the development of disciplinary skills, such as those in mathematics or literacy (e.g., Barr & Stephenson, 2011; Kazakoff et. al., 2013; Relkin et al., 2021; Wing, 2011). While these findings are promising, there is much more we need to understand about how we should engage young learners with CT.

2.2 Sequencing as a Foundational Component of CT

Research has acknowledged that sequencing, the ability to order steps and understand their relationships, is foundational and critical to CT (e.g., Aho, 2012, Gerosa et al., 2021; Kazakoff et. al., 2013; Su & Yang, 2023; Yang et al., 2023). Sequencing within CT is grounded in the principles of logic (Wing, 2011) because logic underlies the ability to determine order to accomplish a goal. Furthermore, sequencing has been identified as a key component of algorithm development (Angeli et al, 2016; Yadav et al., 2016) and algorithm development has been highlighted as a fundamental concept within CT (i.e., Bers et al., 2014; Dong et al., 2019; Saxena et al., 2020). From a developmental perspective, sequencing can be an effective way to formulate young learners' basic CT competencies because it can be meaningfully linked to their everyday lives (Kim, et al., 2024). Furthermore, positive associations have been found between sequencing ability and later CT performance with young children (Gerosa et al., 2021; Yang et al., 2023).

2.3 Unplugged Activities as a Starting Point for CT

As stated previously, work from other areas of STEM education suggest that beginning with concrete models is a good way to help young learners develop understanding of a concept (diSessa, 2004). While various approaches to teaching and integrating CT in curriculum or educational activities have been explored, two main approaches used by educators and researchers to implement CT are plugged and unplugged activities–with plugged activities including the use of a computer or digital device and unplugged tending to use tangible games or materials (Bati, 2022; Chen et al., 2023; Su & Yang, 2023). Unplugged methods are based on the proposition of exposing children to CT without the use of computers by implementing activities such as logic games, cards, or physical movements that improve the understanding of CT concepts (Bell et al., 2009; Brackmann et al., 2017) and help to make abstract concepts more concrete (Vahrenhold et al., 2019; del Olmo-Muñoz et al., 2020). Specifically, it has been suggested that during unplugged activities, tangible materials should be used by children in order to cultivate their CT and problem solving skills (Chevalier et al., 2022). Researchers have examined the effectiveness of unplugged activities in the primary grades and found positive impacts on CT learning both in stand-alone cases as well as when conducted prior to plugged activities (Chen et al., 2023; del Olmo-Muñoz et al., 2020; Saxena et al., 2020). While both plugged and unplugged approaches have shown positive implications for CT ability with young children, unplugged approaches have more often been recommended due to their concrete applications of CT, as well as their low-cost and ease of implementation (Bati, 2022; Chen et al., 2023). In addition, using unplugged activities can also address other barriers commonly associated with learning CS in the early grades such as cost of educational robots or coding software (Sung et al., 2016) and teacher professional development (Rompapas, 2021). Despite the recommendations for using unplugged approaches, few studies have been conducted to understand the benefits of implementing unplugged approaches with children and more are sorely needed (Chen et al., 2023; Kite et al., 2021; Moreno-Leon et al., 2018). Therefore, this work explores young learners' development of CT through unplugged sequencing activities.

3. Research Design and Methodology

To investigate the ways in which children approached unplugged sequencing tasks and how they used manipulatives to solve problems, a descriptive multiple case study design (Yin, 2018) was employed. This type of approach is well-suited when the goal is to describe a phenomena, how children approach unplugged sequencing tasks, and when the real-life context in which the phenomena occurs is relevant and important to the larger understanding of the phenomena. This descriptive multiple case study included six embedded units within the larger case to allow for exploration of individual factors and characteristics that were situated within the larger phenomena and bounded by the same time and activities (Yin, 2018). The multiple case study was ideal particularly in this research as researchers aimed to gain an in-depth understanding of the complexities involved in unplugged approaches to computational thinking in early years. A detailed examination of multiple cases, allows researchers to explore and consider various factors influencing outcomes.

In order to identify students' CT competencies in unplugged sequencing tasks, we used a task-based interview to elicit childrens' knowledge and representation of their ideas, structure, and ways of reasoning (Goldin, 2000; Maher & Sigley, 2020). During task-based interviews, individuals or small groups talk aloud while they work on carefully constructed, conceptually-rich tasks while a researcher prompts learners to get at specific issues of why learners are doing what they are doing or what they are thinking about at a given moment.

3.1 Participants

Due to unforeseen limitations caused by the COVID-19 pandemic, the researchers were unable to conduct the initial round of research in elementary schools. Therefore, in order to continue with initial work with the target audience, early elementary learners in K-2, four girls and two boys (see Table 1), were recruited based on established personal relationships with the researchers. Six participants, while limiting generalizability, allows for a detailed investigation of the cognitive processes related to computational thinking in young children. With a descriptive multiple case study design, researchers can closely examine individual responses and gain a deep understanding of the specific dynamics within the context of the study. The purpose of this initial examination was to serve as a foundation for future research, guiding the formulation of hypotheses and research questions for future, larger-scale studies. Additionally, it is important to note that while the pre-existing personal relationships between the children and the researchers provided a level of comfort and rapport during the study, it also introduced a potential source of bias. The familiarity may influence the children's engagement with the tasks, possibly leading to responses that align with perceived expectations. Within the current limitations and to mitigate potential bias, researchers employed rigorous data analysis and interpretation, including independent coding of the data by researchers with no relationship to the

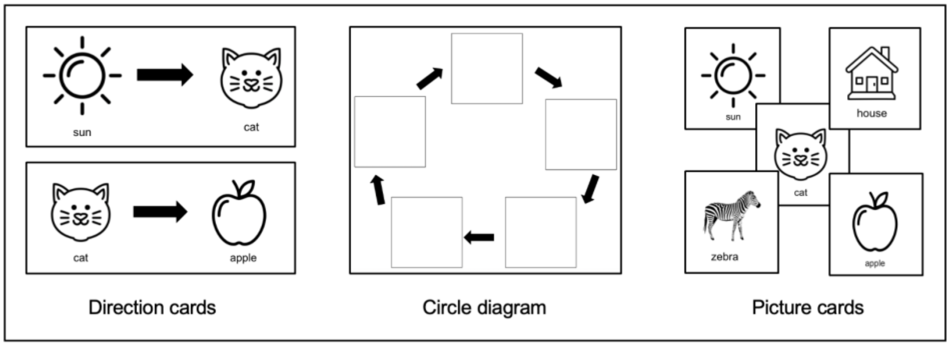
3.2 Unplugged sequencing tasks

Participants engaged in a series of unplugged sequencing tasks to investigate how they approached unplugged activities, used manipulatives, and the extent to which these unplugged activities foster CT skills. These unplugged sequencing tasks are a series of activities without the use of computers or digital devices that use manipulatives to understand the students' reasoning regarding CT. There are multiple versions of each of the two tasks with differing levels of complexity that allow for in-depth investigation of the ways in which K-2 students engaged in these two unplugged sequencing tasks. For this particular study, two unplugged sequencing tasks were developed and students engaged with two tasks that utilized the concept that simple conditional logic is required to construct sequences and to understand how programs store and manipulate data by going from the beginning to the end in an A → B, B → C order. Participation in these two unplugged sequencing tasks will provide insight into what children know, how they approached the tasks, and how they used manipulatives to solve these tasks. Note the images in these tasks have attributions in the Acknowledgements section of this paper.

3.2.1 Task 1 - Sequencing Using Simple Conditional Logic

In Task 1, learners are presented with direction cards that display two images linked by a directional arrow, a circular graphic organizer with directional arrows connecting empty boxes, and a set of picture cards that match the images on the direction cards (Figure 1). Learners are asked to use the direction cards to help determine where to place the picture cards onto the circular graphic organizer. The matching images on the direction cards and picture cards are common, but not related objects, and the circle diagram serves as a graphic organizer for arranging the picture cards into a sequential order. There are three different levels of this task that increase in the number of cards and complexity starting with 5 cards in the first level and then 10 and 15 cards in level two and three. Additionally, for this task, the beginning and endpoints do not matter as these logical ideas include recursion and so participants were intentionally not told which card to start with or where to start on the organizer.

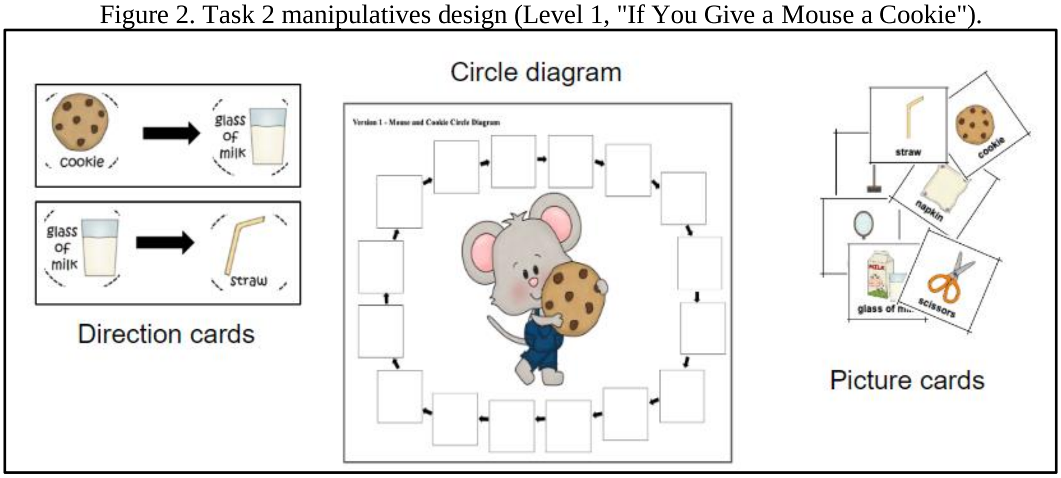
Figure 1. Task 1 design (Level 1 - 5 cards).



3.2.2. Task 2 - Sequencing Using Simple Conditional Logic + Literacy

Task 2 also focuses on utilizing simple conditional logic to place pictures sequentially onto a circular organizer, but with the support of a story books with sequencing components - "If You Give a Mouse a Cookie," "If You Give a Moose a Muffin," and "If You Give a Pig a Pancake" by Laura Numeroff. The picture cards in this task include images from the story (Figure 2) and the circular organizer is a way to organize the picture cards based on the sequential order derived from the story. Learners are asked to place the picture cards in the correct order on the circular graphic organizer and can use the direction cards or the story to determine where and in what order to place the pictures. Similar to Task 1 there are three levels that increase in number of cards and complexity. The difference in this task is that there is a sequential story connected to the picture and direction cards. In the first level of the task, the research reads "If You Give a Mouse a Cookie" out loud, while the learner follows the story and identifies the direction cards that go with the reading of each part of the story. Following the story, learners are asked to retell the story by putting the picture cards in the correct order on the circular graphic organizer..

Figure 2. Task 2 manipulatives design (Level 1, "If You Give a Mouse a Cookie").



The second and third level activities ask the learners to identify the sequence of the story by using the direction cards as the guide to determine the order of where to put the picture cards on the circular organizer. After learners place all of the pictures, then the storybook aloud as a check to see if the sequence of picture cards correctly follows the story.

3.3 Data Collection

Data collection included video-recorded task-based interviews for each participant and across the multiple levels of the two tasks. The researcher set up the camera and microphone to record everything happening in the room during the task interviews in order to capture the children' behaviors, conversation during the task and with the researcher, use of manipulatives, and approaches to solving the task. Researchers conducted multiple levels of the two task-based interviews with each of the children (see Table 1).

Table 1. *The CT Tasks completed by the children.*

Pseudonym, Age, Gender:	**Task 1**			**Task 2**		
	Level 1: 5 cards	Level 2: 10 cards	Level 3: 15 cards	Level 1: Mouse	Level 2: Moose	Level 3: Pig
Grace, 5 year old girl				✓	✓	✓
Patrick, 5 year old boy	✓	✓	✓	✓		
Hollywood, 7 year old girl	✓	✓	✓	✓	✓	✓
Aurora, 7 year old girl	✓	✓	✓	✓	✓	✓
Taylor, 8 year old girl	✓	✓	✓	✓		✓
Travis, 8 year old boy		✓	✓	✓		

Note: ✓ indicates the completed tasks from the participants.

3.4 Data Analysis

For this descriptive multiple case study, the research team analyzed each video recordings for each child across Tasks 1 & 2 to explore how the children approached each sequencing task, utilized the manipulatives, and solved problems. Five research team members watched all of the recordings and thematically coded (Saldaña, 2015) using the INSPIRE CT definitions and competencies (Dasgupta et al. 2017; Ehsan et al., 2021) as a starting point and an initial lens through which to assess and evaluate the children' CT competencies. Following the initial round of coding, the team narrowed the lens to include those definitions that were identified as most relevant to the tasks as well as those that were seen in the data for future rounds of coding (Figure 2). The team engaged in group discussions following each round of coding to build consensus and agreement on the codes and coding process as well as discuss the emergent patterns, categories and subcategories, themes, and concepts in the data (Saldaña, 2015). Following multiple rounds of coding and discussion, analysis moved to in-depth examination of the emerging patterns and themes within each of the embedded cases as well as looking across the multiple cases for a more holistic view of how children approach unplugged sequencing tasks.

Table 2. *INSPIRE Computational Thinking Definitions* (Dasgupta et al., 2017).

CT Competency	INSPIRE Definition	Learning Objectives
Pattern Recognition	Observing patterns, trends and regularities in data	• Identify a given pattern. • Complete a missing pattern with colors and letters (pattern completion). • Show abstraction by representing a color pattern using letters (pattern abstraction). • Create an original pattern.
Algorithms and procedures	Following, identifying, using, and creating a sequenced set of instructions.	• Follow a series of ordered steps to solve a problem • Identify the sequence of steps to be taken in a specific order to solve a problem or achieve some end goal. • Apply an ordered series of instructions to solve a similar problem the algorithm was designed for. • Create an ordered series of instructions.
Debugging	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, and logical thinking.
Problem decomposition	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

4. Findings

In this descriptive multiple case study, we explored how children approached sequencing and how they used manipulatives across multiple levels of the two different sequencing tasks to gain a better understanding of how young children engage with CT. More specifically, we were looking at how and what CT competencies were demonstrated during these unplugged sequencing tasks and how manipulatives were used while engaging in unplugged sequencing tasks?

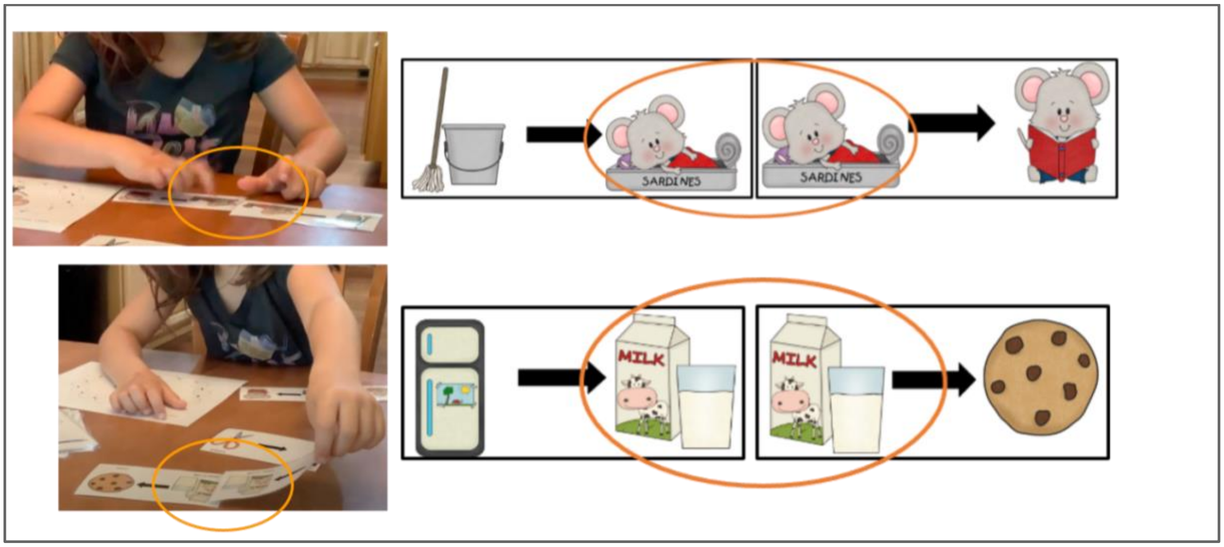
4.1 Children's Demonstration of CT Competencies

During analysis of the data, we found examples of (1) pattern recognition, (2) algorithms and procedures, (3) problem decomposition, and (4) debugging in each of the embedded cases across the tasks. Overall, pattern recognition emerged as a foundational skill not only for successful completion of the sequencing tasks, but as an overlapping skill for the other CT competencies. Each of the CT competencies that were seen in the data is described with examples below.

4.1.1 Pattern Recognition

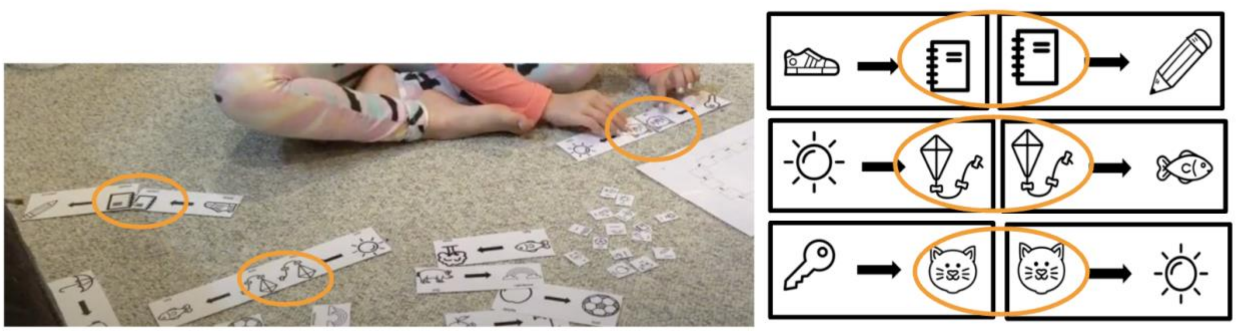
Pattern recognition was a CT competency that was seen multiple times within the data and across the tasks and learners. Pattern recognition is *observing patterns, trends, and regularities in data* (Dasgupta et al. 2017). While engaging with these tasks, children identified, described and matched patterns in the direction cards and with the picture cards as well as noticing that to find the next direction card, they needed to look at the second image from the previous direction card. An example of this can be seen with Aurora, a 7 year old girl, who identified and matched up the same picture on two different direction cards, demonstrating her ability to recognize patterns in the direction cards and then quickly pair up direction cards by connecting the matching images. Aurora explained her thinking by pointing to the same image in different direction cards (top of Figure 3) and then illustrated the pattern with another set of direction cards, pointing to the relevant pictures as she described the pattern: *"They are the same thing! Nap, nap… milk with milk!"* (bottom of Figure 3).

Figure 3. *Aurora pointing to the picture matches in the direction cards.*



In another example, Taylor, age 8, recognized and used the pattern of matching two similar images on direction cards (see Figure 4). She explains how she used pattern recognition to complete the task quickly: *"I am gonna just try to find the picture [in the other direction cards]. That will be more easier because then we connect easily, matching it up."* After searching for a while, she found the direction card with the same image from the previous direction card, and added it to her sequence (Figure 4).

Figure 4. *Taylor finding direction card patterns.*

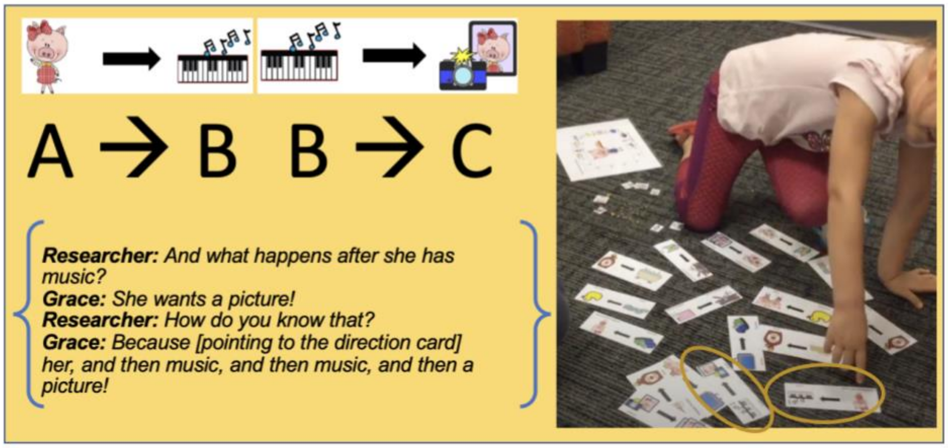


Overall, these observations showed that all of the children could effectively recognize patterns in the direction cards and use those patterns to help with the solving of the sequencing tasks. Furthermore, the ability to recognize and identify patterns was found to be an important step for successful completion of the tasks as the students who struggled was due to their not or not correctly identifying the pattern. This supports previous work suggesting that pattern recognition is an important core idea of CT (Dong et al. 2019).

4.1.2 Algorithm and Procedures

Another CT competency that was demonstrated by the children during completion of the unplugged sequencing tasks was algorithms and procedures, which is defined as following, identifying, using, and/or creating a sequenced set of instructions (Dasgupta et al. 2017). This was most commonly seen once the children recognized patterns in the direction cards, then they were able to use those patterns and direction cards to predict the next item in the sequence and build simple logic or algorithms with the direction cards. Hollywood, a 7 year old girl, described each picture card as steps based on the direction cards and how she lined them up: "First is the sun, second is the cat, third is the apple, fourth is the house, fifth is the zebra." Our youngest learner Grace, for example, used conditional logic of A → B, B → C while also recognizing patterns to determine the order of direction cards and corresponding order of the picture cards (see Figure 5; here, we are using the letters to represent the pictures in the direction cards).

Figure 5. Grace used direction cards to sequence picture cards in order on the diagram chart.



All children in this study were able to identify and use the direction cards as their sequenced set of instructions, or algorithm, to determine the sequence for placing the picture cards on the organizer. This is important as a key component of sequencing is the ability to order steps logically and understand the relationships between those items or steps (Aho, 2012). We also found that the demonstration of algorithms by the children in this study was connected to the ability to recognize the patterns in the direction cards and then use those identified patterns to build a logical sequence or algorithm. This aligns with the suggestions from Aho (2012) that understanding the relationships between events is important not only for being able to construct and order sequences, but also as a foundational skill within CT.

4.1.3 Problem Decomposition

A third CT competency that was seen across all six children was problem decomposition as they were breaking down a complex problem into smaller manageable parts in order to solve the bigger problem (Dasgupta et al. 2017). Within problem decomposition, there were two overarching approaches that the children utilized: (1) a bigger picture approach of breaking it down into two steps with first organizing all direction cards and then placing all of the picture cards (see Figure 6a) or (2) a smaller, step-by step, iterative process of finding one direction card and placing the corresponding picture card before finding the next direction and corresponding picture card (see Figure 6b).

Figure 6a and 6b. *Hollywood's two-step decomposition and Aurora's multiple, iterative decomposition approach.*

The three children (Hollywood, Travis, and Taylor) who used the big-picture approach for the tasks were seen using a similar approach of first organizing all of the direction cards by lining up the matching pictures and then turned their attention to using the direction cards to help them place all of the picture cards into the circle diagram. The other three children (Aurora, Grace, Patrick) applied a smaller and more iterative decomposition approach where they placed one direction card then one picture card over and over again. There was some variation in what the children did with the direction cards and whether or not they organized the cards after using them in the step by step process. For example, Aurora kept them in a stack and used them more like a deck of cards, thumbing through the stack until she found the direction card that had the matching picture. Whereas Grace and Patrick looked for the direction card that was randomly laid out on the table and then placed the matching picture card onto the circular diagram before searching for the next direction card.

The same two decomposition strategies utilized in Task 1 were also seen when adding a literacy component in Task 2. The three children who had used this big picture strategy of laying out all direction cards first then placing the picture cards did a similar thing with Task 2. Two children (Grace and Patrick) once again utilized the simultaneous approach of finding the direction card and then the picture card as they listened to the story and they later retold the story in small chunks using one direction card then picture card at a time to create their retelling. The last child, Hollywood who was familiar with the books, demonstrated a third decomposition strategy by creating the sequence on her own with only the use of the picture cards and not the direction cards or story. At the beginning of the task, Hollywood remarks that she knows the story and the researcher responds by asking if she can complete the sequence using her knowledge of the book. She started by placing three picture cards: the first, the second, and the last cards (Figure 7). When asked why she put them in that order, she responded that she knew because she had done it before (in the previous versions of the task). However, when she was unable to finish the task with this strategy, she went back to the previous strategy of finding one direction and picture card as the story was being read to her.

While some of the children' decomposition approaches varied slightly as the children moved into the higher levels of the tasks with more complexity, their overall approach to breaking down the problem stayed consistent. For example, Hollywood, who used the big picture approach initially, modified her strategy slightly as she moved into more complex tasks. In the first level with five cards, she laid all of the direction cards out first. Then when she went to 10 and 15 cards, she chunked the direction cards into smaller groups and then within the groups laid out all direction cards and then used those to place the picture cards before moving to the next group of a few direction cards. Overall, she was still seeing the pieces as all direction cards and then all picture cards. The overall use of these two different decomposition strategies suggested that the children were seeing and decomposing the problem into different sized parts. With some of the children decomposing the task down to a smaller level of each individual direction card as a step while others saw it at a bigger level of a connected sequence of direction cards as a step and then moving all of the picture cards as the next step.

4.1.4 Debugging

The final CT competency that was seen within the unplugged sequencing tasks was debugging or addressing problems that inhibit progress toward task completion (Dagupta et al., 2017). This was commonly seen at two times during engagement in the task. The first common instance was when a child would often be in the middle of working on the task and notice that either the image or the directional arrow on the direction card did not match the picture cards that were being placed into the circular organizer. They would then often go back to the beginning and start matching up direction and picture card images. For example, Aurora had made an initial error in reading the direction of the arrow on the direction card. When placing the next picture card, she found that the sequence of picture cards did not align with the direction card. She reviewed the directions cards again and found that the zebra should follow the house, not the kitty: “The kitty was not with the house, but it was actually the zebra with the house.” She then replaced the kitty with the zebra by matching the direction card with the correct picture card.

The second common instance of debugging occurred when the children were asked to double check the order by tracing the sequence of the direction cards and picture cards at the end of the task(see Figure 9). As they were moving their fingers along and tracing the sequence, the children were able to identify and correct errors in logic by aligning the corresponding picture cards with the direction cards. For example, Travis identified and corrected a logical error when he was tracing the sequence of picture cards on the circular diagram, and cross-referencing them with the direction cards (Figure 9a): "Kite-fish, Tree-pig? Oh, no. Tree-Orange, Orange-Umbrella ...Pig!". He discovered that the placement of the Orange and Pig cards needed to be switched after pointing to each picture card and reviewing the sequence of direction cards he had arranged. Using that same strategy, Hollywood discovered that she had overlooked the napkin picture card, so she retraced the sequence of direction cards she had laid out below to determine the correct logical placement by pointing to each picture card.

Figure 9a and 9b. Children debug errors through retracing

Interestingly, these instances of debugging paralleled the two overarching themes within problem decomposition where the CT competency occurred either as a larger, big picture approach and more often at the end, or on a smaller and more step-by-step scale while working on the task. This further supports the idea that the children were decomposing the problem into different sized parts as they attended to the tasks.

4.2 Children’s Use of Manipulatives

In the second part of our findings, we detail our results of how children used manipulatives as they engaged with unplugged sequencing tasks. The manipulatives in these tasks were designed by teachers and researchers to help scaffold children during the CT tasks and included the diagram chart, the picture cards, and the direction cards. We found children had different approaches to using the manipulatives that varied not only across children, but also by the same children across tasks. One of the most evident differences was in how they used the direction cards to support their placement of the picture cards. Some of the learners randomly laid out the direction cards, while others had a specific order and pattern to the manner in which they laid out the direction cards. For example, three out of the six children organized their direction cards in a linear manner across both tasks, but organized them slightly differently: Taylor organized the direction cards in two long horizontal linear sequences (Figure 10a), Hollywood organized the direction cards in a circular sequence, mimicking the diagram (Figure 10b), and Patrick organized the direction cards in two vertical lines (Figure 10c).

Figure 10. Children lining up direction cards in specific order in Task 1 ((10a) Taylor, (10b) Hollywood, (10c) Patrick))

The three other children did not organize their direction cards in task 1. All three children used the direction cards more as a checklist where they pointed or glanced at them while they put down the picture cards in order on the diagram chart. As shown in Figure 11a (Travis) and Figure 11b (Aurora), the two children put the direction cards into a linear fashion, but not in an order that matched the images, and they did not move them once they were spread out. In Task 2, which incorporated a story (If you give a mouse a cookie / If you give a moose a muffin), these two children altered this strategy and instead laid out the direction cards in a specific and organized fashion (Figure 11c, Travis; Figure 11d, Aurora). The third child used the checklist approach for both tasks.

Figure 11a, b, c, & d. Travis and Aurora laid out cards in a random order first, and then organized by images and order in the second task

Overall, we found that in the cases where the children explicitly used and organized the direction cards according to the patterns and relationships on the cards were more intentional with their sequences and more successful with completion of the tasks. The children who did not explicitly organize and use the relationships between direction cards to help them took more time and made more errors during completion of the tasks. This suggests that their approaches were more seemingly random placements, involved little planning and were not necessarily based on patterns or a pre-determined sequence of steps or actions. This aligns with recommendations by Chevalier et al. (2022) suggesting that the use of tangible materials is important for cultivating CT skills and competencies.

5. Discussion and Conclusion

This study provides a starting point for thinking about how young children understand about CT and which concepts can be used to develop CT competencies within sequencing activities. Within and across these tasks, we saw a range and overlap of CT competencies, including pattern recognition, algorithms and procedures, problem decomposition and debugging from multiple children supporting the claim that young children can learn and demonstrate CT skills and competencies. Pattern recognition was found to be an important and overlapping skill across tasks, supporting the idea that it is foundational for young children's engagement with other CT competencies (Dong et al., 2019, Saxena et al., 2020). We also found that the scale in which the children thought about and decomposed the problems in these tasks, either big picture or a series of smaller pieces, impacted other aspects of CT within these tasks. This suggests that problem decomposition is also an important and foundational skill for CT with young children. The demonstration of multiple CT competencies within sequencing tasks supports suggestions that sequencing is a developmentally appropriate entry point for young children to begin engaging in other CT competencies ((ie. Gerosa et al., 2021, Kazakoff, Sullivan & Bers, 2013; Yang et al., 2023). When looking more specifically at the sequencing within these unplugged CT sequencing tasks, the children demonstrated fundamental aspects of sequencing as they were able to order steps logically and understand the relationships between the pattern, direction cards and placement of the picture cards into the organizer (Aho, 2012; Gerosa et al., 2021). Additionally, we found evidence and examples of students engaging in aspects of algorithm development as they identified and created a series of intentionally ordered steps. This supports the claim that sequencing is an important component of algorithm development (Yadav et al., 2016) and therefore could serve as an entry point into algorithm development.

The other aspect that was being explored as part of this work, was the use of unplugged approaches with young children for CT learning and to further understanding of how young children approach unplugged activities. Similar to above, we found examples of multiple CT competencies during engagement in these unplugged CT sequencing tasks suggesting that the unplugged approaches did promote CT. This work supports previous findings that recommended the use of unplugged approaches and activities are a developmentally appropriate approach for teaching CT to young children(eg. Bati, 2022; Bell et al., 2009, Chen et al., 2023). Additionally, those students who intentionally used the physical manipulatives while solving the CT sequencing tasks were able to solve the tasks quicker and with less errors and less frustration, which aligns with recommendations that the use of tangible materials is an important for cultivating CT within unplugged activities (Chevalier et al, 2022). However, these unplugged sequencing tasks also provided insight as we integrate CT through the use of computational toys, embodied activities, and plugged simulations. We need to be intentional in the design if the goal is to observe a wider range of CT competencies. We also caution that not all sequencing activities will involve all or any CT competencies, so the design of these tasks is important. For example, asking students to retell a story involves knowledge and ability in sequencing, but if they are only verbally describing to a friend what happened in the story then the task does not necessarily elicit CT competencies from the children.

It is important to note that there were limitations to this study caused by the COVID-19 pandemic, which made it difficult to make bigger conclusions about the learning trajectories and developmental appropriateness of the sequencing tasks as originally planned. However, we purposefully designed the tasks with K-2nd grade teachers to address developmentally appropriate practices and skill sets when thinking about what young children understand and demonstrate about CT within unplugged sequencing tasks.

6. Acknowledgments

The tasks contained images for which we have permission to use.Images from Task 1 are from The Noun Project (https://thenounproject.com/) and are Creative Commons licensed with attribution. The following are the attributions per icon image: BlackActurus (sun), icon 54 (apple), jonata hangga (cat), Alice Noir (zebra), and Vectorstall (house). Images in the Task 2 are the copyright of Scrappin Doodles (https://www.scrappindoodles.ca/) and are used within the parameters laid out on the website.

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