Assessing Computational Thinking Skills in Early Elementary Students: A Focus on Sequencing Tasks

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Abstract: The integration of Computational Thinking (CT) into K-12 education has gained significance in recent years as the field of education experiences the need to equip students with essential skills for the 21st century. This case study focused on two sequencing activities, involving plugged and unplugged tasks, conducted with four children aged four to seven, spanning pre-kindergarten to second grade. The central research question guiding the study was: "What computational thinking (CT) skills were demonstrated by K-2 students as they engaged in two different sequencing tasks?" The study identified competencies in sequencing, reverse sequencing, debugging, pattern recognition, and problem decomposition. The findings suggest that both unplugged and plugged sequencing tasks provide age-appropriate entry points for young children to develop various CT competencies. Furthermore, the study highlights the potential for plugged and unplugged sequencing tasks to be integrated into early childhood classroom activities, offering a practical approach to promoting CT skills in young learners.

Introduction

In recent years, there has been a significant call for teachers to incorporate Computational Thinking (CT) into their classrooms (Author, 2020). This shift towards integrating CT in education is exemplified by initiatives like the "CS for All" campaign, which aims to make computer science education accessible to every student in the United States, and the growing prevalence of programming courses at the secondary school level (Dong et al,. 2019). Additionally, research conducted by the International Society for Technology in Education (ISTE) and Computer Science Teachers Association (CSTA) has highlighted the benefits of introducing CT skills to students early in their educational journey, emphasizing its importance as a foundational skill (Gerosa et al., 2021). As the momentum for CT integration in classrooms continues to build, it is evident that the paradigm of education is evolving to equip students with the skills necessary to thrive in the digital age.

In consideration of strategies aimed at assisting early-year teachers, the integration of CT in K-2 has faced challenges as there is limited knowledge on what young learners are capable of demonstrating and how teachers can find time to include it in the curriculum with limited time to teach all other content areas (Gerosa et al., 2021). For example, a study conducted by Flannery et al. (2013) revealed that the majority of computer programming tools are designed for children over the age of 8 and emphasize academic abilities, such as letter and number recognition, and not advanced cognitive processes. Moreover, the overwhelming curriculum demands in the primary grades often leave teachers with limited room to introduce additional subjects like CS. As a result, it becomes essential to explore strategies for integrating CT with existing curricula, ensuring a well-rounded educational experience for young learners. Given the substantial amount of time dedicated to literacy in the early years (Jacob & Warschauer, 2018), this approach offers a strategic means of not only enhancing students' literacy skills but also instilling essential CT competencies from an early age.

This research seeks to contribute to the broader understanding of young children and CT. In particular, this study seeks to understand the CT competency capabilities of early elementary students and their readiness for CS utilizing sequencing as a foundational skill within CT (Gerosa et al., 2021). Consequently, our study poses the central research question: What computational thinking (CT) skills were demonstrated by K-2 students as they engaged in two different sequencing tasks?

Computational Thinking

CT is the process of identifying a problem and creating potential solutions so that a machine could potentially implement that solution (Authors, 2020). According to Gretter and Yadav (2016), CT is akin to thinking like a computer scientist, employing problem-solving skills centered on pattern recognition, decomposition, algorithmic thinking, and abstraction (p. 511). Yadav et al. (2016) elaborate on CT as breaking down complex problems into manageable sub-problems, employing algorithms for step-by-step solutions (sequence), abstracting solutions for similar problems, and assessing if computers can automate the process for efficiency (p. 565). In essence, CT is considered a valuable skill emphasizing logical reasoning, algorithmic thinking, pattern recognition, and the ability to design and implement solutions to complex problems.

K-2 Students and CT

Studies have shown that the introduction of CT at an early stage is instrumental in equipping young students, particularly those aged 6-7, with problem-solving abilities, fostering positive attitudes towards programming, and instilling an interest in more programming in school (Su & Yang, 2023; Kjällander et al., 2021). Through meaningful CT projects integrated in academic content such as engineering concepts, storytelling, and mathematics, teachers create an environment where K-2 students learn and play creatively (Su & Yang, 2023). Luo et al. (2022) study provides empirical evidence indicating that the integration of CT into diverse subjects, including language arts, not only offers valuable insights but also guides the design of integrated instruction and assessments. These findings, collectively, underscore the importance of early exposure to CT leads to development of computational skills, as well as other related skills such as communication, collaboration, problem solving and fosters positive learning experiences.

Research indicates that supporting CT learning for K-2 students should encompass various activities, including both plugged (using computers) and unplugged (without computers) approaches, along with the use of computational toys such as robots (Battal et al., 2021). A study by Pila et al. (2019) suggests that plugged activities can enhance the appeal and understanding of coding concepts in early childhood. Investigations involving early childhood students, reveal an increase in CT skills following the use of robots like Bee-Bots (Caballero-González et al., 2019; Papadakis & Kalogiannakis, 2020). Preliminary evidence also suggests that a robotics curriculum tailored to the developmental stages of children can promote CT knowledge and interest (Noh & Lee, 2020; Sullivan & Bers, 2013). The integration of both plugged and unplugged approaches, along with the utilization of computational toys like robots, offers a broad strategy for CT learning in K-2 students.

Research Design

This study is situated within a broader design-based research (DBR) project (Kelly et al., 2008), which seeks to develop models for effectively integrating computational thinking (CT) and literacy within K-2 classrooms. As part of this initiative to look at CT competencies with early elementary students, the research team started with a focus on better understanding sequencing as a part of algorithm development and a foundation CT (Yadev, et al., 2016, Gerosa et al., 2021). In order to better understand sequencing the research team developed a serires of sequencing tasks to serve as the task-based interviews (Goldin, 2000) for this multiple case study. In multiple case study design, each of the tasks is treated as an independent case enabling an in-depth assessment of K-2 students' proficiency in sequencing. The within case and across case (Yin, 2018) comparative analyses contribute to a more holistic understanding of K-2 students' abilities in sequencing, a fundamental skill in the realm of CT and algorithm development.

Participants and Context

As a result of unexpected challenges posed by the COVID-19 pandemic, the researchers encountered difficulties in the execution of research within elementary schools. To address these challenges, the researchers enlisted the participation of four girls between 5 and 8 years, chosen due to pre-existing personal relationships with the researchers. All four girls completed task 3 and only two of the four girls completed task 4. It is relevant to acknowledge that the pre-existing relationships between the children and the researchers while fostering a sense of ease during the study, may have potentially influenced the children's level of engagement with the tasks and, consequently, the findings of the research.

The Tasks

The research team developed a series of plugged and unplugged task-based activities that were designed to nurture CT skills in the early years. These activities required students to arrange commands or actions in a specific order to achieve a desired outcome. In the plugged activity, the use of a toy robot offered an engaging and interactive experience for children while developing their understanding of logical sequences. The unplugged sequencing tasks, on the other hand, emphasize hands-on, unplugged activities that do not require digital technology.This study focused on Tasks 3 & 4 described in more detail below.

Task 3 - Reverse Coding + Robot Mouse

Task 3 is a plugged activity that uses the Code & Go Robot Mouse named Colby by Learning Resources. It centers on the coding of an educational toy to teach sequencing and computational thinking. The robot mouse has an array of colorful buttons used to program the mouse (Figure 1a) and coding cards that match the buttons on the robot mouse (Figure 1b). The primary objective is to program the robot mouse to reach a target (cheese) and return to its initial position, essentially a reverse coding challenge. To provide structure to the coding activity, specific guidelines are defined. The robot must pass through all tunnels on the map while avoiding crossing strategically placed walls on the map. The tunnels are orange while the walls are purple (Figure 1c). Participants program the mouse to navigate through the tunnels and walls to reach the cheese and then reverse-code the mouse to return to its starting point.

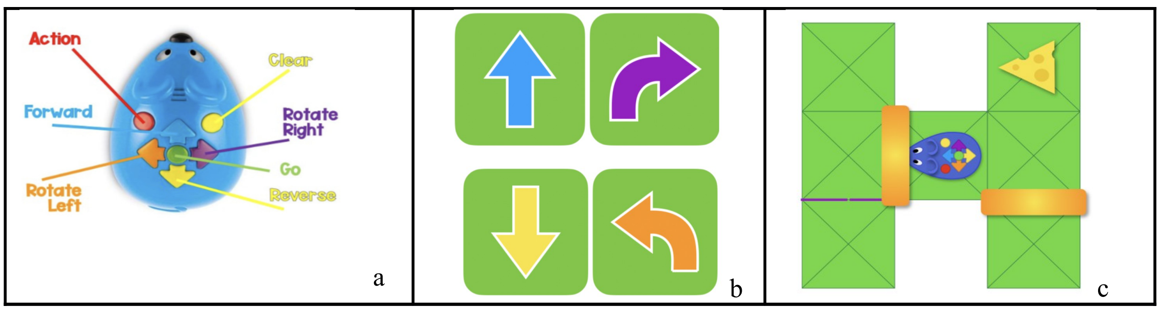

Figure 1. Robot Mouse Computational Toy diagram and other task 3 activity components

Task 4 - Reverse Sequencing + Literacy

This unplugged CT task focuses on forward and reverse sequences within the context of a story. This task makes use of the story "Joey and Jet" by James Yang (Figure 2a), which narrates the adventures of a boy named Joey and his dog Jet. Participants receive a collection of cards (Figure 2b) depicting Jet's actions in the story, along with a flowchart (Figure 2c). The objective is to arrange the cards in chronological order, aligning with the story's actions as Jet runs to fetch the ball that Joey has thrown. The researcher reads the story to the students as they place the cards on the flowchart. Participants are then provided with the "Jet Returns" flowchart (Figure 2d), accompanied by a new set of cards that illustrate the sequence of events involving Jet's return of the ball to Joey, or the reverse of the original sequence.

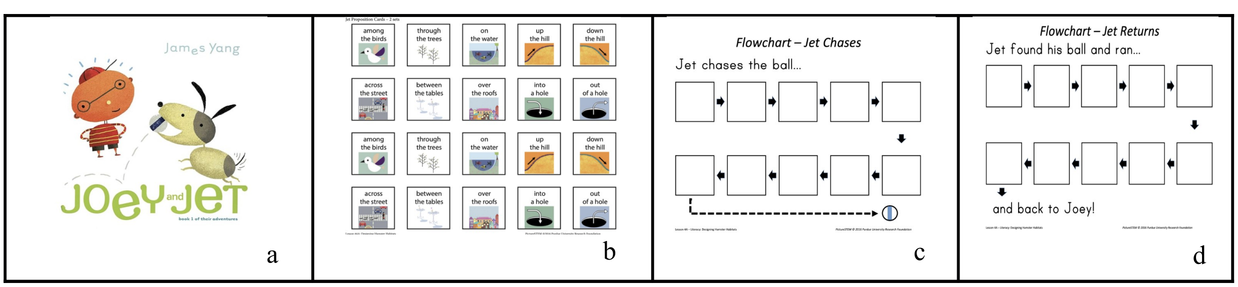

Figure 2. Joey & Jet Book diagram and other task 4 activity components

Data Collection and Analysis

The researchers employed task-based interviews (Goldin, 2000) as a primary method for data collection as part of this multiple case study design. ETask-based interviews involve students verbalizing their thought processes as they engage with purposefully designed, conceptually-rich tasks. Throughout the interviews, researchers guided students with prompts aimed at uncovering the rationale behind their actions and their thought processes during the tasks. To capture a comprehensive record of these interactions, various data sources were employed, including video recordings, researcher observation notes, and copies of student artifacts. This multifaceted approach ensured that the researchers obtained a rich and multifaceted dataset to support their within and cross-case analyses.

Analysis of the data followed a method of constant comparative analysis (Corbin & Strauss, 2014) with an interactive process of open coding, comparing, and condensing data to allow for the emergence of patterns. Research team members undertook a preliminary data analysis for Task 3 & 4 by watching video recordings and then engaged in a thematic analysis (Saldaña, 2015) guided by the INSPIRE CT definitions, objectives, and competencies (Dasgupta et al. 2017) (See Table 1). Once the research team agreed on codes and the coding process, some of the research members engaged in an in-depth analysis to assess children's computational thinking skills in plugged and unplugged sequencing tasks. The preliminary findings show skills observed in relation to some INSPIRE CT competencies.(see table 1).

Table 1. INSPIRE Computational Thinking Definitions & Learning Objectives (Dasgupta et al., 2017)

CT Competency	INSPIRE Definition	Learning Objectives
Algorithms and Procedures/Sequencing	Following, identifying, using, and creating 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 ● Apply an ordered series of instructions to solve a similar problem the algorithm was designed for.
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.
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 with letters (pattern abstraction). ● Create an original pattern
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.

Findings and Conclusions

Our findings indicate that students in this age group exhibited several CT skills during these activities. Sequencing was a prevalent CT skill observed in both the plugged and unplugged tasks. In the plugged activity, students grasped the concept of step-by-step ordering, and organizing commands using direction cards to program the robot mouse. In the unplugged task, they followed the sequence of actions in a story to place cards on a flowchart. The ease with which they followed the sequence in the unplugged activity compared to the plugged activity suggests that storytelling and visual aids can facilitate sequencing in young students. This integration of sequencing skills into literacy activities holds the potential to not only enrich students' understanding of CT but also lay the groundwork for the integration of CT into other content areas, promoting a comprehensive and interconnected learning environment for young children.

Reverse sequencing was less pronounced in the plugged task, as students tended to start over rather than deconstruct their forward sequences. However, in the unplugged task, children successfully reversed sequences, demonstrating logical thinking by explaining their card order choices. It is worth noting that, in plugged sequencing tasks, teachers may need to prompt students to consider the application of a one-to-one reversal of the sequence. Additionally, the incorporation of story context may have contributed to the logical thinking demonstrated by children in successfully reversing sequences in the unplugged task. This approach showcases the role of narrative context in shaping young children's logical thinking abilities, presenting a valuable intersection of computational thinking and literacy.

Debugging skills varied across activities. In the plugged task, students used trial and error to fix errors, while in the unplugged task, they relied on the story to identify and correct mistakes. Using a story to aid debugging in the unplugged task seemed easier and took less time which could be attributed to the context and narrative clarity. This suggests that the integration of literacy and CT may play a role in shaping how young learners approach problem-solving in CT. It prompts the consideration of further research to understand how context may influence and enhance CT skills acquisition in young students.

Throughout the programming tasks, students exhibited a clear trajectory of growth in their computational thinking abilities. Their iterative organization of sequences marked a significant development as they advanced, highlighting their increasing proficiency in coding the mouse. Over time, they relied less on referencing the cards and physically moving the mouse, demonstrating a deeper understanding of the underlying principles of sequencing. This growth indicates that even at a young age, students can rapidly adapt and improve their CT skills, which has important implications for the incorporation of computational thinking into early childhood education programs.

In conclusion, K-2 students displayed various CT skills during sequencing tasks, both plugged and unplugged. These findings suggest that young children can engage in CT activities, and the choice of activity and context can influence the development of these skills. Further research is needed to explore how to best foster and develop CT skills in early education, taking into account the observed variations in their approaches to problem decomposition and debugging.

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