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# Which Way is Up? Orientation and Young Children's Directional Arrow Interpretations in Coding Contexts

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**Abstract:** Many coding environments for young children involve using navigational arrow codes representing four movements: *forward, backwards, rotate left, and rotate right*. Children interpreting these four, seemingly simple codes encounter a complex interaction of spatial thinking and semantic meaning. In this study of how children interpret directional arrows, we found that they interpret each of the arrows as encoding many meanings and that the orientation of the agent plays a critical role in children's interpretations. Through iterative rounds of qualitative coding and drawing on two examples, we unpack some common interpretations.

## Introduction

There has been a push to make computer science education equitable for all students. However, as mentioned in the call for proposals for the ISLS 2023 conference, things that are argued to be more inclusive for many learners have also been shown to disadvantage many others. Sometimes our designs for learning are messy, and as learning scientists, we need to take a step back and try to disentangle the complexity and engage in sensemaking about how learners are interpreting and interacting with our designs for learning and the materials that are meant to support them. Such is the case for the present study. In this paper we explore how young children interpret and interact with the materials we designed to teach and assess their understanding of computational thinking (CT). Like many researchers in early childhood, we use coding as a context to promote CT (Wang et al., 2021). Most coding environments for pre-literate children use navigational codes that are represented through arrows: *forward*, *backward, rotate left*, and *rotate right* (Clarke-Midura et al, 2019). While the idea of using arrows to represent movement may seem simple, it is challenging for young children. The navigational arrow codes are a whole new symbol system they need to make meaning of. It requires understanding what each arrow instructs the agent to do, that one arrow only produces one discreet movement, and that each arrow always produces the same movement but depends on the agent's orientation. In this paper we theorize about the complexity that two codes: *forward* and *rotate left* and how the orientation of an agent affects children's interpretations of the two codes as they engage in tasks designed to assess their understanding of CT. Our inquiry is guided by the following research questions: *How are children interpreting the arrows? How does the orientation of the agent affect children's interpretation of the arrow codes?*

### Background and Context

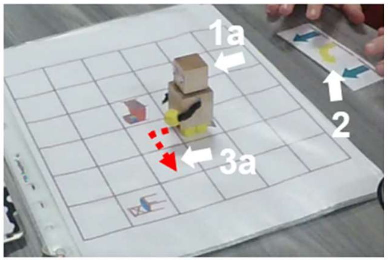
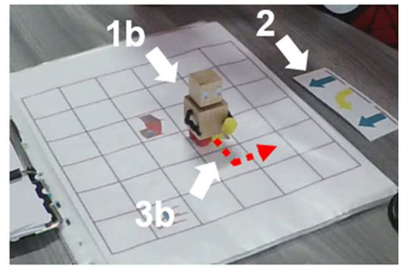
The present study has roots in Papert's (1980) Logo Turtle Geometry where the turtle became a virtual computational agent for children to connect with abstract ideas like angles and navigation in a concrete way through "body syntonicity." Reasoning about an agent's orientations, locations, and navigation in space involves spatial thinking. The National Research Council (NRC) defined spatial thinking as comprised of three elements: concepts of space, tools of representation, and processes of reasoning (NRC, 2006). Children first develop spatial orientation concepts in relation to their own position in space and later develop external based reference systems using landmarks outside themselves (Sarama & Clements, 2009). Yet, few studies have systematically investigated the complexity of spatial orientation in children's understanding of CT.

## Research design and methods

### Task and Materials

We designed two tasks that are identical except for the starting orientation of the agent. In both tasks, children were asked to enact a sequence of codes, *forward, rotate left, forward*, that were provided to them in the form of arrows (see Figure 1). Children were instructed to physically move a tangible agent on a 6x6 2D grid. In Task A, the agent shares the same orientation as the child, while in Task B, it is oriented 90 degrees to the left.

**Figure 1**
*Set up for Task A (left) & Task B (right)*

| | | |
|---|---|---|
|  | 1a: Agent's orientation same as the child's perspective.<br><br>1b: Agent's orientation 90 degrees to the left from the child's perspective.<br><br>2: Program to enact: FLF<br><br>3a & 3b: Expected path the agent will travel if all codes are enacted correctly |  |

## Sample and Data Sources

This research is part of a larger project that is operationalizing CT in early childhood and developing curricular tasks and a performance assessment (Clarke-Midura, et al, 2021a). Data come from video of 146 children aged 5-7, spread across five elementary schools in the western United States, solving the two tasks described above.

## Data Analysis

This analysis started with *a priori* codes that were developed from a previous analysis where we observed how four groups of children (n=16) interpreted the *rotate left* and *rotate right* arrows during a curriculum enactment with different materials but similar navigational codes (*forward, backward, rotate left, rotate right*). In the present study, as we coded the new video data, we modified and refined the codes as new types of arrow interpretations emerged. The codes were cross-checked with each other and with the data from the previous analysis. We compared codes, identified interpretations that appeared frequently or with more clarity, and could be differentiated from each other. This allowed us to create categories and identify themes. We engaged in selective coding, where we refined, solidified, and clarified codes and categories until we reached saturation.

# Results

## Various Interpretations of Forward and Rotate Left

In our context, a *rotate left* arrow makes the agent stay in the square and rotate 90 degrees to the left and a *forward* arrow makes the agent move one square forward *from the agent's perspective.* However, children interpreted the *forward* and *rotate left* arrows in various ways. We identified four *forward* arrow interpretations and five *rotate left* arrow interpretations. The various interpretations indicate that some of the children did not attach one fixed meaning to an arrow and, as a result, each arrow had the potential to do everything.

**Figure 2**
*Children's Forward Arrow Interpretations*

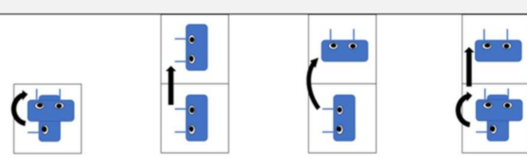
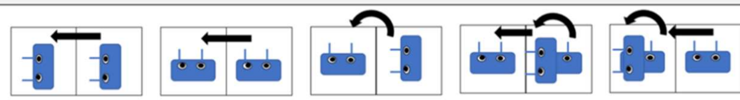
| | **Spin to face this way** | **Slide sideways** | **Curve this way** | **Rotate and slide this way** |
|---|---|---|---|---|
| **Definition** | Reorienting the agent to share a child's perspective | Moving the agent one square above without reorienting the agent to face forward | Making the agent curve to the square above | Rotating the agent face forward and then travel to the square above |
| **Visual illustration** |  | | | |

Figure 2 shows that children used *forward* arrows to do things other than moving the agent to an adjacent square. They assigned two distinct movements, rotating the agent while staying in the square and moving one square forward to one *forward* arrow. They enacted both movements either as one fluid movement by making the agent curve one square in the direction of the arrow (*curve this way*) or as two distinct movements (*rotate and slide this way*). Children sometimes enacted the *forward* arrow as *slide sideway* by moving an agent one square forward when the agent's orientation is different from the direction it travels. In this case, children attached the correct movement (sliding one square) to the *forward* arrow; however, they did not take on the agent's viewpoint when moving it.

**Figure 3**
*Children's Rotate Left Arrow Interpretation*

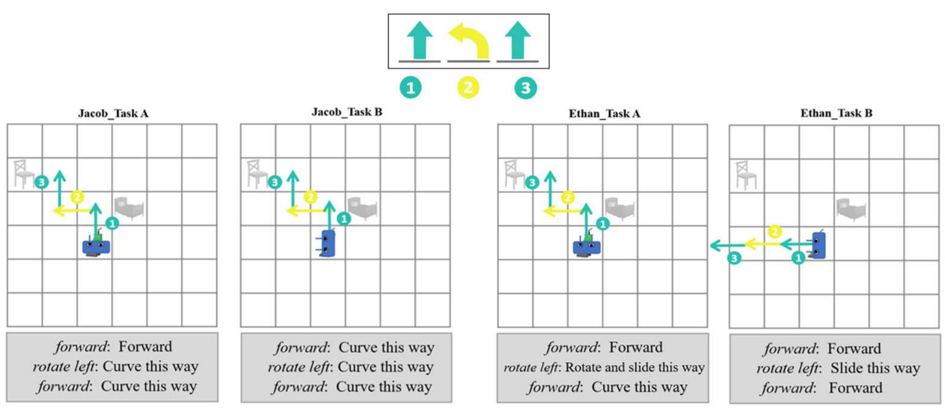
| | Slide this way | Slide sideways | Curve this way | Rotate and slide this way | Slide this way and rotation |
|---|---|---|---|---|---|
| **Definition** | Moving the agent one square in the direction of the arrow | Moving the agent one square to the left without reorienting the agent | Making the agent curve to the square on the left | Rotating the agent face to the left and then travel to the next square | Making the agent travel one square and then rotate it to face to the direction of the arrow |
| **Visual illustration** |  | | | | |

Children used *rotate left* arrows to make the agent move in ways other than rotate 90 degrees to the left (see Figure 3). Some children interpreted the *rotate left* arrow by enacting two moves: first rotating the agent 90 degrees to the left and then sliding it to the next square (*rotate and slide this way*). Sometimes they combined rotation and sliding by making the agent travel in one fluid movement (*curve this way*). When the agent's orientation was facing left (the same as the arrow's), some children enacted the *rotate left* arrow as if it were a *forward* arrow, by moving the agent to an adjacent square without reorienting it (*slide this way*).

## How Orientation Affects Interpretation

Figure 4 presents visual representations of two children's enactment of Task A and B, Jacob and Ethan. The arrow direction represents the direction the agent was facing at the end of each code enactment.

**Figure 4**
*Jacob's and Ethan's Arrow Interpretation*




### Example 1: Jacob

In task A, where the agent shares Jacob's orientation, he enacted the *forward* arrow correctly. However, the enacted the *rotate left* and last code, *forward*, incorrectly. In Task B Jacob enacts both *forward* arrow codes by making the agent curve to the square above. Even though the agent shared his orientation when he enacted the second code, *rotate left* in both tasks, he enacted it by making the agent curve to the square on the left.

### Example 2: Ethan

Ethan enacted the first *forward* arrow correctly in both tasks. In task A, even though the agent shared his orientation when he enacted the second code, *rotate left* he enacted it by rotating the agent to face the left and travel to the next square. In task B, he enacted the left rotation by moving the agent one square in the direction of the arrow (to the left). In Task A, Ethan enacted the second *forward* arrow as *curve this way* yet in Task B, he enacted the second *forward* arrow correctly.

## Analytic Findings

Using the symbolic system of navigational arrows to sequence and enact codes requires understanding *code-to-movement correspondence*, that each code (arrow) makes the agent do a single discreet movement; and *agent-orientation correspondence*, which means codes always produce the same movement but depend on the agent's orientation. We observed various interpretations that violated these rules; the most common example is using a *rotate left* arrow to do *curve this way*. While the orientation of the agent did affect children's interpretations, their interpretations were not consistent. Some children used the same arrow differently in the same program.

Previous studies have characterized the ways children have difficulty determining spatial orientations other than their own (Sarama & Clements, 2009) including in the context of coding with robot coding toys (Wang et al., 2022; Clarke-Midura et al., 2021b). Our findings align with these studies in that they show how not being able to take on the perspective of the agent is associated with mistakes and incorrect use or enactment of codes. Besides perspective taking, arrow interpretation is influenced by the directional relationship between the agent's orientation and the arrow's. When the agent's orientation is the same as the direction of the arrow code to enact, even if children shift their perspective to the agent's, they may still interpret an arrow's meaning other than it is supposed to be. When the agent is facing an orientation different from the orientation of the arrow code to enact, a child may reorient the agent to the direction of the arrow before any further enactment. In our study, many children look only at the tile and see the *forward* arrow is oriented "up" as depicted in the tile and then move the agent to the direction of the arrow, regardless of its orientation and position on the grid. While using arrows to represent navigation may seem like a simple design idea, our findings illustrate how the arrows caused confusion for children.

## Conclusion

In this study, children acted as surrogates by moving a physical agent to solve CT tasks on a two-dimensional grid through arrow-by-arrow enactment. This is a promising context for young children to learn spatial thinking and computational thinking skills. However, the variety of arrow interpretation indicates that tasks situated in this context are also difficult for young children. Children need to coordinate multiple representations and meanings, such as the agent's orientation in relation to the symbolic representation of the arrow's orientation on the code tile, and the position of the arrow tile to the child's orientation. When designing learning and assessment environments for early childhood CT, we need to be aware of how the designs and materials intersect and influence children's spatial thinking skills. This study contributes to our knowledge of the intersection between syntonic learning, spatial thinking, and computational thinking in early childhood.

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