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Embodied responsive teaching for supporting computational thinking in early childhood

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Abstract: Tangible programming toys support body syntonicity, where children use knowledge of their own bodies to solve problems computationally. However, we currently know little about how teachers can support these embodied computational learning processes. In this study, we examine how teachers are *responsive to* and *support* preschoolers' embodied engagement in three computational thinking practices: problem decomposition, debugging, and abstraction. Through interaction analysis, we show how teachers re-"voice" embodied proposals by purposefully taking up and transforming preschoolers' body syntonic problem solving efforts to focus, recontextualize, and decontextualize them. Implications for the embodied teaching and learning of computational thinking with tangible programming toys are discussed.

Introduction

There is broad consensus that tangible programming toys are powerful tools for young children learning to program, problem solve, and engage in a range of *computational thinking practices* (Bers, 2008; Hamilton et al., 2020; Wang et al., 2021a). One promising mechanism through which tangible programming toys support computational thinking is through what Seymour Papert called *body syntonicity*: Children are able to leverage knowledge of how their own bodies move and react, and use this embodied knowledge to engage in a wide variety of computational practices (Papert, 1980). Although there is increasing attention to the role of body syntonicity in learning to program and think computationally (e.g., Berland et al., 2011, Cho et al., 2017, Farris, 2021; Sung et al., 2017), little is known about the role teachers and other adults can play in supporting children's embodied forms of computational thinking with tangible programming toys.

In this paper, we demonstrate how teachers attend and respond to the seeds of computational thinking (K–12 Computer Science Framework, 2016) in preschoolers' (ages 3-4) embodied activity as children work with a tangible programming toy. To reveal the fine details of these instructional processes, we adopt an approach to interactional analysis inspired by ethnomethodology, conversation analysis, and Goodwin's co-operative action framework (2018). In particular, we illustrate how teachers purposefully take up, re-use, and transform learners' embodied ideas to focus, recontextualize, and decontextualize body syntonic knowledge to support students' engagement in the computational practices of problem decomposition, debugging, and abstraction. Overall, our investigation contributes to a better understanding of interactional mechanisms that support computational thinking in early childhood and the nuanced ways in which responsive teaching (Pierson, 2008; Robertson et al., 2016) is a multimodal, embodied phenomenon (Flood et al., 2020).

Background & Theoretical Framework

When children of all ages make sense of STEM ideas, they often use their bodies as meaning making resources to physically adopt the point of view of the phenomena under consideration and draw parallels through body syntonicity (e.g., Crowder, 1996; Keifert, 2019). Through this process, children act out and work through possibilities as if they were the phenomena, leading to important insights into how and why things behave the way they do. Notably, practicing scientists and mathematicians at the frontiers of discovery also use body syntonicity for thought experiments, taking on the viewpoint of and physically embodying abstract theoretical entities and phenomena (e.g., a super-heated crystalline lattice) they are trying to imagine (e.g., Ochs, 1996). Since Papert's seminal research, a number of studies have examined how students use body syntonicity to successfully program, problem solve, and develop computational thinking skills (e.g., Berland et al., 2011; Farris, 2021; Kopcha, 2021; Sung et al., 2017). Children engage in computational thinking practices with their bodies to break down complex problems into manageable parts (decomposition), identify common features to create generalizations (developing and using abstractions), and to recognize, find, and fix errors (debugging), among other practices (Papert, 1980; Berland et al., 2011; Fadjo et al., 2009; Kopcha et al., 2021; Wang et al., 2021b).

In the last decade, there has been an influx of tangible programming learning environments and tools specifically designed to capitalize on and support children's embodied engagement with computational problems (Yu & Roque, 2019). One increasingly popular type of tangible programming learning design includes toy animals and robots that can be programmed to navigate through and interact with the world. Examples include: BeeBot (a

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bee), Cubetto (a cube-shaped robot with a smiley face), Topobo (a dragon), and Code-a-pillar (a caterpillar), among others. These engaging toys have imaginary needs and desires, bodies, facial features, and ways of moving that children can physically relate to, and offer rich opportunities for computational thinking through body syntonicity. In addition to providing powerful playgrounds for computational thinking, tangible programming toys also foster mathematical thinking and learning, art and design skills, storytelling, and the development of fine motor skills (Bers, 2008; Bers et al., 2014).

However, despite the generally well-accepted role the body plays in sense-making while learning to program, there is still much unknown about how teachers can support children's use of body syntonicity to foster computational thinking. Our study joins recent investigations of how educators support students' embodied learning in STEM contexts such as makerspaces (e.g., Vossoughi et al., 2020; Vossoughi et al., 2021) and mathematics (e.g., Flood, 2018; Flood et al., 2020). In particular, we know little about how teachers are responsive to children's use of *body syntonicity* and how they take up and work with embodied knowledge in the classroom. In STEM education, *responsive teaching* involves eliciting, recognizing, and responding to children's ideas with potential disciplinary value or substance, and adapting instructional guidance to make use of these student contributions (Pierson, 2008; Robertson et al., 2016). When teachers take up and are responsive to the "seeds" of disciplinary STEM ideas and practices, it increases students' participation and promotes learning (e.g., Pierson, 2008). In this paper, we investigate what *embodied* responsive teaching (Flood et al., 2020) looks like in the case of preschoolers learning to program a tangible programming toy.

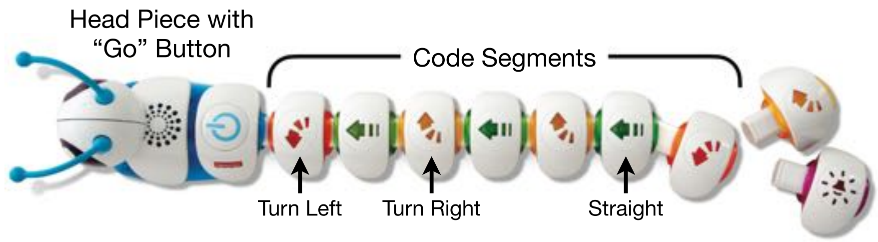
One powerful form of responsiveness is the use of *revoicing* where teachers take up, repeat, and reformulate the ideas children express (O'Connor & Michaels, 1993). Adults' revoicing (also known as recasting) plays important roles in how young children develop language and abstract concepts (Baker & Nelson, 1984; O'Connor & Michaels, 1993). In preschool classrooms specifically, revoicing is ubiquitous and accomplishes a number of functions including building linguistic skills, positively evaluating students' ideas, seeking clarification, and comparing and contrasting different ideas (Yifat et al., 2008). In particular, one of the most important functions of revoicing for all ages is the *reformulation* of learners' ideas, and the reflection of these reformulations back to students (Cazden, 2001; O'Connor & Michaels, 1993). Studies of classroom discourse have identified a number of ways that teachers reformulate the information students contribute. These include: (1*) focusing* students' contributions, where teachers will selectively revoice only parts of what students said, and omit parts that are incorrect or superfluous from a disciplinary perspective; (2) *recontextualizing* students' contributions, where the reformulation shifts or extends the scope of the original contribution, often making new connections with additional information or details that may have been omitted by the student and are relevant to the topic at hand; and (3) *decontextualization* where students' contributions are reformulated to be more general, all-encompassing, or less situated in the immediate, specific details of the situation or context compared to the original contribution (Cazden, 2001; O'Connor & Michaels, 1993).

To date, however, studies of revoicing and recasting have tended to investigate revoicing in speech and have paid less attention to how teachers attend and respond to children's embodied ideas. Drawing on Vygotsky, Goodwin (2018) argues that a fundamental feature of how people learn is through dialogic interactions where more capable others (parents, teachers, mentors, etc.) carefully attune to the bodily experiences of newcomers and are responsive to, take up, and reformulate *all* of the multimodal, embodied communicative resources (e.g., gesture, gaze, bodily demonstration) that newcomers make available when they share ideas or make proposals. Consistent with this perspective, recent work in STEM at the secondary level has demonstrated that teachers are responsive to how learners use their bodies to express and work through ideas multimodally; and they often selectively repeat, reformulate nonverbal resources like gesture or full-body demonstrations, in addition to what learners say (Alibali et al., 2019; Flood, 2018; Flood et al., 2020; Shein, 2012). Inspired by this recent work in secondary STEM education, our present study seeks to better identify and characterize how preschool teachers use embodied responsive teaching, and specifically, how they re-"voice" and reformulate learners' body syntonic engagement with computational problem solving as they work with a tangible programming toy.

Study Context & Methods

This study emerged from a broader investigation of how to support young children's computational thinking with a commercially available tangible programming toy: Fisher-Price's Think and Learn Code-a-pillar (https://www.youtube.com/watch?v=3d4zXauy6EM). As part of this study, a series of programming sessions with the Code-a-pillar were video recorded over 12 weeks at a university-affiliated preschool. Children worked in small groups to complete 15-minute programming challenges with the toy once or twice a week, guided by experienced classroom teachers. Twenty-two children and two teachers participated. The programming challenges involved "helping" the Code-a-pillar navigate to desired locations. The Code-a-pillar (named "Rapunzel" by the children) has color-coded interchangeable body segments that each provide a command: turn right, turn left, go straight, and play music (Figure 1). As part of each challenge, children engage in a range of computational thinking practices including defining computational problems (e.g., decomposing), developing abstractions (e.g., identifying patterns), and testing and refining programs (e.g., debugging). In each challenge, children spontaneously used their bodies to problem solve with the teachers' guidance.

Figure 1. *Code-a-pillar, a tangible programming toy with body segments that provide commands*



We reviewed the 12-week corpus in its entirety and located each instance where the teacher repeated or reformulated students' ideas that were expressed through gesture, demonstrative action with the Code-a-pillar, and/or full bodily activity (e.g., crawling through an obstacle course). Drawing on ethnomethodology, conversation analysis (EMCA, Mondada, 2012), and Goodwin's co-operative action framework (2018), we microanalyzed these interactional sequences to understand what multimodal, embodied resources students used to make proposals, and what aspects of these multimodal and embodied resources were repeated, omitted, or modified in teacher's subsequent revoicing turns. The goal of EMCA is to uncover and document the precise methods and resources participants use to negotiate and make meaning together (Mondada, 2012). Goodwin's co-operative action framework (2018) enriches EMCA by focusing on the embodied ways in which participants take up and transform each other's embodied, multimodal contributions (e.g., gesture, facial expression, prosody, talk, and so on). Each multimodal utterance a participant contributes is considered to be a substrate that can be broken down, reused, and reshaped in the process of co-constructing emergent new ideas and meanings together. Our findings emerged from the careful comparison of student and teacher turns.

For this paper, we selected one focal lesson involving three different groups of children to illustrate three representative cases of how teachers can be responsive to children's body syntonicity through (1) focusing, (2) recontextualizing, and (3) decontextualizing embodied proposals to support the computational thinking practices of (1) problem decomposition, (2) debugging, and (3) abstraction, respectively. We created detailed transcriptions of participants' body movements, gesture, speech, gaze, facial expressions, and vocalizations using conventions adapted from conversation analysis and Goodwin (2018): degree signs for quiet speech (°°); capitals for louder speech; question marks for rising intonation (?); periods (.) for falling intonation; timed pauses appear in parentheses (2.5); colons denote elongated syllables (::); and square brackets show overlapping actions ([ ). Embodied actions are illustrated and co-timed speech is outlined with boxes.

Findings

Throughout the 12 weeks, children spontaneously used their bodies to take the perspective of the Code-a-pillar to complete each programming challenge. The teacher was responsive to students' use of body syntonicity and in almost every case, re-"voiced" students' contributions. Our analysis breaks down students' embodied contributions and the teachers' multimodal revoicing turns to demonstrate how the teacher engages in (1) focusing, (2) recontextualizing, and (3) decontextualizing their embodied proposals. We present a representative example below for each of these forms of embodied responsive teaching. In the focal lesson, children have been tasked with a programming challenge to "help" the Code-a-pillar navigate a path surrounded by wood blocks (The Wood Course) and a path made of green tape (The Green Tape Course) to reach targets at the end of each path (Figure 2). During this challenge, a number of opportunities for computational thinking arise. As children work together to complete the task, they must break down the complex spatial trajectory of The Wood Course and The Green Tape course into a series of discrete steps (decomposition) and select appropriate segments for Code-a-pillar. If Code-a-pillar deviates from the course, they must recognize there is a problem, locate the segments that are responsible, and develop an alternative solution (debug). Finally, students are also asked to notice and investigate patterns that arise for their potential to simplify or aid with the planning process (abstraction).

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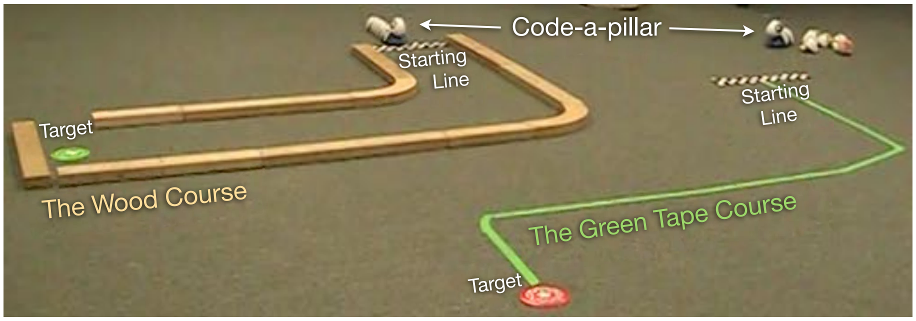
Figure 2. *The challenge: program Code-a-pillar to reach the targets at the end of each course*

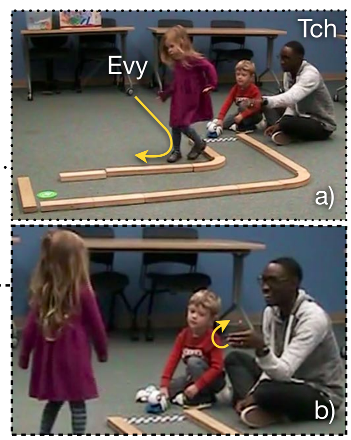


Focusing embodied proposals to support body syntonic decomposition

In Excerpt 1, Evy, Cal, and the teacher are working on helping Rapunzel the Code-a-pillar navigate The Wood Course to reach the green target at the end. To "help" Code-a-pillar navigate the curved path to her target, children must decompose a continuous spatial route into discrete programmable steps. Then, they must attach body segments with commands such as go straight, turn left, and turn right in the appropriate sequence. Decomposition involves breaking down complex problems into smaller or more manageable parts (Shute et al., 2017). In this case, Evy, Cal, and the teacher have already attached a straight segment to Rapunzel and are now examining the course and deciding what to do next. Evy uses her whole body to make a proposal by walking the path: Taking the Code-a-pillar's perspective, she begins from the starting line, strides forward, and then rotates her whole body to the right where the track curves, as if she is Rapunzel the Code-a-pillar (E1.a). As she turns, she raises her arms up and points her hands forward. During the full-body turn, she shouts "left" (E1.05). Her suggestion, from start to finish, is performed in one continuous, fluid motion.

Excerpt 1. *Which Way?*

```
01 Tch: And then which way does Rapunzel need to turn,
02      [after she goes straight.
03 Evy: [((walks straight))
04      ((turns right))
05      LEFT!
06      (0.9)
07 Tch: Or [right
08         [((curves and waves hand to the right))
09      [(0.3)
10 Evy: [°Ri::ght°
11 Tch: Right. But you got the right idea,
12      yeah right, so put on the next piece.
```



Evy's suggestion uses body syntonicity to make a proposal for how to navigate the beginning of The Wood Course and thus contains productive beginnings of decomposition. However, although Evy enacts a right turn, her proposal for what to do next is ambiguous because her bodily activity does not clearly separate the first step (a straight) from the second step (a right turn). When working with Code-a-pillar, children sometimes don't recognize that certain distances will likely correspond with more than one command. Although unclear from her actions, it is possible Evy believes a single turn segment would be sufficient to navigate Code-a-pillar to where she walked to. In addition, Evy's suggestion contains a mismatch in speech and bodily activity (Alibali et al., 1993), since she describes the right turn she enacts as a "left" (E1.05).

The teacher is responsive to Evy's body syntonic proposal for the Code-a-pillar: He takes up and reformulates the proposal to highlight the aspects of decomposition that it embodies. By carefully attending to her embodied proposal, the teacher is able to see that Evy has productive embodied knowledge about the situation, despite the mismatch between her speech and bodily activity, and the potential inclusion of an extra step (the straight). He selectively repeats just one part of Evy's embodied proposal by curving and waving his hand to the

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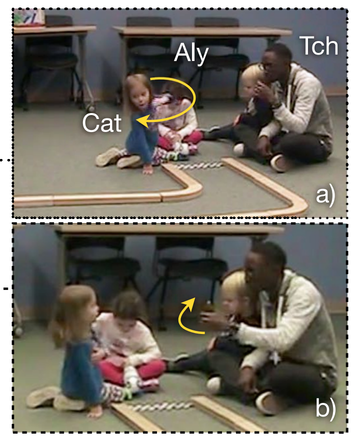
right. This simplification focuses attention on the right turn and not the straight motion. As he re-creates the right-turn motion, he also describes it as a "right" turn (E1.07). Omitting superfluous and ambiguous aspects of the multimodal contribution reinforces a productive direction for the decomposition of the problem: The next step after the straight already added is a right turn. Thus, although Evy's original embodied proposal visually contained two steps (straight and right), the teacher provides a narrower focus to help the children decide on the next step. Evy takes up the teachers' reformulation and repeats "right" (E1.10), and working with Cal, they attach a right turn segment.

Recontextualizing embodied proposals to support body syntonic debugging

In Excerpt 2, Cat, Aly, Ted and the teacher are working to help the Code-a-pillar reach the target in The Wood Course. Currently, the Code-a-pillar has a straight segment, two right turn segments, and another straight segment attached. The group has sent Code-a-pillar for a test run, and during the run, the Code-a-pillar runs into the wooden boundary. As the children simultaneously grab the Code-a-pillar to start pulling off body segments, the teacher asks them to consider what the second-to-last segment (referred to as "it" in E2.01) made the Code-a-pillar do to help them debug their current set of commands. Debugging describes the processes of recognizing, finding, and fixing errors in computer programs. In order to detect, locate, and resolve the bugs that arise with Code-a-pillar's programmed routes, preschoolers must first recognize discrepancies between the program's behavior and the desired outcome (e.g., Code-a-pillar deviates from the desired path), then isolate the problematic command segment(s), and successfully replace them with segments that will cause the desired result.

Excerpt 2. *The Crash*

```
01 Tch: What did it make her do?
02 Aly: Str[ai::ght?
03 Cat:    [Cwra:::sh.
04         [((twists torso clockwise,
05            reaches left hand around right shoulder))
06 Tch: It makes her [crash
07                   [((thrusts hand quickly to the right))
08      into that block. Yeah. Okay.
09 Aly: ((removes second segment))
```



To answer, Aly says "straight" (E2.02), and Cat makes a different embodied proposal (E2.a). Her upper body moves as if she is the Code-a-pillar, in the same direction that Code-a-pillar makes the problematic turn into the barrier. She twists her whole torso towards the location where the Code-a-pillar struck the wooden track, and she also stretches her right arm across her body, twisting her right hand past her left shoulder to point at the crash site. As she turns, she gazes towards the exact location where the collision occurred. To make this turning motion and twist her arm around, she contorts her body in a way that appears uncomfortable, which may be an attempt to illustrate the discomfort, awkwardness, or the undesirability of the situation. As she moves, she says "cwrash" (E2.03). Cat's bodily activity provides important information that is not captured in her speech about the location of the crash and the undesirable nature of the situation. In particular, exactly where along the track the collision occurred is valuable information that has the potential to help them locate and confirm the source of the bug, and decide which of the segments (the end piece or an earlier piece) was responsible for the undesirable outcome.

The teacher takes up Cat's embodied proposal and is responsive to the productive beginnings of debugging that it contains. He *recontextualizes* this proposal by extending and reconnecting the undesirable outcome Cat embodies with its *cause.* With his hand, he transforms Cat's embodied twist into a quick jerking motion to the right, depicting the direction of the crash. The quick speed of his hand motion preserves Cat's depiction of its undesirable nature (E2.b). While his gesture depicts the right turn that results in the crash, the teacher's speech *extends the context* of Cat's contribution and links the undesirable outcome (the crash into a particular part of the wooden track) back to the specific code segment they are discussing. He performs this extension by adding "it" (which *ties* the idea back to the second segment; Goodwin, 2018) "makes her" (which adds the *causal link*) (E2.06). This addition also clarifies the agency involved in the crash: It is the programmer's choice of commands that is responsible for the error, not the Code-a-pillar herself, and the faulty command can be isolated and changed by the children. Overall, this additional information recontextualizes Cat's proposal in the specific details of the situation – the reason for the crash – and implies a potential fix, which are all important aspects of the debugging processes. Although Cat does not immediately respond, Aly, who is holding the Code-a-pillar, demonstrates her understanding of the recontextualized proposal and removes the problematic segment.

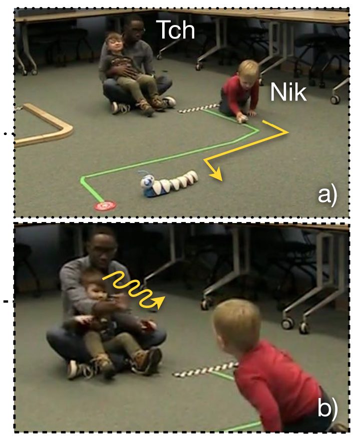
Decontextualizing embodied proposals to support body syntonic abstraction

In Excerpt 3, Nik, Pat, and the teacher are working to help the Code-a-pillar navigate to the target at the end of The Green Tape Course. After some trial and error, they eventually program a route where the Code-a-pillar mostly stays on the green tape and ends up very close to the target. The teacher asks the children to reflect on this route, and asks what they have done to get Code-a-pillar near the target. Nik answers, grabbing a spare Code-a-pillar segment and tracing it along the Green Tape Course where the Code-a-pillar traveled (E3.a). As he traces, he also crawls the path and narrates the processes, starting with "She went this way" (E3.01). As he makes each turn, he narrates with the same sound effect "zoom" (E3.02, E3.04). When he gets to the end of the route, he changes the sound effect to "vroom," (E3.06) pretending to connect the segment he is holding to the Code-a-pillar.

Nik's embodied proposal is body syntonic and adopts the point of view of the Code-a-pillar as he crawls through the course, demonstrating the specific ways the Code-a-pillar moved to get to where she is. His embodied idea contains productive beginnings of *abstraction*: He uses the word "zoom" to punctuate *both* the left turn and the right turn, marking them as similar, and potentially, as members of the same category (or type of thing).

Excerpt 3. *Keep Turning!*

```
01 Nik: She went this way
02      [°zoom°
03      [((turns segment and crawls right))
04        [°zoom°
05        [((turns segment and crawls left))
06      [and vroom.
07      [((pretends to add segment to caterpillar))
08 Tch: So you added on
09      [different pieces that helped her keep turning
10      [((turns hand back and forth))
11      to the food.
12      ((turns hand back and forth again))
13 Nik: Yeah.
14 Tch: Yeah.
```



The teacher is responsive to Nik's embodied proposal and the potential elements of abstraction it presents. He takes up and re-"voices" the proposal, but modifies it in a way that *decontextualizes* it and increases the level of abstraction: While Nik's full-body enactment through the course is environmentally-coupled (Goodwin, 2018) and preserves the precise *location* and *direction* of the left and right turns, the teacher uses a more general gesture, turning his hand back and forth left and right, to represent the *general* case of turns (which can be in either direction). In speech, he provides a more generalized description of what helped the Code-a-pillar get to the target: "keep turning" (E3.09). He also re-emphasizes the causal connection (i.e., adding the code segments) and the children's agency in the process.

Computational problem-solving processes can be simplified by recognizing patterns and similarities within and across situations. Nik's original proposal is situated in the specific context and details of their last run of the Code-a-pillar on The Green Tape Course. Identifying common features in complex scenarios (e.g., the *turns* in a winding course with several left and right turns) is an important aspect of pattern finding and abstraction. To support the children's abstraction and pattern finding, the teacher's reformulation extracts relevant, common information from Nik's proposal and recasts it with less detail. After the reformulation, Nik agrees with the teacher's generalized version of his proposal (E3.13).

Concluding remarks, significance, and implications

By closely examining the ways in which teachers take up and respond to preschoolers' *body syntonic* problem solving with the Fischer Price Code-a-pillar, this study helps to expand our understanding of embodied responsive teaching practices and strategies teachers can use to support children's engagement in computational thinking. In particular, we showed how a teacher attended and responded to the productive beginnings of problem decomposition, debugging, and abstraction present in children's embodied problem solving. To be responsive, teachers can reformulate children's embodied proposals by (1) focusing them, (2) recontextualizing them, and (3) decontextualizing them, which each can respectively support different computational thinking practices.

In each case, elements of the spatio-dynamic and kinesthetic information children shared with their bodies were preserved by the teacher's use of gesture. This provided a visual, embodied bridge for the children to see connections between their original idea and the teacher's reformulation. This process is congruent with the mechanism Vygotsky (1986) proposed for how interactions between adults and children drive learning and development: It provides an arena for spontaneous, intuitive interpretations of the world (e.g., those that arise from body syntonic experiences) to grow together with cultural and academic concepts. By reformulating children's embodied proposals, teachers may help children reconcile body syntonic intuitions and interpretations with specific cultural and disciplinary ways of organizing the world and approaching problems (e.g., in computer science, processes of decomposition or abstraction). In addition, reflecting these embodied ideas back to children may provide them with important opportunities for increased examination of their own ideas (Flood et al., 2020).

In particular, we argue that understanding how teachers support young children's learning with tangible programming toys requires careful attention to bodily activity and multimodal resources. By attending and responding to body syntonicity, teachers are able to shape the computational thinking that emerges through this physical activity. Our study demonstrates how a focus on speech alone would provide an incomplete picture of the nature of the instructional support in these settings. In addition, understanding children's embodied learning in this setting is irreducible to each child's isolated, individual ideas. Instead, it is necessary to expand the unit of analysis for learning with tangible programming toys to the broader interactional context. Our investigation joins other recent approaches in the learning sciences (e.g., Farris, 2021; Vossoughi et al., 2020; Vossoughi et al., 2021; Wang et al., 2021b) to show how the intricacies of computational thinking practices can be distributed across participants' bodies and co-constructed between preschoolers and teachers. We demonstrated how Goodwin's co-operative action framework (2018) provides a powerful analytic approach for illuminating the embodied nature of responsive teaching that may otherwise go overlooked: The multimodal microanalysis of interaction provides a powerful tool to understand the nuanced ways in which teachers take up, re-use, and transform students' embodied utterances during programming sessions.

Notably, teachers' abilities to be responsive to young children's embodied computational thinking also suggests that children need not have sophisticated vocabulary and language skills as a prerequisite for meaningful engagement in practices like abstraction, decomposition, and debugging. As computer science, programming, and computational thinking are increasingly being introduced in early childhood, teachers sometimes feel unprepared to teach these areas to young children. Our study illustrates how teachers can adapt techniques from their existing repertoire of teaching practices (e.g., revoicing) in embodied ways to support children's computational thinking. In addition, creating professional development to support teachers to recognize and embrace early learners' embodied forms of computational thinking may be especially important since, historically, embodied competencies and ways of knowing have been delegitimized in STEM spaces (Takeuchi et al., 2019).

One limitation of our study is that we cannot know from our current investigation how these embodied responsive teaching practices impact longitudinal learning outcomes surrounding computational thinking. As Cazden (2001) notes, any one instance of revoicing where focusing, recontextualization, or decontextualization occurs is not likely to result in mastery of academic topics or practices. However, Cazden argues that continuous engagement with adults, in which children's ideas are frequently taken up, reformulated, and reflected back to them, provides a powerful sociocultural mechanism for learning through socialization. Given the well-established importance of body syntonicity in children's development of computational thinking, more research is needed to understand how embodied responsive teaching supports children's computational thinking and what impact this has over time.

References

Alibali, M. W., & Goldin-Meadow, S. (1993). Gesture-speech mismatch and mechanisms of learning: What the hands reveal about a child′ s state of mind. *Cognitive psychology*, *25*(4), 468-523.

Alibali, M.W., Nathan, M.J., Boncoddo, R., Pier, E. (2019) Managing common ground in the classroom: teachers use gestures to support students' contributions to classroom discourse. *ZDM, 51,* 347–360.

Baker, N. D., & Nelson, K. E. (1984). Recasting and related conversational techniques for triggering syntactic advances by young children. *First Language*, *5*(13), 3-21

Berland, M., Martin, T., Benton, T., & Petrick, C. (2011). Programming on the move: Design lessons from IPRO. In *CHI'11 Extended Abstracts on Human Factors in Computing Systems* (pp. 2149-2154).

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72*, 145-157.

 © ISLS

Cazden, C. B. (2001). *Classroom discourse: The language of teaching and learning.* Heinemann.
Cho, E., Lee, K., Cherniak, S., & Jung, S. E. (2017). Heterogeneous Associations of Second-Graders' Learning in Robotics Class. *Technology, Knowledge and Learning, 22*(3), 465–483.
Crowder, E. M. (1996). Gestures at work in sense-making science talk. *JLS*, *5*(3), 173–208.
Fadjo, C. L., Lu, M. T., & Black, J. B. (2009). Instructional embodiment and video game programming in an after-school program. In *EdMedia+ Innovate Learning* (pp. 4041-4046). Association for the Advancement of Computing in Education (AACE).
Farris, A. (2021). Voicing code in STEM: A Dialogical Imagination. MIT Press.
Flood, V. J., Shvarts, A., & Abrahamson, D. (2020). Teaching with embodied learning technologies for mathematics: Responsive teaching for embodied learning. *ZDM Math Education, 52*(7), 1307- 1331.
Flood, V. J. (2018). Multimodal revoicing as an interactional mechanism for connecting scientific and everyday concepts. *Human Development*, *61*(3), 145-173.
Goodwin, C. (2018). *Co-operative action*. Cambridge University Press.
Hamilton, M., Clarke-Midura, J., Shumway, J., & Lee, V. R. (2020). An emerging technology report on computational toys in early childhood. *Technology, Knowledge and Learning, 25*, 213-224.
K–12 Computer Science Framework. (2016). Retrieved from http://www.k12cs.org.
Keifert, D., & Stevens, R. (2019). Inquiry as a members' phenomenon: Young children as competent inquirers. *Journal of the Learning Sciences*, *28*(2), 240-278.
Kopcha, T. J., Ocak, C., & Qian, Y. (2021). Analyzing children's computational thinking through embodied interaction with technology: a multimodal perspective. *Educational Technology Research and Development*, *69*(4), 1987-2012.
Mondada, L. (2012). The conversation analytic approach to data collection. In J. Sidnell & T. Stivers (Eds.), *The handbook of conversation analysis* (pp. 32–56). Blackwell Publishing Ltd.
O'Connor, M.C., & Michaels, S. (1993). Aligning academic task and participation status through revoicing: Analysis of a classroom discourse strategy. *Anthropology and Education*, *24*, 314–318.
Ochs, E., Gonzales, P., and Jacoby, S. (1996). "When I come down I'm in the domain state": Grammar and graphic representation in the interpretive activity of physicists. In *Interaction and Grammar (*pp. 328–369). Cambridge University Press.
Papert, S. (1980). *Mindstorms: Children, computer, and powerful ideas.* New York: Basic Books.
Pierson, J. L. (2008). *The relationship between patterns of classroom discourse and mathematics learning*. The University of Texas at Austin. Doctoral Dissertation.
Robertson, A. D., Scherr, R. E., & Hammer, D. (Eds.). (2016). *Responsive teaching in science and mathematics* (pp. 1-35). New York, NY: Routledge.
Shein, P. (2012). Seeing with two eyes: A teacher's use of gestures in questioning and revoicing to engage English language learners in the repair of mathematical errors. *JRME*, *43*, 182–222.
Sung, W., Ahn, J., & Black, J. B. (2017). Introducing computational thinking to young learners: Practicing computational perspectives through embodiment in mathematics education. *Technology, Knowledge and Learning, 22*(3), 443-463.
Takeuchi, M.A. & Dadkhahfard, S. (2019). Rethinking bodies of learners through STEM education. In P. Sengupta., M-C. Shanahan., & B. Kim (Eds.). Critical, transdisciplinary and embodied approaches in STEM education (pp.199–216). Springer.
Vossoughi, S., Davis, N. R., Jackson, A., Echevarria, R., Muñoz, A., & Escudé, M. (2021). Beyond the binary of adult versus child centered learning: pedagogies of joint activity in the context of making. *Cognition and Instruction*, 39(3), 211-241.
Vossoughi, S., Jackson, A., Chen, S., Roldan, W., & Escudé, M. (2020). Embodied pathways and ethical trails: Studying learning in and through relational histories. *Journal of the Learning Sciences*, 29(2), 183-223
Vygotsky, L.S. (1986). *Thought and language*. (A. Kozulin, Ed.). MIT Press.
Wang, X. C., Choi, Y., Benson, K., Eggleston, C., & Weber, D. (2021a). Teacher's role in fostering preschoolers' computational thinking: an exploratory case study. *Early Education and Development*, *32*(1), 26-48.
Wang, X. C., Flood, V. J., & Cady, A. (2021b). Computational Thinking through Body and Ego Syntonicity: Young Children's Embodied Sense-Making Using a Programming Toy. In de Vries, E., Hod, Y., & Ahn, J. (Eds.), *Proceedings of the 15th International Conference of the Learning Sciences - ICLS 2021*. (pp. 394-401). Bochum, Germany: ISLS.
Yifat, R., & Zadunaisky-Ehrlich, S. (2008). Teachers' talk in preschools during circle time: The case of revoicing. *Journal of Research in Childhood Education*, *23*(2), 211-226.
Yu, J., & Roque, R. (2019). A review of computational toys and kits for young children. *International Journal of Child-Computer Interaction*, *21*, 17-36.