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"My Cars don't Drive Themselves": Preschoolers' Guided Play Experiences with Button-Operated Robots

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Abstract
Computational thinking (CT) is considered an essential literacy skill for all children to develop, yet conceptual, practical, and empirical work with preschool-age children is scarce. A particular gap in the research is how CT instruction should be enacted (e.g., free play, guided play, levels of scaffolding, degree of child-initiated activities, and structure of programming tasks). Therefore, we aimed to describe what preschool children's CT experiences are like when button-operated robots are introduced into their guided play. This interpretive phenomenological study applied the Mosaic Approach to explore the emergence of CT skills during guided play with a button-operated robot (Bee-Bot). Participants were 29 preschool-age children from an early childhood education center in the northeastern United States. Data sources included audio-visual recordings, observations, child focus groups, and child-generated artifacts. The findings suggest children constructed meaning across the CT dimensions, connected with others through dialogue and negotiation, and used guidance from adults to extend their learning.

Keywords Computational thinking · Button-operated robot · Phenomenology · Early childhood education · Preschool education · Guided play · Mosaic Approach

Introduction

There is growing global interest in computer science curricula in early childhood education (Wood et al., 2020), particularly in relation to computational thinking (CT). Broadly, CT is a set of skills, habits, and dispositions used to formulate and solve problems (Bers et al., 2019). To broaden and sustain CT participation, scholars have proposed strategies such as integrating CT in earlier grades (Cortesi et al., 2020), expanding collaborative computing opportunities (Fields et al., 2015), and attending to the distinctive needs of diverse learners (Angeli & Valanides, 2020). Introducing CT in preschool classrooms may foster more equitable participation in computer science education and support development of essential skills, but it is yet unclear how young children engage with educational robots and what they learn through these experiences (Jung & Won, 2018). Therefore, this study sought to explore what preschool children's CT experiences are like when button-operated robots are introduced into their guided play.

Technology and Toys in Early Childhood Education

Near the turn of the millennia, educational technology research and practice in early childhood settings were primarily focused on meaningful and appropriate uses of desktop computers (Jack & Higgins, 2019; Plowman & Stephen, 2003). Plowman et al.'s (2010) extensive research on preschool children's play with computers demonstrated three primary areas in which technology supports learning (i.e., subject area knowledge, operational skills, and dispositions to learn). Play remains a powerful path for learning with technologies (Mehta et al., 2020; Resnick, 2018), and guided interaction from adults has been established as a critical support for young children's leaning with technologies in both home and preschool settings (Plowman & Stephen, 2005; Plowman et al., 2008). Although definitions of technology

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in early childhood settings have adapted to the ubiquitous nature of computing, tangible interfaces, anthropomorphic toys, and emerging robotics (National Association for the Education of Young Children [NAEYC], 2020), the crucial role of practitioners' direct and indirect guidance has remained essential to supporting children's play and positive engagement with technology (Stephen & Plowman, 2013).

Following the increased attention on CT in early childhood education (Manches & Plowman, 2017; Rich et al., 2019), there has been a proliferation of technologies designed to engage young children in play-based activities that will facilitate their CT development (Ching et al., 2018). Coding applications (Papadakis, 2020) and a variety of robots (e.g., button-operated, screen-based, blended, tangible interfaces)(Hamilton et al., 2020) have been common computational tools introduced in preschool settings (McCormick & Hall, 2021; Ching et al., 2018). For example, preschool children have learned coding skills by playing the Scratch Jr. coding application alongside a parent (Sheehan et al., 2019). Sheehan et al.'s (2019) results highlighted that adult's proximal guidance were key contributors to children's learning. In a different study, five-to-six-year-old children who participated in robotics activities with Bee-Bots demonstrated significant learning gains in both computational thinking and spatial relations (Angeli & Valanides, 2020). Finally, Wang et al. observed preschoolers engaging in perseverance, collaboration, and communication during scaffolded CT activities with the Code-a-pillar (Wang et al., 2021). These studies, therefore, illustrate the growing evidence for the potential of computational toys and play to support a range of learning outcomes in preschool settings and elucidate their growing popularity (McCormick & Hall, 2021; Plowman et al., 2010).

While the introduction of CT in preschool classrooms through robotics and early programming continues to expand (Wood et al., 2020; Yu & Roque, 2019), research on how to design and facilitate developmentally appropriate CT experiences is yet emerging (Manches & Plowman, 2017; Wang et al., 2021). Scholars have examined what CT concepts, skills, and perspectives to teach (e.g., sequences, events, loops, debugging, and expressing), but discussion ensues about how CT instruction should be enacted (e.g., free play, guided play, levels of scaffolding, degree of child-initiated activities, and structure of programming tasks) (Bers, 2018, 2019). Research on how to design CT experiences for young children is needed to ensure programs effectively support diverse learners with developmentally appropriate approaches (McCormick & Hall, 2021; Wang et al., 2021). Moreover, Jung and Won (2018) underscored the dearth of research on "the processes of young children's robotics learning (p. 10)." Considering this gap in research, the next section overviews the theoretical foundations of robotics education and the connection to research in early childhood settings.

Foundations of Educational Robotics

Constructivism and constructionism are regarded as the theoretical undergirding of educational robotics (Anwar et al., 2019; Papert & Harel, 1991; Piaget, 1954). In their systematic review, Jung and Won (2018) observed that scholars still employ these two frameworks more frequently than any others when designing and implementing robotics curricula in elementary and preschool settings. Furthermore, the most commonly cited benefits of robotics education with young children—its "process-oriented activity and the sensory-engaged process" (Jung & Won, 2018, p. 10)—are grounded in constructivist and constructionist perspectives. Thus, scholars have recurrently linked these theories' fundamental assertions with the proposed affordances of robots (McCormick & Hall, 2021).

Key tenets of constructivism are that leaners actively construct knowledge through interactions with their environment and by connecting new information with prior knowledge, experiences, beliefs, and attitudes (Anwar et al., 2019; Kimmons, 2018; Lenters, 2013). Based on constructivism, researchers have noted the importance of authentic computational tasks (Kanaki & Kalogiannakis, 2018), peer interactions in the process of solving robotics-related problems (Anwar et al., 2019), and the critical role of a child's environment—an environment in which a robot can be perceived as a problem-solving tool or a humanoid partner (Mazzoni & Benvenuti, 2015).

Closely aligned with the external, iterative, and physical processes of learning characterized by educational robotics (Anwar et al., 2019), a constructionist approach to learning values the creation of real-world artifacts to support the construction, refinement, and expression of knowledge (Ackermann, 2001; Kimmons, 2018). Early examples of constructionism and educational robotics were young children using the LOGO programming language to code floor robots (Logo Foundation, 2015). Based on constructionist notions, scholars have designed early childhood robotics curricula (Bers et al., 2014), developed frameworks for assessing CT (Brennan & Resnick, 2012), and proposed multidisciplinary approaches to robotics integration (Monteiro et al., 2021). Discussed in the next section, these foundations are evident in the conceptual frameworks which guided this study.

Conceptual Frameworks

This study's overarching research goal was to examine preschool children's CT experiences when button-operated robots are introduced into their guided play. Three conceptual frameworks informed various parts of the study, from the design of the guided play experiences to the collect and analysis of data implementation, data collection, and analysis: 1) integrating computational thinking through a constructionist perspective, 2) designing play-based experiences, and 3) participatory, multi-method approaches to researching *with* children—Mosaic Approach. Each of these frameworks and their pertinence to this study will be discussed in the succeeding sections.

Computational Thinking Framework: Concepts, Practices, and Perspectives

Viewed as important for all learners (Rich & Hodges, 2017), the International Society for Technology in Education has defined CT as "strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions" (2016). Common CT strategies include algorithmic thinking, decomposition, pattern recognition, and abstraction (Hunsaker, 2018). Previous research of early childhood CT has indicated that engagement with CT experiences promotes important cognitive skills such as analytical problem-solving, visual memory, language skills, and number sense (Sullivan et al., 2013).

Brennan and Resnick's (2012) framework, informed by a constructionist philosophy of learning and used to ground this study's conceptualization of CT, categorizes CT along dimensions of concepts, practices, and perspectives. While concepts (e.g., sequences and events) and practices (e.g., debugging and iterating) have been initially examined in preschool settings (Murcia & Tang, 2019; Saxena et al., 2020), few studies have investigated how young children develop or evidence CT perspectives of expressing, connecting, and questioning (McCormick & Hall, 2021). These perspectives are critical to children's "understandings of themselves, their relationships to others, and the technological world around them" (Brennan & Resnick, 2012, p. 9). Given the importance of CT perspectives, practices, and concepts, this study sought to explore how preschool children experienced and made sense of these dimensions when button-operated robots were introduced into their guided play.

Guided Play Experiences

Young children are natural explorers whose optimal growth and development necessitates high-quality early learning environments that utilize play-based experiences (NAEYC, 2020). Through these experiences, children gain critical social and emotional skills, as well as the ability to hone their language, physical, and cognitive abilities (Golinkoff et al., 2006; Han et al., 2010). Thoughtfully planned guided play experiences balance child autonomy and adult scaffolding toward a learning goal (Pyle & Danniels, 2017; Weisberg et al., 2016). These types of activities are considered a developmentally appropriate approach to teaching and learning in preschool settings (NAEYC, 2020). In contrast to completely child-controlled play (i.e., "free play"), guided play maintains the child-driven nature of free play and integrates age-appropriate learning outcomes into the experience (Weisberg et al., 2016). Therefore, to investigate young children's CT experiences, we employed a guided play approach that allowed children to be self-directed and semi-autonomous in their play with age-appropriate button-operated robots.

Researching with Children Through the Mosaic Approach

Children are competent meaning-makers who actively engage with their learning environments, particularly when those learning environments are play-based (Weisberg et al., 2016). A qualitative research lens emphasizes children's voices and lived experiences when new technologies are introduced (Angeli & Valanides, 2020; Cilesiz, 2011; Newhouse et al., 2017). To highlight and value children's experiences when investigating a play-based approach to CT, the researchers in this study used an interpretive phenomenological design (Valentine et al., 2018; van Manen, 2014), gathered data according to the Mosaic Approach (Clark & Moss, 2011), and analyzed the data using a live coding approach (Parameswaran et al., 2020).

The Mosaic Approach is a multi-method research framework that positions children as competent social participants who are co-constructors in the process of meaning-making in early childhood spaces (Clark & Moss, 2011; McCormick, 2018). The approach includes multiple tools for seeking and representing the voices of children (e.g., observation, interviewing, photography, tours, and child-generated artifacts). Since young children convey their thoughts in numerous, diverse ways, the Mosaic Approach privileges numerous modes of communication, beyond verbalized speech. This allows children who are emerging speakers to represent their thinking in diverse ways (e.g., representing thought through play, depiction, manipulation of objects, dramatic enactment, etc.) (Clark, 2005). Since this study explored preschool-age (ages 3–5) participants' experiences with a button-operated robot, a multi-method data gathering approach was necessary.

Methodology

The study used a qualitative, phenomenological research design to address the research question. Given the limited literature background on CT experiences in play-based settings (McCormick & Hall, 2021), a qualitative approach that was descriptive and interpretive in nature was most fitting

Table 1 Participant demographics

Bluebird Classroom				Meadowlark Classroom			
Participant	Name	Age	Gender	Participant	Name	Age	Gender
1	Remy	3 years	F	1	Erin	3 years, 8 months	F
2	Clara	3 years, 1 month	F	2	Lily	3 years, 8 months	F
3	Caroline	3 years, 2 months	F	3	Mia	3 years, 8 months	F
4	Henry	3 years, 2 months	M	4	Penelope	3 years, 8 months	F
5	Connor	3 years, 2 months	M	5	Olivia	4 years, 1 months	F
6	Abe	3 years, 2 months	M	6	Jade	4 years, 2 months	F
7	Daniel	3 years, 5 months	M	7	Chloe	4 years, 3 months	F
8	Mattie	3 years, 6 months	F	8	Lola	4 years, 3 months	F
9	Keenan	3 years, 6 months	M	9	Rob	4 years, 4 months	M
10	Brenden	3 years, 6 months	M	10	Harper	4 years, 6 months	F
11	Jamison	3 years, 7 months	M	11	Jackson	4 years, 8 months	M
12	Bailey	3 years, 9 months	F	12	Hudson	4 years, 8 months	M
13	Hugh	3 years, 10 months	M	13	Sophia	4 years, 9 months	F
14	Emanuel	3 years, 11 months	M	14	Seth	4 years, 10 months	M
				15	Jonathan	4 years, 11 months	M

to achieve the study's aims. Since the study focuses on children's meaning-making around CT experiences, an interpretive phenomenological orientation was warranted. Interpretive phenomenology acknowledges the complex lifeworlds of individuals and emphasizes intersubjective understanding among participants and researchers (Valentine et al., 2018; van Manen, 2014). Rather than attempt to bracket researcher assumptions and experiences, as seen in the descriptive tradition (Cilesiz, 2011), interpretive phenomenological approaches embrace the researcher's role and positionality in making sense of a shared experience (van Manen, 2014).

Setting & Participants

The study was conducted with an early childhood education center located in the northeastern United States during fall 2019. The center is nationally accredited through the NAEYC and serves as a professional development school site for the local university's teacher education program. The participants included 29 three-to-five-year-old children from two preschool classrooms at the center (the Bluebird[1] and Meadowlark classrooms). There were 15 female and 14 male participants. Individual participant details in each classroom are provided in Table 1. Participants' parents or guardians provided consent on behalf of their child prior to the start of the study. Children provided verbal assent prior to participating in each guided-play experience.

The classrooms included a lead teacher and teaching assistant. To gain a better understanding of the environment, researchers met individually with the lead teachers and toured both rooms prior to the study. Throughout the room, teachers created spaces for a range of centers (e.g., art table, block area, math and science, dramatic play, group meeting rug) and viewed their role as managing groups of activity. Teachers described their approach to curriculum as "super open, …very open-ended" and "kid-centered." While they noted adapting the curriculum to fit students' needs each year, social skills were often a key learning goal from which academic and physical skills were integrated. The teachers had not used robots with the children before and commented that technology was minimally used in their classrooms. One teacher shared that a single desktop computer which they had previously used to watch educational videos had been removed from the classroom in anticipation of replacing it with a newer device that had a larger monitor. Although this was the only technology students interacted with in the classroom, teachers used tablets and an application for observing students' progress and communicating with parents. While describing their teaching approach as "very unplugged," teachers shared their belief that children were gaining abundant digital experiences in the home and were hesitant of incorporating too much screen time with this age group.

Data Collection & Analysis

Data sources were informed by the Mosaic Approach (Clark & Moss, 2011) and included photographs, video, child conferences, child-generated artifacts, and researcher observations (see Table 2). Each data source was considered to hold equal weight in its potential to represent young children's experiences. Prior to analysis, all audio data were transcribed

[1] All classrooms and participants were assigned pseudonyms.

Table 2 Data sources by classroom

	Bluebird Classroom	Meadowlark Classroom
Photographs	79 images	82 images
Videos	1 h, 38 min	1 h, 31 min
Focus Groups	4 interviews (1 h, 34 min)	4 interviews (2 h, 49 min)
Artifacts	2 Bee-Bot murals	2 Bee-Bot murals

and other raw data (i.e., photographs, videos, child-generated artwork, and observation notes) were cleaned and uniformly formatted. Initial codes and themes were developed using the photographs and observation notes. Video analysis followed a live coding approach (Parameswaran et al., 2020), which involved directly coding video recordings rather than coding transcribed text of video data. The authors first identified key video segments from the video recordings. Then, both authors simultaneously watched/listened to the key recordings and transcribed non-verbal cues (e.g., gestures, body positioning, utterances) and verbal speech. Following the viewing/transcribing of each segment, the authors collaboratively coded the segment and made analytical memos. Finally, authors aggregated codes from each data source and identified broad themes.

CT Experience Design

The CT experiences implemented in this study were designed using a guided play approach (Weisberg et al., 2013). Guided play activities were structured and facilitated by an adult yet were flexibly designed to allow for child-directed learning. These activities purposefully integrated and emphasized a specific CT learning goal while remaining open for children to engage in exploration and self-directed learning. Across this 6-week study, the authors facilitated six standards-based, guided play CT activities with the children during the first three weeks; and in the second three weeks, authors conducted focus groups with the children.

In both classrooms, the daily schedule included time for children to rotate around the classroom and visit five learning centers of their choosing. These centers were designated spaces in the room for small groups to engage with selected materials. To help manage the space and available resources, a maximum of six children were typically present at a center. If children were waiting to visit a center, the teachers managed transitions between the centers to allow for each child to have an opportunity to visit the more popular centers. It was within this choice-based centers approach that the CT activities were integrated. Each time the authors visited a classroom, they offered a CT activity as one of the centers for children to visit. Author 1 facilitated the centers in the Meadowlark classroom and Author 2 facilitated activities in the Bluebird classroom; one research assistant accompanied each author to video record the center, capture photographs, and write field notes. Each activity included a structured "Invitation to Play" card (see Fig. 1), one Bee-Bot™ per participating child (up to 6 children), and associated props. Two out of the six activities are presented in this article ("Bee-Bot Mail" and "Bee-Bot Mural"). Narrowing the data made a deeper descriptive analysis of children's experience possible.

The Bee-Bot is a button-operated robot designed to support mathematical reasoning, problem-solving, and computational literacy for children as young as three and was used in this study. The robot ($125 \times 100 \times 75$ mm), created to look like a small bumblebee with an axle and two wheels, includes 7 basic buttons (i.e., forward, backward, left, right, go, pause, and clear) and can be given up to 40 commands. It moves 15 cm in the given direction and can be used with various other tools.

Following the host classrooms' center-based learning approach, on the day a CT activity was offered, children rotated through the centers of their choosing. Children were encouraged to visit the CT center when it was open but were never forced to engage in the activity. In the Bluebird classroom, 13 of 14 children participated in the Bee-Bot Mail activity, and all children participated in the Bee-Bot Mural Activity. In the Meadowlark classroom, 13 of 15 children participated in both activities; the same two children did not participate in either activity. Each activity began with a brief introduction of the invitation to play and was followed by reminders (e.g., how to handle the bot safely "*Remember, the Bee-Bot likes to stay on the ground and have its buttons tell it where to go*"). During children's play with the Bee-Bots, facilitators referenced the questions on the back of the "Invitation to Play" card as they guided children's play. The facilitators intervened in the play when a child specifically requested help, when a child exhibited moderate to severe frustration, or in instances of peer conflict.

Findings

In examining how preschool children experienced guided play with button-operated robots and how they made meaning of these CT experiences, the analysis of video data, photographs, and child focus groups resulted in three primary findings. First, preschool children constructed meaning across CT dimensions (i.e., concepts, practices, and perspectives), and these meaning-making experiences were informed by feedback from the Bee-Bot. Second, the children connected with others through dialogue and negotiation with peers; third, they used guidance from adults to extend their learning. In this section, these themes will be presented with representative examples from the data.

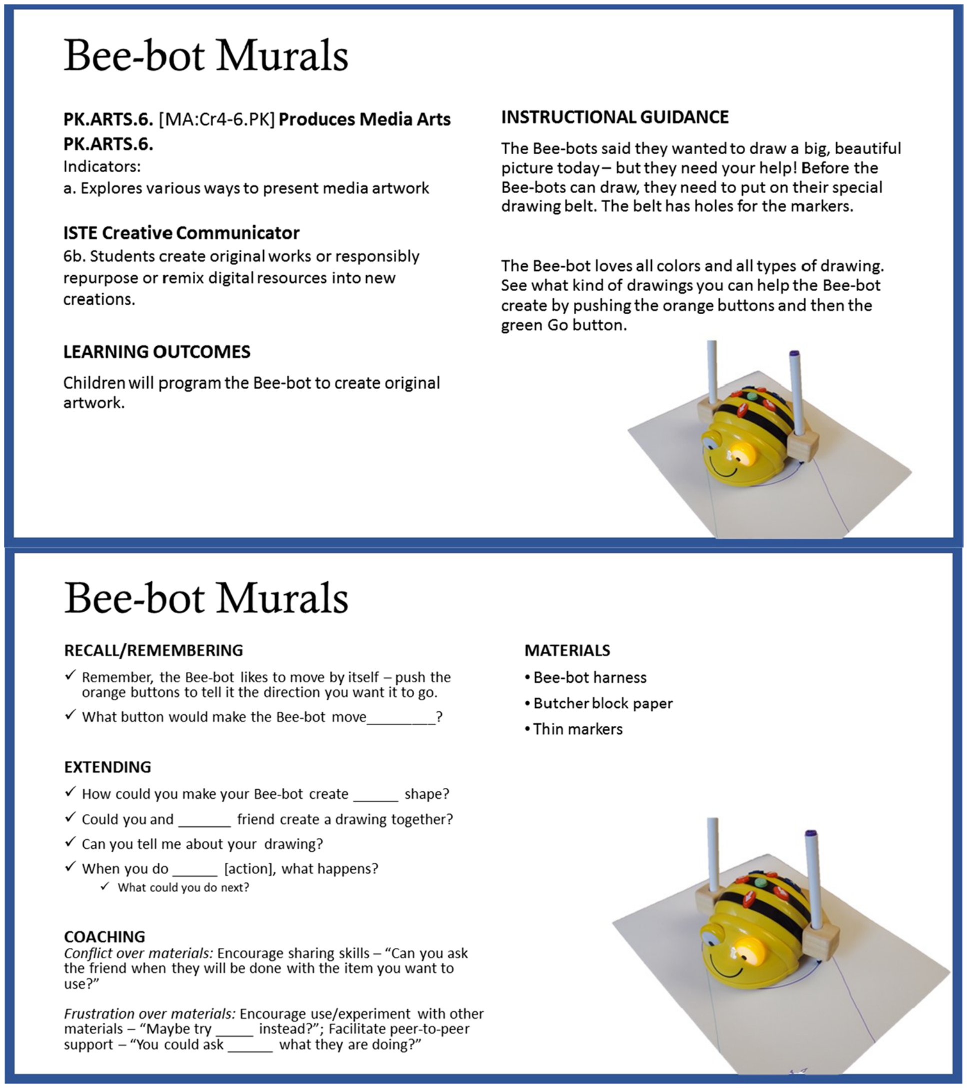

Fig. 1 Sample "Invitation to Play" card for Bee-Bot mural activity (front & back)

The children's play often evidenced meaning-making across CT dimensions (Brennan & Resnick, 2012), and Fig. 2 illustrates this child-directed movement between CT dimensions. In this figure, Keenan (3 years, 6 months [3y, 6 m]) and Remy (3y) independently identified a problem (i.e., programming the Bee-Bots to move through a tunnel) and created sequences for achieving their goal (concept). Keenan and Remy's play also evidenced the CT practices of experimenting and iterating as they first programmed a single bot to travel through the tunnel. They then programmed two Bee-Bots to meet in the tunnel. Their final iteration (practice) was programming two Bee-Bots to travel simultaneously through the tunnel. Finally, the children's body posture, shifting gaze, and facial expressions evidenced a connection with one another (perspective).

While not all concepts, practices, and perspectives identified in Brennan and Resnick's framework were evident in children's play during these CT experiences, Table 3 highlights children's experiences with the concepts of sequence and event; the practices of being incremental and iterative and of testing and debugging; and the perspectives of expressing and connecting. As will be further illustrated in this section, the children's experiences with these CT dimensions were informed by feedback from the robot, dialogue and negotiation with their peers, and guidance from an adult facilitator.

"Bee-Bots Are Driving Crazy"—Making Sense of the Robot's Actions

Observing Events and Sequences

As children interacted with their Bee-Bots, there were many opportunities to receive feedback from the robot. The robot's eyes, for example, illuminated when it was on and blinked to confirm a command had been received. Additionally, the

Fig. 2 Keenan and Remy explore the Bee-Bot tunnel

robot produced a beeping sound whenever a button was pressed; this feature can be turned on and off. Observing the robot enact a sequence is another method of receiving feedback from the Bee-Bot. The children, however, made sense of this feedback quite differently. These distinctions can be seen in how Lily (3y, 8 m) (see Table 3: Case 7) picked up the robot and looked closely in its eyes while trying to debug her sequence. Lily checked to see if the robot was on, but in another instance, Mia (3y, 8 m) asked the researchers if there was a way to turn the robot's eyes off. When the researcher responded that the robot's eyes are always on when it has power, Mia questioned why this must be the case. Lily used the feedback from the robot's eyes to inform her questions, and Mia questioned why these lighted eyes must correspond with the robot's powered state.

Similar distinctions in meaning-making can be observed in how children responded to the robot's actions during the CT experiences. In Table 3: Case 1, Sophia (4y, 9 m) was precise in her creation of a sequence as she pressed Forward exactly five times. She then pressed Go and stayed to observe the robot move through the tunnel. Using this same prop, Jonathan (4y, 11 m) placed a Bee-Bot at the tunnel entrance for his robot's third trip through the tunnel and pressed Forward over 20 times. He did not appear to be counting as he rapidly pressed the button. He then pressed the Go button. He seemed confident in his program, as he left the bot immediately after he had pressed the Go button. Both children pressed the Forward arrows and Go button, but only Sophia stayed to observe the resulting sequence in action. Earlier at this center, Sophia had programmed her Bee-bot to move forward one movement, and it became stuck in the car wash. Now at the tunnel, she observed whether five forward movements would be a sufficient sequence. Instead of staying to observe the sequence in action, Jonathan chose to visit a friend at another part of the center and returned to retrieve his robot after it had reached the other side of the tunnel. The robot was still moving when Jonathan returned to it, and he manually redirected it to the next destination. Meaning making from the robots' actions likely differed for Sophia and Jonathan as their observations of the sequence were unique.

Children's play also involved embodied ways of making sense of the robots' actions. As seen in Fig. 3, Jade (4y, 2 m) points to her robot as it created a visual map of the programmed sequence. Using her index finger, she brought the attention of the researcher and peers to the event. The researcher's hand (palm up with splayed fingers) portrayed a shared interest and excitement. Similarly, children used their hands to explain the concept of sequencing. In Table 3: Case 6, Keenan used his left and right thumbs to act out the input sequence he programmed ("I pushed it this way [holds left thumb pointing to left] and this way [holds right thumb pointing to the right]."). Beyond gesturing, children also used their bodies to engage in deeper CT play. In Fig. 3, Abe (3y, 2 m) is seen with his head on the play mat, his gaze intently focused on the markers as they touched the mural paper. As he watched the mark-making, he made sense of sequence and events.

Observing the robot's sequence, an important element for successful debugging, led to various interpretations of robots' actions. During the focus groups, Hudson (4 y, 8 m) expressed his understanding as, "Bee-Bots are driving crazy." Jackson (4y, 8 m) shared these sentiments about the Bee-Bot's potential autonomy when describing his experiences in a focus group,

Table 3 Meaning-making across CT dimensions

CT Dimensions	Data Excerpts
Sequence—Computational Concept	Case 1: Sophia (4y, 9 m) points to the different props on the play mat identifying each prop ("tunnel" "house"). She places the Bee-Bot at the tunnel's entrance and then positions her head so that she can see the Bee-Bot in line with the tunnel (as if sighting through a scope). She presses the Forward arrow five times, presses the Go button once, and observes her Bee-Bot move toward the tunnel entrance (video data) Case 2: Focus group excerpt Henry (3y, 2 m): My cars don't drive by theirselves Researcher: What? Henry: My cars don't drive by themselves Researcher: Your cars don't drive by themselves? Henry: Yeah… Researcher: And the Bee-Bot does? Henry: Yeah… Jamison (3y, 7 m): The Bee-Bots do drive by themselves Researcher: They do sort of, but who tells them where to go? Jamison: Me Remy: Us… Researcher: Does the Bee-Bot come up with its own idea on where to go? Jamison: No. No, never Researcher: Are you sure he doesn't? Jamison: No Researcher: Well, how does he know where to go? Jamison: I don't know Henry: We tell it where to go Researcher: Like in this picture, how does this Bee-Bot know where to go? Henry: [The child] tells it where it goes…
Event—Computational Concept	Case 3: Focus group excerpt Researcher: I wonder what you are doing in that picture? Lily (3y, 8 m): I'm pushing the Bee-Bot buttons Researcher: You are pushing the Bee-Bot button. What button are you pushing? Lily: The Turn button Researcher: What is the Bee-Bot going to do when you press Go? Lily: Go Researcher: It's going to go? Go where? Lily: Uh…on the ground… Researcher: Is he going to run into that Bee-Bot? Lily: No Researcher: How come? Lily: Because he's going to turn, and she's going to press the Go button Researcher: Oh, it's going to turn when you press the Go button? Lily: Yeah Case 4: Focus group excerpt Sophia: Can we watch the rest of the video now? Researcher: Sure, let's see what Mia's going to do Sophia: She stopped it Researcher: How did she stop her Beebot? Sophia: You press the Back button Mia (3y, 8 m): No, no you press the green one Researcher: Oh, I thought the green one was go Sophia: Yeah Mia: And stop

Table 3 (continued)

CT Dimensions	Data Excerpts
Being Incremental and Iterative—Computational Practice	Case 5: Jamison presses Forward once and then Go. He observes the Bee-Bot move while trying to press more buttons. The Bee-Bot does not receive these new commands, as it has already started moving. After the Bee-Bot stops, Jamison presses Go again and observes the Bee-Bot move without attempting to press more buttons this time. He presses Go again and observes the Bee-Bot move forward once. He repeats this sequence two more times. The Bee-Bot has now reached the end of the mat. Jamison picks it up with his hands and moves it to a new location on the mat where it is close to another edge, but there is a bit more space for the Bee-Bot to move forward. He presses Go and observes it move forward one time. The Bee-Bot has reached the edge of the mat again. He picks it up with his hands, turns it around, and places it in a more central location on the mat. He clears the program by pressing Clear (X), presses Forward two times for this sequence, and then presses Go. He tries to add a Backwards command, but the Bee-Bot has started moving (video data) Case 6: Keenan (3y, 6 m) presses Forward once and then Go. Keenan observes the Bee-Bot and then adds a Right turn and Left turn to the program. Keenan observes these results and then reports it to the researcher, "I pushed it this way [holds up left thumb pointing to left] and this way [holds up right thumb pointing to the right]." He then adds a Left turn and Right turn and presses GO. He observes the bot's movement. He adds a Right turn, presses GO, and observes the bot's movement again (video data)
Testing and Debugging—Computational Practice	Case 7: Lily sets her bot down in front of the tunnel. She lightly presses Forward and then more firmly presses Go. The Bee-Bot indicates receiving the Go command by blinking its eyes and beeping, but it did not receive the Forward input. The Bee-Bot does not move. Lily appears confused. She presses Go again, but the Bee-Bot does not move, since it never received the initial Forward command. She tries to pick the bot up with one hand, but it slips and turns over. She picks it up with both hands and brings it close to her face to look into its eyes and make sure it is on. She turns around and looks toward the researcher for assistance. The researcher joins her and asks what she has pressed. She demonstrates that she pressed Forward then Go and explains that it did not move. The researcher clears the bot and asks how many times Lily thinks she would need to press Forward for the bot to move through the entire tunnel. Lily responds, "Six!" Appearing more confident, she firmly presses the Forward button 6 times, then presses Go, and exclaims "Oh! It went through!" (video data)
Expressing—Computational Perspective	Case 8: Sophia orients the bot with two hands, sets it down behind the car wash, and then sits behind the bot. Jonathan (4y, 11 m) moves his bot toward the carwash (physically); at first, he puts his bot in front of the car wash, but realizes it needs to go behind it. He moves the bot to be behind the car wash (in front of Sophia's bot). "Stop! Stop! Stop!" Sophia says, moving her hands rapidly as the bots collide in front of the car wash. She appears unsure of what to do. She presses the GO button right when Jonathan's bot is at the carwash. This stops the bot. Sophia moves her bot to the beginning of the car wash and moves Jonathan's behind hers. "They have to line up," Sophia explains to Jonathan about the way this car wash works. She then presses Forward five times followed by Go. The robot moves through the car wash. Sophia presses Go to stop the bot. Jonathan's bot remained stationary on the other side of the car wash. "Now it's clean!" Sophia says after her bot successfully exits the car wash (video data)
Connecting—Computational Perspective	Case 9: Keenan leans forward toward the tunnel with his right hand on the bot and his knees back off the mat. He presses Forward twice, but before he can press go, Remy (3y) moves her bot in front of Keenan's. He then crawls to the other side of the tunnel and presses GO on his bot. Both children lean down, place their faces close to the opposing tunnel entrances, and observe their bot's movement. The bots collide in the tunnel. There are squeals as this occurs, and Keenan smiles widely as he squeals with excited laughter and lifts his hands in the air. He then lifts the tunnel to see where the bots have stopped (video data)

Fig. 3 Jade and Abe Observe the Bee-Bot

> I pushed the Go and then I pushed it Forward and then it just kept on going forward, and I didn't even press the button. I only pressed it Go and then Straight and then it kept on going straight and straight…I only pressed the Go and Straight and then I didn't press any buttons, and then it just kept on going.

Children's conception of sequence and event thus appeared to contribute to how they made sense of the feedback being provided by the robot's actions. If the robots were understood as independent agents, their actions could be interpreted as autonomous – disconnected from the sequence input by the child. Making sense of the concepts of event and sequence, therefore, were essential elements in children's debugging experiences.

Responding to the Robot's Actions

As children made sense of the robot's actions, they attempted various methods to help the robots arrive at the desired destination and address potential errors in the programs. If the problems resulted in the robot not moving (see Table 3: Case 7), children's problem-solving processes were more apt to involve debugging – they needed to address errors in the program to help the robot move. While at the Bee-Boot Mural center, Daniel (3y, 5 m) attempted to make the Bee-Bot move by pressing Go prior to inputting a sequence. After being reminded by the researcher that he needed to tell it where to go (pointing to the directional arrows), Daniel pressed Forward once and then Go. The bot moved forward one unit. Pleased with this result, Daniel smiled down at the bot and looked up at the researcher.

In cases where the Bee-Bot was moving, but the sequence did not achieve the desired result, children's responses tended to bypass a computational solution in favor of an immediate physical action that could address the problem. Jonathan's previously mentioned sequence that had over 20 Forward commands, for example, successfully programmed the Bee-Bot to the other side of the tunnel but was not going to reach Jonathan's ultimate destination (i.e., the silo). Needing the Bee-Bot to take a ninety-degree left turn and observing that it was still moving straight, Jonathan used his right hand to turn the robot left and steer it toward the silo. In similar fashion, Sophia's 5-Forward program successfully directed her robot to move through the tunnel, but as it exited (still enacting the sequence), she quickly picked it up, walked across the mat, aligned it with the opening of the car wash, and set it down to continue its sequence through the car wash.

While Jonathan and Sophia physically redirected the robot to accomplish their goals, Keenan's response was to physically reorient props in response to his observations of the robot's sequence. Attempting to have his robot move through the tunnel, Keenan set his robot down to begin its sequence and pressed Go. Since there were turns in the program from a previous sequence that was not cleared, Keenan crawled around moving the tunnel to match the robot's movement until the robot finally made it through to the other side of the prop. Children's observations and interpretations of the Bee-Bots' actions thus informed their understanding of potential programming errors and the actions they took to arrive at the desired solution.

Interpreting Observations of the Robot

The feedback provided by the robot's actions was not always linked to the underlying causes, thus the feedback contributed to misconceptions in children's meaning-making about events and sequences. These misconceptions were observed in the focus group and video data. The focus group conversation below occurred as Sophia and Mia watched a video clip of the children playing with the robots.

> Sophia: They're [the Bee-Bots] going out.
> Researcher: Going out where?
> Sophia: I can't see it anymore. It went under the black thing.
> Researcher: How did…it to go that far?
> Mia: He pressed the green [Go] button and then the orange [Directional] button.

Researcher: Oh really?
Sophia: He pressed the orange button and then the green button.
Researcher: Oh, orange then green button?
Sophia: Or maybe he just pressed the orange button.

In this conversation, Sophia and Mia were unclear what button produced the action observed in the video. They saw the robot moving, and they saw the child in the video press buttons, but they were unsure whether the directional commands or the Go button produced the observed action. They vacillated between the sequence of steps and concluded that "maybe he just pressed" one of the buttons.

This uncertainty occurred within children's play often due to programs not being cleared. Being that children could come and go from the center, this movement resulted in robots – with a sequence still in their memory – being passed from one child to the next. At other times, children may have begun with a clear Bee-Bot memory but forgot to continue clearing its memory as they played. They then expressed frustration when the enacted sequence did not match what they anticipated. In the video data, Seth (4y, 10 m) oriented the Bee-Bot to move straight toward the silo to join friends and their Bee-Bot. The Bee-Bot had a single Forward command stored in its memory. Seth proceeded to press Go and then Forward one time. Seth's press of Go caused the Bee-Bot to begin producing its stored program of one forward movement. Although Seth pressed Forward after pressing Go, the Bee-Bot did not receive this input. However, Seth's subsequent actions indicated that his observation of the Bee-Bot moving forward a single time were a result of his pressing Go then Forward, since Seth repeated the process of pressing Go followed by Forward seven times. If the Bee-Bot had received the input of the now eight Forward commands that Seth had input, it would have incrementally increased its forward movements each time Seth pressed Go; yet on the eighth iteration, the Bee-Bot moved forward a single space. Since the button presses occurred in swift procession and the produced Bee-Bot action was exactly what Seth anticipated, this feedback reinforced the misconception that the sequence should or could be input after the event was triggered.

When children experienced a stationary robot, the feedback loop from the Bee-Bot appears to have contributed to making sense of CT concepts. When observing an unanticipated sequence, children may have interpreted the Bee-Bot's actions as independent. Yet at other times, children's misconception of event and sequence may have been further reinforced by observing Bee-Bots enact stored sequences. CT understandings were also formed as children interacted with their peers through dialogue and negotiation of meaning. The Bee-Bots "can't talk…[they just] beep, beep, beep, beep!" Seth emphasized in the focus groups; talking with peers within each center was also an essential element of the guided play experience.

Fig. 4 Participants Interacting with the Bee-Bots in the Activity "Bee-Bot Mural"

"It Can Turn. It Can Turn. Watch."—Dialogue and Negotiation with Peers

Throughout the preschool children's play with the button-operated robots, we observed that their play was enriched by experiencing the CT perspective of connecting with others (Brennan & Resnick, 2012). These connections were observed in the ways children created sequences, artwork, and play scenarios for and with their peers. As they created together, the children's dialogue and negotiated meanings offered glimpses of what Karagiorgi and Symeou (2005) referred to as the co-construction of meaning with knowledge-building tools.

Creating Meaning and Computational Artifacts Together

The preschool children's experiences documented in Fig. 4 are illustrative of their creating with one another. As children arrived at this center, the researcher demonstrated how the Bee-Bot's wooden belt could hold a marker on the left and right side of the robot's body. The researcher asked whether anyone remembered how to have the Bee-Bot draw a circle. Lola (4y, 3 m) quickly pointed to the Right arrow button. Each of the children took a turn pressing the Right arrow button and then pressed the Go button. The Bee-Bot remained in the same spot but turned its body four, 90-degree turns. Jade, a child who watched the action, was ecstatic that the Bee-Bot had made a circle. Later at the center, Jade worked on creating her own Bee-Bot circle by having the robot rotate repeatedly in the same location. She exclaimed, "I made my Bee-Bot circle! I wanna color inside this circle!" As can be seen in Fig. 4, the children created many additional Bee-Bot circles in the mural and used these circles as creative inspiration.

As a new group of children arrived at the center, Jade decided that she wanted to program one final circle. She pressed Go, and the Bee-Bot turned right, then left. She wanted it to turn more so she pressed five Right arrows and then pressed Go. She was not pleased with this program and looked for a way to stop it. She tried pressing the Left and Right buttons and even pressed the Clear button, but the Bee-Bot continued to move. She verbally expressed frustration, "I don't know how to stop this thing!" Lola pointed to the Go button to remind her that the Go button also stops the Bee-Bot.

Seeing the new group arrive and the new mural paper being provided, Jade stayed at the center and modeled for the incoming children how to use the Bee-Bot with the belt. "Watch this," she instructed as she showed Jonathan how to put the belt on and insert the markers. Jade then pressed the Forward button twice and the Go button once. "See, it's already making!" Jade prompted her friends to observe the results. She added steps to her model sequence, but when she noticed the robot was about to move off the mat, she quickly pressed the Go button to stop the bot.

After this modeling session, Jade remained at the center and noticed that Jonathan's bot was only moving in a straight line. "Guess what? It can turn!" Jade excitedly said to him. Jonathan appeared to be fully engaged as he leaned forward, vigorously chewing his tongue, and pressed Forward many times followed by Go. As the robot moved forward, Jonathan's eyes followed its movements, and his body crawled alongside it. "It can turn. It can turn. Watch," Jade encouraged Jonathan as she picked up his bot to demonstrate this newly learned sequence.

Jade, Lola, and Jonathan's interactions showed how creating with one another enabled them to support their peers. They could learn from each other, help debug programs, model their knowledge, and encourage one another to attempt new sequences. Also evident in their interactions was the motivation to create for others. The children would eagerly call out to friends and show their peers a sequence they had created or invite them to join their robots in pretend play. Similar to Jade's excitement for equipping Jonathan with the props and knowledge for the center, children would communicate novel ways for interacting with the robots.

Negotiating Shared Understanding of the Experience

In the children's interactions with each other, we also observed negotiated meanings. Examples of these negotiated meanings can be seen in Table 3: Case 2 and Case 4. Although beginning with the claim that Bee-Bots drive themselves, Henry (3y, 2 m), Jamison (3y, 7 m), Remy and the researcher negotiated an understanding of what this means. Eventually, the children concluded that the Bee-Bots drive themselves but only go wherever the children tell them to go. In the excerpt of Sophia and Mia's dialogue, they negotiated an understanding of *event* – which robot button would produce the Stop event. Mia, who was the focus of the video used to prompt this focus group, was able to explain to Sophia that the Go button is used to begin a sequence and preemptively end a sequence when needed. The researchers helped to prompt this dialogue and negotiated meaning in the focus groups, and they were critical to the co-construction of meaning during the CT experiences as well.

"How did you make it do that?" Guidance from Adults

As children made meaning of their experiences with the robots, they used guidance from adults to extend their learning. The facilitators primarily intervened in the play when a child specifically requested help, exhibited moderate to severe frustration, or in instances of peer conflict. By having access to the facilitators in these guided play experiences, children also chose to create artifacts for them and shared their successes with them. These conversations were typically initiated by the children's desire to talk about their robot's sequences with the facilitator. To express interest in what the child was sharing and to prompt further meaning making, the facilitators' responses were frequently, "How do you make it do that?" This invitation to explain their thinking provided another opportunity for children to externalize their CT understandings and created spaces for reflecting on their play with the robots.

Extending Their Learning

Illustrated by the focus group conversations in Table 3: Cases 2, 3, and 4, the children's responses to the facilitator's guidance indicated that they were extending their CT understandings. During the centers, the facilitators similarly utilized questions to invite children to talk about their play with each other or with the facilitator. For example, one facilitator asked Jade, "Can you tell Mia about this station?" Additional video data show the facilitators at various times inviting children to talk about their sequences by asking, "How'd you get it to do that? How did you make a circle with the bot? What orange button did you tell it to do? Which of these did you press?" Children's responses were part of their meaning-making process, and conversing about their play with robots became a routine part of the centers.

Using Adult Assistance

As previously mentioned in the section on how children responded to the robot's actions, the Bee-Bot's feedback did not always clearly communicate the underlying problems with a sequence. In Table 3: Case 7, Lily looked to the facilitator for assistance with why her robot was not moving. Daniel, in another example, kept pressing Go prior to inputting a sequence. These instances created opportunities for problem-solving as Lily attempted multiple strategies for debugging her program, but they also could lead to feelings of frustration.

In another segment of video data, Hugh (3y, 11 m) repeatedly pressed the Go button and observed a stationary Bee-Bot. Observing Hugh's repeated efforts, a facilitator intervened by asking, "If you want it to go this way [uses marker to motion forward direction], what should you press? If you want it to go that way [uses marker to motion backward direction], which button do you press? If you want it to go, which big green button should you press [motions a circle in the air with marker]?" After this interaction, Hugh pressed the Backward button, the Forward button, and then pressed Go. The Bee-Bot moved backward then forward. After observing the Bee-Bot enact these steps, Hugh informed the facilitator that his sequence was successful. When facing frustration or seeking adult assistance, the children used the facilitator's questions or prompts to identify errors in their sequences or consider additional approaches to their goal.

Connecting with Facilitators

The facilitators were present during the entirety of the guided play centers, and children viewed the facilitators as another audience for their interactions with the robots. Jade (see Fig. 3) directed a facilitator's attention to her robot's movements by pointing her finger toward the robot, and Harper (4y, 6 m) (see Fig. 4) used her finger to trace a circle on the paper as she told the facilitator how it was made. Lola also attended to this conversation about making circles as she directed her posture and gaze toward the facilitator and Harper. The children connected with facilitators by sharing how they were playing with the robots. During the focus groups, Sophia further explained the children's drawings from Fig. 4, "You, you…I can show you a picture, so you can see…this is you…and circle, circle, circle." Similarly, Harper shared during the focus groups, "I see me, and I'm drawing you…I made you right there…I made a circle." Thus, the children connected with facilitators by also creating computational artifacts for them. Finally, Keenan observed the sequence he had created and sought out the facilitator to explain what he had accomplished (see Table 3: Case 6). Children, therefore, connected with facilitators by describing their computational accomplishments to them. Children's excitement to share their play with the facilitators, create artifacts for them, and detail their CT understandings to them evidence that connecting with the facilitators was an important part of these guided play experiences.

Discussion

Significant attention has recently been directed toward reviewing the efficacy of computational tools designed for young children (Hamilton et al., 2020; Papadakis, 2020, 2021) and examining young children's capacity for learning foundational CT concepts (Saxena et al., 2020) and practices (Angeli & Valanides, 2020). Furthermore, a scoping review found that pre-post designs with interventions and task-based measures of CT outcomes have been prominent in studies conducted with preschool-aged children (McCormick & Hall, 2021). To add to these valuable perspectives, scholars have recommended that research should also focus on learners' experiences with media as situated within their environments and lived experiences (Cilesiz, 2011; Valentine et al., 2018). Research, for example, is needed to examine how young children use button-operated robots to facilitate their "knowledge-construction and meaning-making" (Jonassen et al., 1994, p. 35). This study sought to address this gap by exploring preschool children's CT experiences when button-operated robots were introduced into their guided play.

Robot Features and Children's Play

This study found that children's meaning-making across CT dimensions (Brennan & Resnick, 2012) was a process of observing the robots, interpreting the robot's actions, and constructing a response to these actions. Previous research has affirmed that children are competent meaning-makers who actively engage with their learning environments (Weisberg et al., 2016), and these findings support that children were highly engaged in making-meaning through their play with the robots. While the design of this button-operated robot supported engagement with concepts, practices, and perspectives, it also contributed to the emergence of misconceptions about sequences and events. When a sequence was unknowingly stored in the robot's memory, children expressed confusion at why the robot was not enacting the buttons they had pressed. In cases when the stored sequence mirrored the sequence being input by the child, children could be observed misattributing events.

While the button-operated robot was designed with physical features to facilitate the development of CT concepts, these features may have also inhibited its ideational potential within a play-based context (Hamilton et al., 2020). For example, the default storing of a sequence in the robot's memory affords the potential to facilitate learning about problem decomposition and iterative thinking, but for children who had yet to comprehend the robot's memory or the purpose of the clear button, this intended affordance may have been a constraint. As educators evaluate the variety of computational toys that can be made available to children (Ching et al., 2018), it is important to consider how children might use these media to construct knowledge (Jonassen et al., 1994). Since play is a hallmark of children's development and learning (Mehta et al., 2020; NAEYC & Fred Rogers Center for Early Learning and Children's Media [FRC], 2012), additional studies should focus on how children understand and use the physical and ideational features of computational toys during their play.

Let's Figure this Out Together: The Importance of Peer Dialogue

The guided play environment in this study created an opportune setting for the emergence of CT understandings through dialogue with peers. This finding aligns with previous recommendations to incorporate peer interactions and community building within early childhood CT experiences (Bers et al., 2019; Resnick, 2018). Synthesizing years of research in their joint position statement, NAEYC and the FRC reiterate that developmentally appropriate integration of technology can foster learners' social skills, language development, and problem-solving skills. In contrast to this recommendation, Papadakis (2021) found that in 21 studies of apps aimed at developing young children's CT, none of the activities with the apps promoted collaboration and sharing. Instead, they noted that "in all studies, coding seems to be a solitary activity" (Papadakis, 2021, p. 8). Conversations between peers were an essential component of children's play and their emerging CT understandings in this study. The results evidenced that children invited others to join them in their play, helped peers debug errors, modeled how to operate the robot, taught peers new sequences, discussed the meaning of observations, and inspired their peers' creations. While this study did not investigate social or emotional outcomes, further research should examine the impact of dialogue and negotiation during play-based CT experiences. Additionally, researchers and designers should explore how the principles of guided play could be leveraged to encourage similar peer interaction when CT apps are integrated within preschool settings.

Structures and Support: The Role of Adults in Children's CT Play

Providing prompts, props, robots, and the freedom to play were essential roles played by the adults in this study, as these elements were the structures of the invitations to play. As Mehta et al. (2020) highlighted, adults can have a tremendous impact on how children "spend their time, and how (or how much) they are able to play" (Mehta, 2020, pg. 687). The initial role of the adults in this study was to create an inviting structure for play. All children engaged with these invitations and also engaged with the adult facilitators during their play. Similar to Wang et al.'s study (2021), the children in this study also used support to make connections and approach problems in a computational manner. Children would look to the facilitators for assistance when initial debugging attempts were unsuccessful, and facilitators would use purposeful questions to guide children. Research with parent–child dyads using a coding application demonstrated the positive impact of task-relevant talk (Sheehan et al., 2019), and children in this study used the questions to build upon their CT understandings. With CT becoming a regular part of childhood and early childhood curricula, future research should examine how to help educators develop pedagogies for facilitating CT experiences (Alqahtani et al., 2022; Wang et al., 2021).

Limitations

The study described here highlights the potential benefits of using a guided play approach to explore CT skills, however, a few limitations must be considered. The participant age group ranged from 3–5 years; most of the children were between three years, six months and four years, six months old. While it was not the intention of the study to describe children's experience across developmental ages, future research could investigate developmental variation across the 3–5-year-old age span. Another limitation of this study was the choice-based nature of the CT activities. It was not a requirement that each child participate in the activities; children were allowed to choose if and for how long they participated each day. This approach was purposeful as it mirrored the host classrooms' learning philosophies and served as an attempt to minimize the power differential between the researcher and child. To be sure, all participants are represented in the data, however, individual children's participation in each activity was varied. Finally, the findings provide a rich description of children's CT play in one early childhood center and could be transferable to other settings. Future studies could explore play-based CT experiences across multiple and diverse settings to create a clearer picture of young children's play-based CT experiences.

Conclusion

Much attention has been given to the potential for computational toys to affect children's learning; however, the role of the learner and context for learning are equally important to consider (Jonassen et al., 1994). In this study, children's experiences in the context of guided play demonstrated the potential affordances and constraints of a button-operated robot for facilitating their knowledge construction. Dialogue with peers and guidance from adults were also essential characteristics of children's co-construction of knowledge during the CT experiences. Our study aims to enrich early childhood CT scholarship and will contribute knowledge to the gap in research concerning young children's play-based CT experiences. Additionally, given the fine-grain, rich account of children's CT learning through their own 'voices', this phenomenological study offers much-needed young children's perspectives of the experiential qualities of engaging with technology (Cilesiz, 2011). The results, therefore, may inform future CT integration in early childhood programs and support improved designs of play-based robotics activities.

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Declarations

The authors have no relevant financial or non-financial interests to disclose.

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Informed Consent The authors obtained informed consent from legal guardians for all individual participants included in the study. Parents signed informed consent forms regarding publishing their children's data and photographs.

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