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Embracing Culturally Relevant Computational Thinking in the Preschool Classroom: Leveraging Familiar Contexts for New Learning

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Abstract

Computational thinking (CT) is an important twenty-first century skill that begins developing early. Recent interest in incorporating early CT experiences in early childhood education (i.e., preschool) has increased. In fact, the early years mark an important time during which initial competencies are acquired, interest and motivation begins to form, and in which children may develop a sense of belonging in STEM fields. As a result, providing children with access to robotics and computer science experiences to support CT that are also developmentally appropriate and culturally relevant is key. This paper uses the "powerful ideas" of computer science, seven developmentally appropriate CT concepts that children can learn, as a framework and explores the experiences of two (composite) teachers who participated in and co-developed a culturally relevant robotics program and the processes they undertake to support children's CT development and learning. This paper considers practices that support the seven key powerful ideals while leveraging existing instructional routines and contexts that are already occurring in most classrooms, such as centers, small group activities, classroom environments, and read-alouds. Of note, this paper prioritizes approaches that acknowledge, center, and feature the ethnic, cultural, and linguistic backgrounds of young children and their families. Identifying affordable and accessible practices, this paper provides educators with tangible, integrated, and authentic practices to support children's computational thinking, STEM learning, and sense of belonging.

Keywords Computational thinking · Robotics · Preschool · Literacy · STEM

"Good morning, buenos días!" Ms. DeRose greets her prekindergarten students and they engage in a conversation about how they got to school that morning. They also brainstorm where they have seen robots and other computing systems (i.e., watches, phones, cars) at home or in the community. A short while later, Ms. De Rose introduces the children to Code-a-Pillar, a new battery powered robot that she will add to the classroom construction zone. She shows her students the robot's capabilities and functions ("look, if I push these buttons like this it turns 4 times and moves in a circle; en un circulo. Similar to our bus making stops in the neighborhood"), which helps children build knowledge of robotic functions in relevant, meaningful ways.*

Across town, Ms. Galloway starts her morning by going through the daily schedule with her preschoolers. She reminds them of the "daily algorithm," in that first, they have large group time, then centers, then small groups, then lunch. She reminds them that in some ways the order of these events matters—that they can't go to lunch yet because it is too early. In other ways, however, the order does not matter—it wouldn't matter if they did small groups or centers first. Ms. Galloway asks the students to share about different foods their families prepare at home and steps they take to make the meals. After this conversation, she pulls out a book for the morning read-aloud that uses a non-linear structure to exemplify this idea of order mattering and not mattering depending on the context and culture, serving as a key example of how algorithms work in that sometimes the order of codes programmers input matter while other times, the order is less important or insignificant.*

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Both teachers are enacting culturally relevant computational thinking activities with young children in different settings, with differing demographics of children, and in distinct ways. Ms. DeRose teaches in an urban school largely serving Latinx children who are emerging bilingual learners. Ms. Galloway, who teaches in the same district but in a different part of town, teaches in a classroom of almost entirely Black children. Through a glimpse into these teachers' classrooms and practices, this article will highlight approaches to robotics and computational thinking for young children in culturally responsive, relevant ways in a variety of contexts to leverage existing instructional routines as well as children's funds of knowledge, to develop computational thinking.

Background and Review of Literature

A critical skill associated with 21st-century citizenship, computational thinking (CT; Wing, 2008), is fundamentally linked to STEM learning across disciplines (e.g., Bers et al., 2019). While a greater focus has been placed on CT in K-12 education in the past (e.g., State of Computer Science Education, 2019), research and policy dedicated to supporting CT in preschool and other early childhood spaces have recently increased (e.g., Ching et al., 2018; Sullivan & Bers, 2016). Given these shifts, it is important for practitioners, like Ms. DeRose and Ms. Galloway, to provide CT-related experiences for preschoolers that are developmentally, culturally, linguistically, and ability appropriate.

Consistent research suggests the power of digital technology to engage children (e.g., Fantozzi, 2021), support learning (e.g., Neumann, 2018), and offer affordances for new and creative types of digital play unavailable outside of technology (e.g., Rowe & Miller, 2016). That said, longstanding concerns with children's access and use of technology persist, however technology is here to stay. How much technology is leveraged makes the difference. Current recommendations suggest children should have somewhat limited access to screens/technology and access should be active and interactive, engaging, positive, meaningful, age-appropriate, and balanced with other aspects of daily life (Common Sense Media, n.d; Hirsh-Pasek et al., 2015). Research suggests challenges associated with excessive screentime (e.g., McArthur et al., 2022; Zhang et al., 2022) and further work demonstrates that some preschool teachers may hold negative feelings towards technology integration (Blackwell et al., 2013; Wood, 2018). As a result, this article offers approaches to developing important twenty-first century competencies in CT that engage children and prepare them for effective technology use, focusing largely on "unplugged" activities that reflect playful approaches to technology, robotics, and CT (Bird & Edwards, 2014). Thus, teachers can support CT without wading into contentious screentime waters or making investments in costly robotics that may be outdated in a few years.

Computational Thinking Powerful Ideas in Preschool

One approach to understanding CT in ECE is to consider the 'powerful ideas' of computer science (Bers, 2021), which serves as the guiding framework for this article. The powerful ideas feature seven core understandings that comprise the computer science discipline and support the development of children's CT. These include—algorithms (steps taken to complete a task), the design process (a process that engineers use to solve problems and answer questions), modularity (breaking tasks down into smaller pieces), control structures (specific commands used within a computer program), hardware/software (grasp of critical components for computing including physical parts/hardware and the instructions or code needed to run the program/software), debugging (specific problem solving that requires identifying the problem and solving it), and representation (understanding that concepts and codes can be represented using symbols and signs) (e.g., Bers, 2021).

What makes these ideas even more powerful for use in early childhood are the ways in which they can connect preschool coding meaningfully to other content areas, curricular domains, social emotional competencies, and cultural backgrounds (e.g., Kotsopoulos et al., 2022). For example, algorithms are crucial to computer science; they serve as the basis for coding. Algorithms can be seen in many of the storybooks children are exposed to in preschool that have a linear progression. One event precedes another and that precedes the next event, and so on. Just like an algorithm, order can matter and changing an aspect of the story (or a part of a code in CS) can change the outcome. Similarly, when computer programmers go through the process of debugging, they seek to address bugs in their code by first identifying bugs and diagnosing issues, then remedying them by enacting a very intentional problem-solving process that might exist in a number of other early childhood curricular domains or in interpersonal conflicts. For instance, children are arguing over the use of materials and the teacher scaffolds by first naming and diagnosing what the issue is [scarcity of materials, not wanting to take turns, etc.] and second, working with the children to identify particular solutions [setting a timer, using materials together, etc.] that will mitigate the problem ["We worked together to figure out what the problem was and solve it like programmers do to debug. I will check back in to make sure it works"]. This article focuses on a few powerful ideas and how they come to life in preschool contexts in meaningful, connected, and appropriate ways.

While these powerful ideas can serve as a foundation to the development of CT, it is critical to consider how this instruction can be culturally relevant for all students by leveraging cultural, contextual, and individual assets, ultimately building children's sense of belonging in STEM fields. This process supports children in learning more about themselves and others and considering ways in which CT and technology can address societal challenges (Harper et al., under review; Scott et al., 2015). Early childhood teachers are well positioned to support children's learning through culturally responsive practices. In fact, professional recommendations (e.g., Armstrong, 2020; National Association for the Education of Young Children (NAEYC), 2019) stress the need for teachers to imbed and honor children's cultural, social, and linguistic backgrounds, foster connections to the community, and promote agency, choice, and open-ended experiences for children to problem solve and collaborate.

Rationale and Current Work

Irrespective of technology, research suggests an overall decrease in access to play in early care and learning contexts (Wohlwend, 2023; Yogman et al., 2018). Particularly for children from marginalized backgrounds, recent literature demonstrates a greater emphasis on rote academic skills and behavior modifications and a decrease in play opportunities for children in these contexts (Hirsh-Pasek et al., 2020). There is a need to reposition play at the center of early childhood education (e.g., NAEYC, 2020) as well as emergent curriculum and project-based learning that support children's skills and interests across disciplines. Meanwhile, research and professional recommendations also stress the need for preschool instruction and opportunities to be contextually appropriate and relevant to children's cultures and social worlds (e.g., Durden et al., 2015; NAEYC, 2020). A recent project (Harper et al., 2022) sought to develop materials to support children's CT in culturally responsive ways within both classrooms and homes by partnering with families and teachers to co-construct and enact the program. This program positions CT experiences as "playground not playpen" experiences (Bers, 2021) both for experiences that included technology, robotics, or screens, and those "unplugged" experiences that did not; experiences were open-ended, flexible, had multiple points of entry, and allowed for free expression and creativity. This article represents a few of the experiences, supports, and lessons learned to carry out the school-based work in ways that honored the communities served, leveraged teachers' knowledge and expertise of their children and contexts, and built CT learning upon solid existing foundations.

Context, Participants, and Procedures

The findings of this multi-year culturally relevant robotics program and partnership that brought together university faculty and graduate students, preschool teachers and their instructional coach, and families, are presented here. The study took place in a midsized city in the southeastern region of the US. The focal school district is the third largest in the state and serves over 60,000 students in schools in urban, suburban, and rural contexts. The participating teachers taught in publicly funded classrooms serving 3–4 year olds (preschool) or 4–5 year olds (PreK). Teachers used a district-mandated, interdisciplinary curriculum in their classrooms (Connect4Learning; Sarama et al., 2016).

In the first year of the program, STEM education, early childhood education, and computer science faculty and graduate students worked alongside teachers, their instructional coach, and families to co-develop home and classroom programs to support preschool-aged children's computational thinking; this article focuses solely on the school/classroom-based program. The programs and their associated activities were piloted during the first year. In the second year, more teachers joined the project and implemented the co-developed program in their classrooms.

The program focused on four six-week phases. Each phase centered primarily on one powerful idea (Bers, 2021, see above) and consisted of the same structural elements and temporal settings that were familiar to participating teachers—environmental considerations (i.e., modifications that could be made at the onset or during a phase to support learning in that phase), centers (i.e., materials and activity suggestions that could be added to centers to engage children so that they could engage in aspects of the phase independently), small group activities (i.e., more focused opportunities for targeted instruction and assessment), text suggestions for read-alouds (i.e., books that connected with the powerful idea of the given phase that teachers could use to further engagement and connection), intersections between CT and other curricular areas such as literacy (i.e., ways for teachers to connect CT to other aspects of the curriculum or vice versa), and cumulative, focal experiences that served as summative experiences for the phase. University partners supported teachers through providing resources and materials, professional learning meetings, and classroom visits and co-teaching. Considerable time was spent in teachers' classrooms generating fieldnotes and video data that served as the basis for this work.

Across the two-year project, a total of fourteen lead classroom teachers participated. The following vignettes represent practices observed in classrooms across the sample, and not particular teachers. The schools in which teachers worked served heterogenous student populations. Thus, this article documents practices observed across our participants. Two pseudonyms, Ms. Galloway and Ms. DeRose, represent composites of our participant sample and their practices as illustrations of what is possible when we engage with culturally relevant computational thinking. Results are presented in terms of the familiar structural elements/temporal settings (e.g., environments, small group activities) and our observations of teachers' practices in these contexts. For each learning context, additional information, potential other applications, and supporting research is provided.

Establishing the Environment

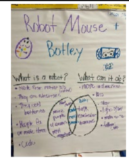
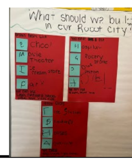
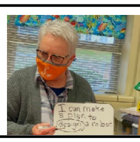
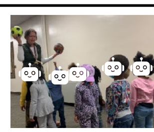
- Create flexible spaces that can be used for multiple purposes, with varied grouping sizes, and to support different interests
- Use pedagogical documentation to support learning, depict classroom activities, and create opportunities for reflection and further engagement
- Thoughtfully select materials; robots do not have to be a huge investment and loose parts are open-ended and can be sourced freely or inexpensively

Before school began, Ms. Galloway decided to redesign her classroom to support her use of culturally relevant robotics activities and children's CT. She was seeking new ways to support children's ongoing project work that can be left "in progress" instead of being sent home or put away each day. She understands that children need time to enact the design process and create computational artifacts through project work. Ms. Galloway also rearranged her classroom furniture to encourage small group collaboration and larger areas for play. She added portable dividers and lightweight wooden crates to build flexible spaces. She labeled shelves where children can access robots, drawing/writing supplies, and blocks. Ms. Galloway removed many posters from the walls and developed plans for documenting children's work through wall displays. The posters she was using had little connection to children's daily classroom experiences. She also began searching online for new materials to add. She knows children acquire key CT understandings when they are encouraged to use loose parts, construction materials, and a variety of manipulatives to solve problems, think creatively, and work collaboratively. Suddenly, Ms. Galloway remembered how recycled and natural materials can be used to teach STEM instead of [or in addition to] expensive, store-bought items. She makes plans to partner with families to gather these materials and loose parts around the school and within the community. Ms. Galloway also knows children need ongoing access to open-ended materials while engaging with the robots that she already has in the classroom. She envisions how the classroom design and the combination of unplugged materials with robots will lead to rich CT and meaning-making for the children. (See Table 1).

In this scenario, Ms. Galloway is using her knowledge of the environment as the third teacher (i.e., that classroom environments are inherently instructive; Malaguzzi, 1996) to design flexible learning spaces with intent to foster CT. Classroom arrangements should encourage children to work collaboratively where there is ample table and floor space. This provides children with opportunities to build relationships and sort through problems and conflict with teacher support. Bers (2008) recommends at least six feet of floor space for forward and backward-moving robots. For smaller classrooms, outdoor spaces and corridors can also be used, weather-permitting, ideally with concrete or tile floors where robots can move freely. Preschool classrooms also need defined areas that foster long-term work (Bullard, 2016). Children should be able to construct projects while standing up, sitting, and working on the floor (Bers, 2008). Four-year-olds move quickly from one task to another so it is expected they will leave and revisit project areas frequently throughout the day. When possible, classroom spaces should accommodate different group sizes as children's CT project work emerges. It is difficult to predict how projects will develop and differ based on children's cultural assets, interests, knowledge, and skills (Derman-Sparks & Edwards, 2020; Helm & Katz, 2016). Often, the number of preschoolers allowed in one center is controlled to provide ample space for learning, but flexible furnishings can accommodate different group sizes (Curtis & Carter, 2014). Positioning tables, dividers, and shelves in ways that provide boundaries but still allow for full visibility ensures safety and collaborative work. Further, open spaces can be powerfully used for play and exploration. However, since young children seek out large muscle play and are physically restless (Wood, 2018), large unrestricted areas can lead to behavior challenges if there are not clear expectations and teacher guidance.

In preschool classrooms, walls provide opportunities for documentation, memory-making, and teaching (Bers, 2008). Highly effective wall displays contain a combination of work samples, conversation excerpts, and photographs (Krechevsky et al., 2013). To develop more meaningful learning for the children, Ms. Galloway made a conscious choice to remove posters that were disconnected from current classroom experiences and activities. Rich documentation supports young children's reflection, introspection (Stacey, 2015), and likely, their sense of belonging in STEM. When documentation is placed

Table 1 Examples of culturally relevant robotics across contexts

Context	*Connecting powerful idea* and example		
Classroom environment	 *Debugging:* Space for ongoing projects that children can revisit	 *Modularity:* Room for large exploration of robots	 *Representation:* Documentation and displays of current learning
Centers/Free choice	 *Control structures:* Threading and weaving toys in math/manipulative area	 *The design process:* Recyclables in art area to make robot prototypes	 *Algorithms:* Sequencing word cards in writing center
Small group activities	 *Algorithms:* Sequence a story activity	 *Modularity:* Plan a robot city	 *Hardware/software:* Explore robots together
Large group experiences	 *The design process:* Plan for and discuss robot components, functions, and community needs	 *Control structures:* Play gross motor games to explore computing concepts (i.e., passing the ball over/under)	 *Algorithms:* Collaborate to "code" familiar schedules and routines

within a certain time and place, this can provide children with reassurance that they belong in the classroom (Albin-Clark, 2020). Wall displays should evolve across the year as projects and experiences develop. For instance, teachers may choose to initially document children's engagement in robot exploration and later create displays of the design decisions children made while developing robot prototypes.

Access to various tools, materials, and robots is key when children are developing knowledge of the powerful ideas in CT. Deciding what types of robotics equipment to invest in is difficult. Robotics can be costly and the benefits of some robotics may not be fully realized if they are too advanced, more constrained, or more abstract than is reasonable for young children to benefit from. The teachers of focus in this article, and more broadly in the project from which this article stems, focused on more affordable options such as:

- Code & Go Robot Mouse (Learning Resources; https://www.learningresources.com/item-stem-robot-mouse),
- Code-a-pillar Think and Learn (Fisher Price; https://service.mattel.com/us/productDetail.aspx?prodno=DKT39&siteid=27) and
- Botley (Learning Resources; https://www.learningresources.com/catalog/product/view/id/4361/s/item-botleyr-the-coding-robot/).

Each retail for less than $55 and are durable, engaging, and sufficiently open-ended for children to explore. Many other robotics exist in the market, such as more expensive options (KIBO, for example; https://kinderlabrobotics.com/kibo/) and those which use iPads or other tablets (i.e., Scratch Jr.; https://www.scratchjr.org/) (see Yu & Roque, 2018). Regardless of which robots are selected, modeling their use is a necessary first step to encourage children to use them thoughtfully, carefully, and in purposeful ways.

In addition to robotics, it is essential for children to be given extended open-ended time to explore unplugged materials and loose parts of different sizes, shapes, colors, and textures. In many areas of the classroom, teachers can use these materials to present provocations that promote computational thinking and learning. Recycled and natural materials lead to rich sensory exploration of the powerful ideas and promote other types of interdisciplinary learning for preschoolers, particularly related to counting, cardinality, sensorimotor, and fine motor development (e.g., Sear, 2016). It is imperative to provide children with access to these types of materials for extended time periods before expecting them to create specific prototypes or products. These loose parts and recycled materials are considered culturally sustaining and a helpful way to foster connections and celebrate differences as these materials are open-ended and multifaceted (Beloglovsky & Daly, 2018). Such materials, if collected from families and community sources, can also honor cultures in ways that many store bought and commercially produced materials do not.

Centers and Play-Based Learning

- Provide center experiences that are engaging, open-ended, and connected to the powerful ideas
- Build in opportunities for problem solving

Ms. Galloway is eager to think outside the box when it comes to providing opportunities for children to develop knowledge of CT in classroom learning centers. For quite some time, there have been eight designated centers in her classroom: blocks, library, writing, art, dramatic play, manipulatives, technology, and science. Even with the systems she had in place last year, children were less engaged in play and had more conflicts than in prior years. Now that Ms. Galloway has a plan to revamp her classroom environment, she is eager to rethink how center time operates and how she supports play. Ms. Galloway remembers key concepts she learned about how center time should include choice, encourage creativity, and provide opportunities for different forms of expression and representation. She also reflects on how children need extended time to explore CT concepts introduced in small and large groups. Ms. Galloway decides her initial focus will be on the block and dramatic play areas. She plans to add four robot mice (with directional cards) and Magna-Tiles to her block area after introducing them to the children. In dramatic play, she would like children to engage in routines, act out stories, and follow recipes, all ways to connect dramatic play with the powerful idea of algorithms. She would also like the children to develop a sense of belonging in STEM by acting as computer scientists in whatever ways they imagine.

Across town, Ms. DeRose has been brainstorming ways to provide rich, collaborative experiences for the emerging bilingual learners in her class. She would like to scaffold the children to problem-solve and debug when authentic problems emerge during STEM-focused play experiences. Ms. DeRose knows this means helping children identify problems, determine approaches for solving them, and test out their plans. Since many of the children in her class are learning English, she plans to be more present during center time, positioned on the floor where she can engage with children and support their language use, as needed, but not hinder their play. Ms. DeRose is eager to foster teamwork during daily center time as children co-construct a city for their robots to travel through. (See Table 1).

Both Ms. Galloway and Ms. DeRose value a playground approach (Bers, 2021) to center time that fosters children's development of CT through discovery-based learning. When provided with time, adequate space, and appropriate materials, children can explore powerful ideas in CT through open-ended play (Lee et al., 2023). Further, making explicit connections between CT and play provides a strong rationale for why play should be fostered, not diminished, in early childhood classrooms (e.g., Kaup et al., 2023). In a blocks/construction center, children can foster understandings of the design process, sequencing, algorithms, modularity, and hardware/software while engaging with robots, blocks, and structures. Dramatic play cultivates knowledge of representation as well as sequencing and algorithms when children act out routines and stories using props and authentic devices. Puzzles and games that typically exist in many preschool classrooms can teach children about sequencing, algorithms, and debugging. In the writing center, children can learn about representation as they create stories about how robots help solve problems and engage in the design process while drawing plans for robots they want to construct. Using software on computers or tablets, children can create and code their own robots and begin developing understandings of hardware/software and control structures (Bers, 2021). In the art center, children can be designers and makers as they use recycled materials and loose parts to build robot prototypes.

Ms. DeRose and Ms. Galloway see potential in supporting children's development of CT through social-emotional, constructivist approaches. Problem solving is a key part of social emotional development (Rademacher & Koglin, 2018) and emerges naturally when children are given extended time to play (Ramani & Brownell, 2014). Problem solving can support iterative and cyclical ways of thinking. Problems can be worked on gradually, plans can be developed and modified, and new problems and questions can emerge. Children develop self-regulation skills when persisting at solving problems over extended periods of time (e.g., Bohlmann & Downer, 2016) and early persistence relates to later outcomes (e.g., McClelland et al., 2013). Also, when children can return to play scenarios, keep some block structures intact, and use building materials to engage in project work, they become invested in learning and flourish as inquirers and investigators (Helm & Katz, 2016; Mraz et al., 2016).

Small Group Experiences to Support CT

- Connect powerful ideas and cultural responsiveness in activities that support children's learning and identities
- Establish clear goals for small groups in order to build CT meaningfully

Ms. DeRose calls her first small group over to the table and explains their activity. She holds up a placard and reads it aloud: "I can sequence a story!" and then continues "Today, we are going to put the story events in order or in a sequence. Just like when we are coding our robots and have to enter the code in a certain order, we have to make sure our story events are in order." During this activity, with the use of picture cards corresponding to story events, she discusses the story events, scaffolds children remembering the order in which they appeared in the narrative, and supports the use of algorithmic language in English and Spanish to engage all her learners (first, then, next, finally becomes primero, después, próximo, finalmente). When children have misordered a few events, she stops to help them figure it out by looking at the book, taking the whole story in segments and focusing on the events in one segment before the next, and re-assembling the sequence with those students who are struggling. At the end of the activity, students are asked to write and draw the events to correspond with their sequence. (See Table 1).

In this activity, Ms. DeRose expressly supported the powerful idea of algorithms but by supporting children in problem-solving and identifying and then remedying issues means that she was also supporting debugging, even if not explicitly stated. By breaking the story apart into segments, as a form of scaffolding for those children who were struggling with the task, she was also supporting their understanding of modularity. Last, by asking children to represent their understanding of the story sequence using writing/drawing supports their representation, yet another powerful idea.

In addition to supporting powerful ideas, this activity also demonstrates how small changes and teachers learning about children can build cultural responsiveness (Boutte, 2008). By supporting children in learning key terms cross-linguistically, Ms. DeRose honors her students' home language and translanguaging practices (García et al., 2017). Choosing a book that reflects the cultures, experiences, and identities of students in her class supports children to learn about one another while also developing CT (e.g., *La Princesa and the Pea*—Elya, 2017; *Carmela Full of Wishes*—Peña, 2018). This example also demonstrates the ways in which these activities can support CT without necessarily using technology or robotics which can be daunting and/or cost prohibitive.

Small groups to support CT are effective when they have clear goals (see: Ms. DeRose's initial use of the placard at the start of the lesson so that children understand the goal; Wasik, 2008) and clear and intentional connections to the powerful ideas and cultural significance (Durden et al., 2015; Su & Yang, 2023). Other activities may include using child-appropriate robotics such as Code & Go Robot Mouse (e.g., initial explorations, comparing functionality of two robots; using the robots to craft a shared story, etc.), playing coding games (tech-based or screen-free; such as "programming" a friend to walk across the classroom), designing and building prototype robots to meet the needs of the children, classroom, or community (e.g., determining problems to solve and imagining robots that can solve them, figuring out what functions would be needed and how commands to the robot would be communicated, revising plans and prototypes as needed), working together to design solutions to problems (e.g., collaboratively building using the design process).

Using Read-Alouds and Other Literacy Experiences to Support CT

- Use read-alouds to discuss story sequences in narratively structured books; contrast these with books that lack a narrative structure
- Use read-alouds with particular CT/robotics focus to build on specific powerful ideas
- Use books about famous STEM figures to demonstrate that diverse voices are needed in STEM
- Make connections between literacy and CT through modularity and representation

While in a school-wide unit about plants and how things grow, Ms. DeRose reads Gabi's If/Then Garden *and asks children to think about how Gabi used computational thinking processes in her gardening—"if the tomatoes were red, then what happened? If they were green, what did she do?" She connected this with experiences in the community garden and knowing when and if to pick plants (like Gabi), water them ("IF it rained, THEN we don't need to water"), and what to do with them after ("IF we want to make sun tea, THEN what should we pick?"). Lastly, she broadens their discussions to talk about farming and agriculture, something many of the families of her students are involved in or familiar with.*

Similarly, across town, Ms. Galloway reads How to Code a Sandcastle (Funk, 2018) *while students are engaged in a school-wide unit on architecture, buildings, and bridges. They discuss how Pearl uses the robot to help her build a sandcastle using modularity, in other words, breaking the task down into smaller parts. They discuss ways robots can help to build cities and structures and look for robots in their* *community and the ways in which these robots help their communities and what ways robots might help to improve things even more.*

In addition to embedding CT into curricular experiences like centers and small groups, whole group experiences can also support CT. Read-alouds are an instructional routine that occurs daily in many classrooms that naturally provides authentic opportunities for CT. Computer coding is a form of literacy in which meaningful commands or codes must be communicated in a particular way for the code to be enacted properly. This is like writing and speaking, in which we must combine words to form sentences and communicate meaning. For example, in a shared, interactive writing experience where teacher and children are collaborating on crafting a morning message, a teacher might support children to arrange words in a particular order, much like codes in a sequence. The connections between computer science and literacy do not end here. In fact, many aspects of CT correlate directly with literacy skills and processes (e.g., Bers, 2021). Sequencing and algorithms can be seen plainly in stories with strong narrative structure. Many classic children's favorites, such as *The Very Hungry Caterpillar*—Carle, 1994*, If You Give a Mouse a Cookie*—Numeroff, 2015*,* and many more) reflect stories where the order of events matters to the overall story. The sequencing of story events, as a result, can be used to think through how coding works: pieces of information are put together in a specific order toward a result and by changing a part, it can change the whole. Many books reflect this structure, but also algorithms and sequences can be powerfully discussed in ways that can be culturally relevant when order matters less like in nonlinear narratives (e.g., *Be Boy Buzz*—Hooks, 2016; *Black and White*—Macauley, 2005) or books in which both order matters and does not in equal measure (e.g., *Fry Bread* includes a recipe which can be used to support coding processes as recipes mimic code structures, but also maintains a less linear narrative structure; Maillard, 2019). All students benefit from learning about the varied cultural traditions of storytelling, which can lead them to imagine innovative possibilities for computer programming and technology.

While many books can be used to intentionally target powerful ideas (e.g., algorithms and sequencing in stories with a clear sequence), there are many new stories that specifically focus on computer science, coding, and providing initial exposures to powerful ideas in computing. For example, as in the examples shared above, *Gabi's If/Then Garden* (Karanja, 2018) and *How to Code a Sandcastle* (Funk, 2018) provide helpful, child-friendly, and authentic examples of control structures and modularity, respectively. In addition to computer science-specific picture books, many books detail the lives of prolific STEM professionals and famous figures. By reading books and stories featuring characters from backgrounds that reflect the students in their classes, Ms. DeRose and Ms. Galloway show children how important STEM is and how their voices are important for STEM. Books such as *Computer Decoder* (Diehn, 2019) about prominent Black computer scientist, Dorothy Vaughan, and *The Astronaut with a Song for the Stars* (Mosca, 2019) about the first Latina astronaut, Ellen Ochoa, allow teachers to discuss these important figures, their challenges and successes, and the ways they furthered their STEM fields, providing children with the opportunity to see their own place in STEM, regardless of their background.

When, during the phonological awareness portion of large group time, Ms. DeRose works on rhyming words and reminds her students, she says "Remember, if we take the word apart, piece by piece, we can figure out the starting sound and the part that rhymes. Listen to /c/ at and /h/ at. Do those words rhyme?" When children respond affirmatively, she follows up "How do we know? What is the same about them? What is different?" Children provide a variety of answers but ultimately arrive at the initial sound being different and the remainder (or, the part that rhymes) being the same. Ms. DeRose then makes a meaningful connection for them: "Just like when we were coding our robots and we needed to break the steps down into smaller pieces, we can do that with words—this is modularity!".

Modularity, in which larger tasks are broken into smaller steps, can be seen in many aspects of the school day and life more broadly. At home, children may be familiar with taking a complex task, such as making dinner or doing chores, and breaking into smaller chunks (first, you chop the vegetables, then you cook them; or, first, you can sweep all the floors, then mop). In school, modularity can be seen in literacy, as above, but also when creating a class book or learning lines or motions of a song/dance. Modularity can be incorporated into many aspects of the school day, and drawing connections and intentionally discussing the concept of modularity can develop children's understandings of modularity, deepen curricular connections, and integrate cross-discipline connections.

During whole group meeting, Ms. Galloway writes a morning message on her board, modeling her process for children to see which is part of the regular morning routine. She writes and narrates: "Good morning, class! Today, we will have granola and yogurt for snack, and we will be programming Robot Mouse during small group time." While writing, she stops to think aloud about how to spell certain words ("I hear /r/ at the start of robot, I think it starts with R", form certain letters ("to write a lowercase t, I need a long line down and a short line across", and construct sentences to express her ideas ("I think I will share two of our activities today."). After completing the writing, she takes a second to connect to the powerful ideas explaining while reading back what she had written, "I wrote letters and *words to* represent *ideas, just like computer programmers use codes to* represent *their ideas."*

The powerful idea of representation entails using codes to represent commands like understanding that writing conveys meaning. Ms. Galloway showed the children how the *code* in text we read and write is like the ways in which coding languages express ideas. By drawing this comparison, children can start to grasp the symbolic nature of the coding process while they are simultaneously emerging in their literacy understandings. Ms. Galloway also provides children with opportunities to demonstrate different ways writing can be used, for example, in messages, notes, and letters like this example, creating classroom books with children, modeling writing instructions or lists, and more. In these instances, Ms. Galloway is quick to remind children about how letters, words, and sentences *stand for* ideas, representing something, the same way that codes represent algorithm actions.

Focal, Cumulating Experiences

- Create summative experiences that stimulate children to work together to answer big questions, such as solving societal problems and addressing community issues
- Use iterative problem-solving steps (i.e., the design process) to ask questions, brainstorm solutions, plan and goal set, test solutions, and share more widely

Using their general curriculum, Ms. Galloway is finishing up a unit with her students about the environment. To draw in some connections to robotics and build children's CT, she has been discussing environmental issues in their community throughout the unit. At the end of the unit, Ms. Galloway and the children work together, using the powerful idea of the design process, in which various steps are taken in order to address questions and problem solve. Ms. Galloway shares with students that they will build a robot together to solve community challenges. To begin, Ms. Galloway and her students discuss what is meant by community*—discussing their classroom, school, neighborhood, and city and discussing important elements of these communities. Children brainstorm solutions to issues facing their community—"If the robot has long arms, it can pick up litter!" and "Maybe it could have a horn to blast at cars that go too fast by the school." After these conversations over the course of a few days, recording children's ideas and suggestions, and building prototypes as a part of small group experiences, Ms. Galloway and the children work together to build a robot using materials recycled from homes and the classroom. They determine how the robot will function (i.e., what does it need to do to meet the community's needs?) and they determine how the functions will be enacted (i.e., how will we be able to "code" the robot to enact its tasks?). Using old cardboard boxes, straws, popsicle sticks, an old funnel, tubes, and other loose parts and recycled materials, children build a robot. Though the robot does not work in the traditional sense, the children and Ms. Galloway imagine and discuss its functions, how it might be programmed, and all its possibilities within their community.* (See Table 1).

This example of practice in Ms. Galloway's class demonstrates an approach to robotics education that does not actually involve any robots at all, but rather imagines their possibilities. While older children and youth may be able to use technology to address genuine social issues (e.g., Scott et al., 2015), teachers can mimic this experience for young children through imagined and play-based scenarios (Harper et al., under review). This activity specifically allows teachers to work with children to use the design process to ask questions about a problem or complex issue, imagine possible solutions, plan how to reach goals and enact solutions, and eventually create these solutions. From here, teachers can help children "test" their creations—does it meet the needs of the community? If this robot were operable, would it achieve their objective? Does it alleviate the complex problem? Children and teachers can work together to improve their designs and plans, and share what they have designed. Often, in sharing, they come to new questions and new problems to solve, thus starting the cyclical design process all over again. This specific activity supports children in considering their own communities and naturally provides opportunities to explore community resources and assets, as well as challenges.

Conclusion

Through intentional integration of culturally relevant computer science and CT activities across the school day, Ms. DeRose and Ms. Galloway are not only supporting their students' computational thinking, but also their sense of belonging in STEM by showing children that they are STEM users, that computer scientists and engineers look like them, and their powerful ideas are needed in STEM fields. By building and promoting open-ended play, choice, and children's agency in their classroom designs and center time, by supporting children's home languages, by including books and materials that reflect children's identities, lives, experiences, and contexts, and by using STEM and robotics experiences to help students solve social, societal, and community problems, teachers are engaging in culturally responsive instruction to support CT.

Through leveraging existing routines already taking place during the day, implementing CT activities for young children was within reach. Just adding a few materials to centers or reading a few relevant books during read-aloud time can provide an entry into these important practices.

This can lead to the addition of activities—small and whole group, alike—aligned with the powerful ideas that are relevant to children's cultural backgrounds and contexts and that will further learning and provide opportunities for connected activities across the day and around the room. These experiences support children's CT, but equally as important foster interest and engagement in STEM disciplines. There is untold potential of early childhood classrooms to be spaces in which children, particularly those from backgrounds that are underrepresented in STEM fields, have initial, high-quality, open-ended, and engaging exposures to coding, computer science, and computational thinking. That these experiences can be tailored to encompass and align to children's cultural backgrounds makes them even more powerful.

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Declarations

Conflict of Interest The author declare that they have no conflict of interest.

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