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Exploring Design Principles in Computational Thinking Instruction for Multilingual Learners

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Abstract

Background: Multilingual learners have been overlooked and understudied in computer science education research. As the CS for All movement grows, it is essential to design integrated, justice-oriented curricula that help young multilingual learners begin to develop computational thinking skills and discourses.

Purpose: We present a conceptual framework and accompanying design principles for justice-centered computational thinking activities that are language-rich, with the aim of supporting learners' agency and building their capacity over time to use computing for good in their communities.

Setting: Our work takes place in a research–practice partnership centered in an elementary school in California with a significant multilingual Latinx population.

Research Design: We have engaged in two cycles of design-based research with preservice and in-service teachers at an elementary school. Through analysis of one case study during the second and most recent cycle, we examined the potential of teachers using our design principles for supporting multilingual learners' language development through engagement in computational thinking.

Conclusions: Our findings suggest that multilingual learners will engage in productive discourse when computational thinking lessons are designed to (1) be meaningfully contextualized, (2) position students as agentic learners, and (3) promote coherence over time. However, more research is needed to understand how teachers use these principles over time, and what additional supports are needed to ensure coordination

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between stakeholders to develop and effectively implement coherent learning progressions.

Keywords
computational thinking, elementary school, multilingual learners, epistemic agency, language development

Interest in computer science (CS) education has grown significantly in the United States since the national CS for All initiative propelled CS education and computational thinking (CT) forward as an educational priority (Smith, 2016). CS education efforts, however, have primarily focused on secondary students learning programming skills (Blikstein & Moghadam, 2018). Bringing CS to *all students* requires an approach that recognizes the structural power dynamics and inequities embedded in the U.S. educational system and actively resists the marginalization of students underrepresented in science, technology, engineering, and mathematics (STEM) learning. Thus conceived, CS education is both an educational imperative and a social justice goal (Margolis & Goode, 2016; Vakil, 2018), in addition to an essential problem-solving approach and discourse broadly applicable to everyday life (Grover & Pea, 2013). Moreover, we posit that structuring the learning of discourses in domains to complement underserved learners' existing strengths (see Gutierrez, 2008; Warren et al., 2020) better positions students to have agency in their learning and can better connect CT concepts and practices with purposes they see as relevant to their communities.

Multilingual learners (MLLs), who represent a growing number of marginalized learners, are often overlooked and understudied in CS education. This condition might be the result of the common misconception that MLLs are not able to learn content, especially STEM content, until they are fluent in English (Lee & Stephens, 2020). Yet, research has shown that MLLs can learn language and STEM content simultaneously (Celedón-Pattichis & Turner, 2012; Lee et al., 2013), especially when they are encouraged to translanguage (Vogel et al., 2019) and leverage their complex linguistic and social identities (Jacob et al., 2020). CS education must therefore be thoughtfully planned and widely available, and teachers who work with MLLs must be prepared to provide quality CS instruction.

In this article, we describe how a novice preservice teacher (PST) incorporated CS into her teaching—with corresponding language objectives—using three design principles that we believed would act as a useful guide in the lesson's development and implementation. This case study and design-based research (DBR; Barab & Squire, 2004) approach allowed us to test our design principles. In short, we wanted to put our ideas "in harm's way" (Cobb et al., 2003) to assess the potential of our design principles, and we did so by collaborating with the PST on the lesson planning, materials, and methods (e.g., Fernandez & Yoshida, 2012). Researchers, the PST, and other practitioners engaged and supported this work at an elementary school in California as part of efforts in a larger research–practice partnership (RPP; Coburn & Penuel, 2016).

Project Background

The RPP's overarching goal was to provide equity-oriented CS (Denner & Campe, 2018) for Latinx MLL students and their families across the district, with the wider goals of developing global citizens, critical thinkers, and communicators. A three-part strategy was designed to meet these goals: (a) integrate CT into the core curriculum and develop a K–8 pathway for CS, (b) engage families in computing, and (c) build long-term local support for CS education in local schools. As part of the first strategy, we recruited PSTs to develop and pilot elementary lessons that integrated CT into core subjects. Working with PSTs provided the RPP with the flexibility to test design approaches and better navigate competing school and district initiatives.

The school, Marea Elementary,[2] is a Title I school in California. More than 67% of the students are Latinx, and the majority are of Mexican descent. A total of 40% of all students were designated English learners at the time of our study. Marea does not have a bilingual or dual-language program, and almost all instruction is conducted in English. This mainstream instructional approach offered an opportune test of our design principles.

Our DBR approach permitted us to investigate cycles of design and implementation of strategies to integrate CT into core content. DBR requires taking into account the structural opportunities and constraints that educators face. In our case, Marea Elementary had already engaged in a multiyear professional development program for language teaching built on Project GLAD (see Education Northwest, 2018). Fortuitously, the GLAD design relies on content-based instruction to drive language learning and therefore matched well with our project goals.

Computational Thinking Practices Include Language and Literacy Development

In our project, we recognized the following CT concepts as foundational to future CS learning: decomposition, pattern recognition, algorithms, and abstraction (International Society for Technology in Education & Computer Science Teachers Association, 2011). In addition, we also considered the following practices of CT (Barr & Stephenson, 2011; Grover & Pea, 2018)—iteration, moving between levels of abstraction, using CT vocabulary, collaboration, and communicating to achieve common goals—to be powerful tools for language acquisition. Indeed, language itself is a set of communicative repertoires embedded in human actions and learned through participating in discourse communities (Valdés et al., 2014). Activities such as projects, presentations, and investigations encourage language growth through a variety of linguistic tools (van Lier & Walqui, 2012). Similar to mathematics, CS is sometimes

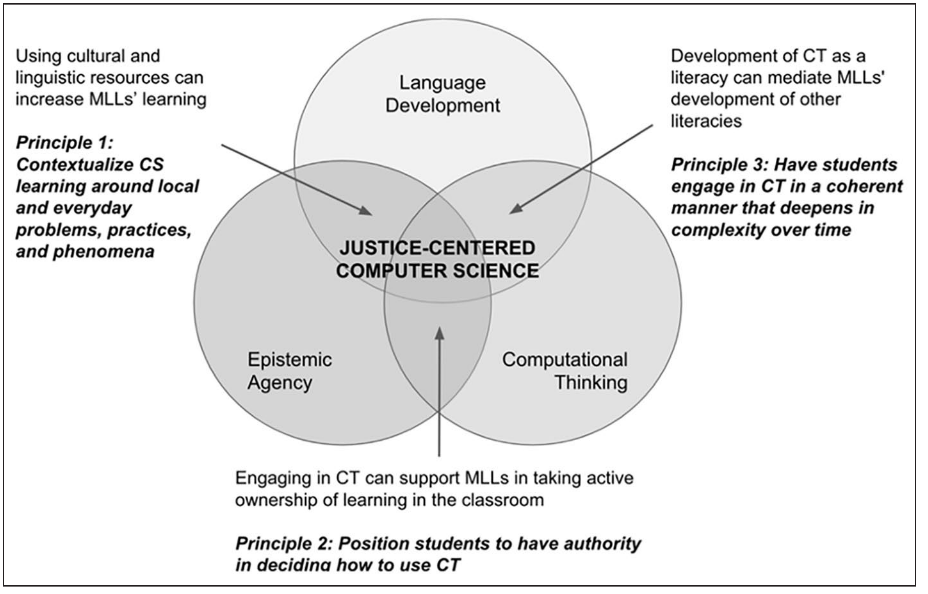

Figure 1. Conceptual framework.

naively thought to be language-neutral; this view ignores that languaging and literacies are necessary for communicating with others in order to understand, solve, and present artifacts from a computing task. The necessity of language to CT is evident when students engage in it; for example, "You will hear them talk about sequences, inputs, outputs, saved value, how complex a solution is" (Barr & Stephenson, 2011, p. 51). Such collaborative approaches facilitate learners' engagement with interpretive and productive language practices—keys to developing literacy in a content domain (e.g., Lee et al., 2013). Furthermore, research has demonstrated that when elementary students engage in CT, they develop fundamental ideas around social justice, such as fairness, community, empowerment, and action (Denner et al., 2015), which can prove to be engaging contexts for underserved students (Anderson & Adams, 1992; Sólorzano et al., 2005).

Framework and Principles for Equitable Computational Thinking Integration

Drawing on research in sociocultural language development, best practices in MLL instruction, and CT learning, we developed a set of design principles that embody our conceptual approach to justice-centered CS learning. Our three-part conceptual framework is shown in Figure 1.

As indicated, our design principles focus on creating opportunities for heterogeneity or hybridity (Gutierrez, 2008; Warren et al., 2020), meaning that MLLs can use their cultural and linguistic resources in concert with CS and with core subject concepts and practices. The emphasis on MLLs' having agency in their navigation of CS reflects a commitment to equity, specifically in terms of designing learning opportunities that privilege students' strengths and aiming for universal accessibility (Rose & Meyer, 2002). While our principles share a focus with previous work that provides guidance on how to promote MLLs' learning in core subjects by engaging students in disciplinary practices and privileging students' prior knowledge and experiences (e.g., Understanding Language, 2013), we view CS not as simply another domain for MLLs to master; instead, we see it as an additional literacy to be leveraged to support learning, one that resonates with students while promoting language development. Next, we offer a summary of our design principles:

1. **Concretize CT opportunities within core instruction by contextualizing learning to revolve around locally relevant or everyday phenomena and problems.** Contextualized learning for abstract concepts is an important component of effective STEM teaching, but it is crucial for MLLs to comprehend lessons and be able to participate productively (e.g., leveraging funds of knowledge; Moll et al., 1992).
2. **Position students with authority to continually exercise volition in using CT concepts and practices**. This includes creating conditions that are language-rich, prioritize collaboration and communication, and are inclusive of MLLs' linguistic practices, such as translanguaging, gestures, and other nonverbal communication.
3. **Aim for coherence over time to have students collectively build up their capacity for engaging in CT**. Longitudinal engagement with CT is critical for MLLs to develop the skills and literacies they will need to contribute productively to social justice efforts in an increasingly computational world as they grow.

Although these principles were tailored for our context, we believe that they may generalize to any condition in which educators and researchers are working toward an equitable future in CS education; one that assumes MLLs deserve CS instruction. As "principles," they serve as a guide, a means to support and enhance teachers' professional agency for how to develop and enact innovative and equitable instruction within their classroom, with the broader aim of supporting productive shifts in instruction across an entire educational system (e.g., school district).

It is important to note that our principles are rooted in effective teaching practices for MLLs (Goldenberg, 2013). Following sociocultural approaches to facilitating language development, we place an emphasis "on integrated conceptual, academic, and linguistic development and activities that encourage student interaction and include both planned and in-the-moment scaffolding" (Valdés et al., 2014, p. 22). In classrooms where MLLs and their monolingual peers are expected to learn side by side (cf. the context at Marea, our focal school), it is critical to create environments where language supports are embedded in the design of the lessons and offer all students a chance to master concepts. For CS and CT learning in particular, given that they are new curricular components, MLLs must have access to both high-quality CT instruction and high-quality language facilitation to achieve justice in and through CS learning.

Within each of the following three subsections, we examine key ideas from our framework, as informed by prior research, before delving into how we have envisioned operationalizing and making these ideas more tangible with our three design principles.

Using Cultural and Linguistic Resources Can Increase MLLs' Learning

Our linguistic focus follows Bunch and Martin's (2021) argument for frameworks that help researchers and educators see what MLLs *do* with language in academic contexts and how they use disciplinary practices to display their thinking. This asset-based perspective anchors the principles in the recognition that MLLs have a wealth of linguistic resources they can use in service of academic learning (e.g., Martínez & Mejía, 2020; Vogel & García, 2017), and it emphasizes the importance of positioning students with the agency to actively grapple with how to use content and language to accomplish tasks. Because language is learned through use in social contexts and is a medium for learning (e.g., Vygotsky, 1980), we understand that its development is supported by effective disciplinary instruction (e.g., National Academies of Sciences, Engineering, and Medicine, 2018). For example, Celédon-Pattichis and Turner (2012) found that explicit language instruction helps MLLs understand how language is learned within mathematical discourse. Content learning is made visible when the requirements of language are explained and students are encouraged to use their entire linguistic repertoires, including nonverbal communication, to understand challenging content (Dominguez, 2005; Turner et al., 2013).

Design Principle 1: Concretize CT Opportunities Within Core Instruction by Contextualizing Learning to Revolve Around Locally Relevant or Everyday Phenomena and Problems. Purposefully anchoring CT and core instruction within contexts relevant to students, such as solving an everyday problem or exploring an observable phenomenon (Rivet & Krajcik, 2008), can support students in making their learning purposeful and meaningful. Contextualizing learning allows MLLs to more readily leverage their prior knowledge and experiences in service of acquiring CT concepts and practices for their own use, including through computational discourse. Additionally, anchoring instruction around tangible real-world phenomena through multiple representations helps both MLL and monolingual students overcome the abstract nature of CT

(Griffin et al., 1995; Grover & Pea, 2018). CT instruction, by design, approaches language as a means to reach a wider cognitive objective. Thus, strategically examining *how* language is used in a given CT context is critical for anchoring MLLs' understanding (Gibbons, 2018).

Engaging in CT Can Support MLLs in Taking Active Ownership of their Learning

All students can become epistemic agents who take the lead and have the authority to shape knowledge and practices in their learning community, and educators should help students believe that they can construct knowledge themselves and be expert practitioners of a domain (Miller et al., 2018). This includes creating the conditions that facilitate MLLs' expression of ideas within the domain, for "languaging practices are . . . intertwined with the nature of the discipline itself and its epistemology" (Bunch & Martin, 2021, p. 547). To this end, we draw on the notion of a "secondary stimulus" to support the design of experiences for MLLs to engage with CT. Vygotsky (1980) described how a secondary stimulus in his experiments could promote agency for the learner. The "first" stimulus is the task or problem, and the "second" stimulus is an object that has some degree of ambiguity (e.g., a clock). Learners choose how to imbue or complete the second stimulus with their own cultural and linguistic resources to make it useful and meaningful for attending to the first stimulus. For situations with no set solutions, participants can better negotiate their own solutions to a problem through the support of secondary stimuli. We posit that positioning MLLs to co-construct CT knowledge by using their prior knowledge and linguistic resources can support students' epistemic agency; over time, this approach can develop students' agency for collective and transformative purposes (Sannino et al., 2016).

Design Principle 2: Position Students With the Authority to Continually Exercise Volition in Using CT Concepts and Practices. Students should be positioned to take ownership of their learning and have opportunities to actively express and use their knowledge (Lee et al., 2013), which situates students to have agency in how they develop knowledge and the capacity to use practices associated with CT and core disciplines. Language itself becomes a way for MLLs to express their agency (van Lier & Walqui, 2012). More tangibly in terms of envisioning students' agency, students should have the authority to make choices in their own learning as part of taking on the intellectual responsibility in a classroom for collectively deriving new knowledge and meaning (Blumenfeld et al., 1991; Severance & Krajcik, 2018). Special attention should be given to tools or arrangements that increase students' epistemic agency, particularly as it relates to increasing their capacity for using CT. Vygotsky's (1980) work suggests that carefully designed secondary stimuli become both an artifact of the culture and a tool for accomplishing tasks. Applied to our current context, instructional objects in

CS, such as an empty flowchart or conditional logic sentence stems, become mediational means to support students in accomplishing more with CS objects than they would without them, thus promoting agency. For MLLs, being positioned as active participants in classroom discourse, capable collaborators, and agentic learners is critical for learning (e.g., Turner et al., 2013; Yoon, 2008).

Development of CT as a Literacy Can Mediate MLLs' Development of Other Literacies

As a literacy, CT represents a set of problem-solving skills and communication processes that use computational tools for sense-making and the expression of ideas (Jacob & Warschauer, 2018). However, computational literacies are linked with MLLs' existing multiple literacies, such as understanding the norms of communication for a particular audience (Martínez & Mejía, 2020; Vogel et al., 2019). From an early age, children deploy their literacies through language to accomplish a variety of tasks, enlarging their capacity to communicate and thereby participate in ever more complex linguistic interactions (Lee et al., 2013). Activating and building on students' prior knowledge coherently is particularly important for MLLs to contextualize new concepts, learn disciplinary discourse, and engage in dialogic learning (Téllez & Waxman, 2006). Hence, CT literacies are tools supporting further computational discourse learning. Notably, as MLLs acquire the discourse of a discipline like CS over time, they should do so in a heterogeneous manner in concert with their existing strengths (Gutierrez, 2008; Warren et al., 2020).

Design Principle 3: Aim for Coherence Over Time to Have Students Collectively Build Up Their Capacity for Engaging in CT and Develop CT Literacy. Scaffolding coherent learning progressions for MLLs requires not just generic support for participation, but also specific support so that students can contribute to classroom discourse (Athanases & de Oliveria, 2014). Students should have the opportunity to build and deepen their knowledge in a coherent manner over time (Fortus & Krajcik, 2012) rather than learning different facets of CT in isolation and disconnected from one another. Students should also have a sense of the collective purpose of their learning as they build their knowledge and deepen their engagement with content over time (Reiser et al., 2017). Previous work has shown that interdependent activity and collaboration appear with regularity in everyday activity, and designed learning settings may benefit from using similar activity structures or valuing activity in which the end purpose benefits the group (Rogoff, 2014; Severance, 2021).

Examining the Promise of the Design Principles

As of this writing, we have completed two cycles of DBR, each involving unique cohorts of PSTs who volunteered to develop and implement CT lessons outside their regular coursework with the support of researchers and district personnel. The first cycle, in early 2020, explored possible approaches to using CT for language development, including the potential of PSTs as primary participants. We found that working with the PSTs provided important flexibility within the real, and often constrained, situations of schools and also provided us with ample material to develop design principles that could better support teachers of all experience levels in using CT for language development. The second design cycle, in fall 2020, focused on refining and enacting our design principles with a new PST and with the narrower aim of understanding how to better develop instruction to support MLLs in engaging with CT disciplinary content and discourse. This article focuses exclusively on data collected during the second design cycle.

Participants and Methods

Three education researchers, the district's CS coach, and a cooperating teacher supported the PST, Catherine, in her design of a lesson. The lesson aimed to allow students to begin to build an understanding of different aspects of CT (e.g., decomposition, pattern recognition, algorithms, and abstraction) and create opportunities for MLLs to take up CT discourse with their peers. At the time of the study, Catherine was in her early 30s and self-identified as white. She was pursuing a multiple subject teaching credential, had extensive experience as a substitute teacher, and had very limited Spanish skills. Through coplanning sessions with Catherine and district CS coach, researchers seeded key concepts from the principles into discussions and into written feedback on lesson materials (e.g., presentation slides). We did not expect Catherine to create an exemplary lesson embodying all aspects of the design principles; rather, we saw her design work as the initial steps of a longer trajectory of professional learning. As such, we focused on how she engaged aspects of the design principles to gain insights into the challenges teachers may face when using the principles to develop longer lesson progressions. We collected multiple sources of data, including (1) video recordings of Catherine's enactment of the lesson (which were content logged for coding); (2) lesson materials developed by Catherine; (3) field notes of planning and debrief sessions between Catherine and the district CS coach after enacting lessons; and (4) Catherine's written reflections on lesson enactment. All lesson development and implementation occurred online because of the COVID-19 pandemic.

Analysis

The data were analyzed using a case study approach (Yin, 2009) to identify evidence that could support (or refute) claims about how effectively our design principles support the design of instruction that employs CT to facilitate language development. The initial coding scheme employed a deductive approach, with coding categories derived from our conceptual framework; an inductive approach was used to revise the coding scheme as new categories emerged (Saldaña, 2011). Two researchers applied the initial coding scheme to data excerpts; differences led to discussion in which the researchers renegotiated the coding scheme to reach agreement. The final coding scheme consisted of six categories: CT, sociocultural pedagogy, English language development (ELD), STEM pedagogy, epistemic agency, and teacher learning. From the analysis, we selected data to present that best articulate indicators of the promise and challenges of the design principles for teachers unfamiliar with facilitating language development via CT.

Case Example: Creating Algorithms in an English Language Arts Technology Unit. Catherine was placed in a first/second-grade classroom and had taught the class on her own before implementing this lesson. Her goal for integrating CT was to learn a new content area and make lessons accessible for MLLs who were struggling in English language arts (ELA).

Catherine taught a 20-minute lesson to 12 second graders, six of whom were designated English learners but were not newcomers, and six of whom were identified as English-only. The lesson introduced the students to simple algorithms as part of the launch of a new ELA unit centered on technology. In the opening lesson of the ELA unit, students saw an image of a robot carrying a tray of food. Using that image, Catherine designed an activity for students to create algorithms, described as "a list of steps to follow" or a "sequence," in order to help the robot deliver the food to Dog Man, a beloved book character (see Figure 2). The choice of centering the lesson on helping Dog Man sparked students' motivation and concretized an abstract concept in a problem they could understand (Design Principle 1). This lesson was also meant to build on the last lesson of the previous unit, in which students considered the properties of a computer; this lesson built a coherent path for students to engage with CT (Design Principle 3). Additionally, Catherine attended carefully to the comprehensibility of the lesson and included multiple representations of content and language scaffolding throughout. The multimodal components of the lesson provided alternate representations of the content to assist with comprehension; they also prompted the students to respond in writing, drawings, and verbally, following GLAD strategies for input and guided language production and creating the conditions for a linguistically rich lesson in which students could be successful in contributing to their own learning in multiple ways (Design Principle 2).

During the lesson, students first watched a short video introducing the theme of the unit. Second, the students looked at pictures of technology and typed questions they had about the pictures into prepared slides. Catherine selected a few who shared their thoughts verbally with the class. Third, Catherine drew the students' attention back to the robot carrying a tray of food and set up the problem of getting the food to Dog Man, who was "soooo hungry!" "We have the power to help the robot with sequencing," Catherine told the students. "What steps does the robot need to take to get to Dog Man?" Students drew at least one path through the grid, presented using another slide (see Figure 2). Catherine also encouraged the students to find multiple paths through

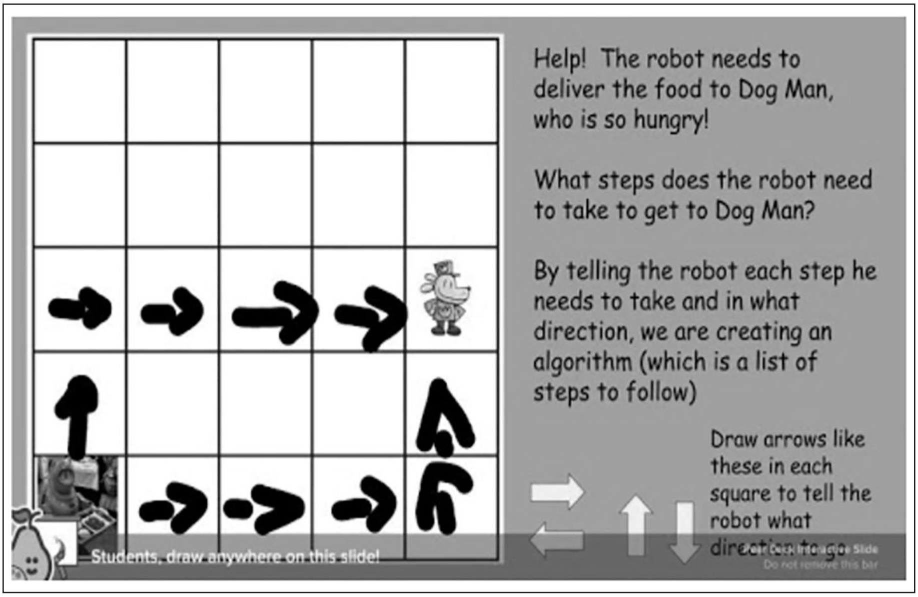

Figure 2. Carla's solutions to get the food to Dog Man.

the grid. "Do you think there are a few different sequences that he can use to get to Dog Man and deliver the food?" she asked the second graders. Finally, the students wrote a sentence about what they had learned in the lesson into a second prepared slide.

At the end of the lesson, Catherine also challenged students to extend their learning about sequences to their homes and to think of algorithms to get from their bedrooms to their kitchens. We focus our analysis on the third activity because it was where students' problem-solving practices and CT discourses were most elicited.

Catherine spoke continuously throughout the lesson, carefully enunciating and describing the new vocabulary words "sequencing" and "algorithm" in different ways. She also made an effort to give all students a chance to speak at least once during the lesson, doing what she could to give them opportunities to learn dialogically within the constraints of distance learning. When students shared their sequences, she engaged in dialogue, praising them and encouraging them to verbally explain their thinking. Though the pattern of discourse also followed an initiation-response-evaluation (IRE) structure, the responses from the students demonstrated the complexity of their thinking. For example, Catherine scaffolded two students designated as English learners, Carla and María, to develop CT positionality and discourse:

Carla: I do front and then two up because there's how he gets to that. Then the next is that he goes up and to and to the right. And then- *[Catherine interrupts]*

Catherine: Excellent work. *[Pause, waiting for Carla to finish speaking. Continues when Carla is silent.]* Great job, Carla. Thanks for sharing your sequence. María?

María: Well, he goes up and this side *[moves her arm up and across her body from left to right, tracing the line she drew in the air]*

Catherine: Very good. So he just goes up. How many times does he need to step up?

María: Um, he has go- *[video lags and audio cuts out]*

Catherine: He steps up. . . *[prompts María to continue]*

María: *[audio returns]* . . .three times and to the side he has to go *[audio cuts out]* two times to the
side

Catherine: Very good María. Thank you for breaking that down for me.

In this example, Carla's and María's explanations indicate their emerging yet perfectly intelligible English, as well as their understanding of the task. Notably, María makes use of gestures to convey her solution, which Catherine accepts; Catherine then provides targeted verbal scaffolding to help María give her response in words and gestures. By responding to their ideas and eliciting full participation in class, she positions Carla and María as knowledgeable contributors in the CS lesson and validates their problem-solving methods. It should be noted that at this point in the lesson, a few of the English-only students had shown that they were familiar with this kind of problem and had shared shortened versions of their solutions (e.g., "go to the right four times and up twice"). Catherine, however, paid close attention to these participation structures and made a deliberate choice to ensure that the MLLs in the class were heard.

Analysis and Discussion

Subscribing to perspectives in DBR that call on researchers to test and refine ideas by putting them "in harm's way" (Cobb et al., 2003), this study examined how teachers new to computing, a novice PST in this case, might take up design principles intended to support language development through CT. We discuss next how Catherine engaged each design principle in her lesson design and implementation.

Exploring Design Principle 1: Contextualizing and Concretizing CT Within a Familiar Context Promotes Comprehension and Engagement

In this lesson, students' familiarity with Dog Man allowed them to connect with the problem presented (e.g., eating, delivering items). Catherine's challenge to students to describe how they might navigate their own house at the end of the lesson also contextualized the relevance of CT to students' everyday lives. Notably, Dog Man seemed to draw both MLLs and English-only students into the lesson, which highlights that "relevant" problems in these contexts (e.g., young learners' lived experiences and their affinities with media) are indeed cultural but not always connected to students' ethnic or linguistic heritage. The degree to which such references must be both popular among children *and* related to MLL cultural backgrounds is an open question. For instance, would MLLs have responded differently if instead of Dog Man, El Chavo, a very popular character on a long-running television show in Mexico, was the character in the lesson? While Catherine's design choices in this instance demonstrate the promise of orienting toward Design Principle 1, choosing an effective context and problem that will resonate with MLLs and allow them to better access and leverage their cultural and linguistic resources effectively in a "hybrid" (Gutierrez, 2008) manner with CT concepts and practices will remain an ongoing design challenge, particularly for a sequence of multiple lessons. Notably, the depth of design support Catherine received as part of the RPP would be challenging to replicate on a larger scale. This points to the need for planning tools—such as exemplar contexts created with or vetted by students and mapped to CT ideas—that teachers can engage with in lieu of close collaboration with researchers and district personnel.

Exploring Design Principle 2: Student Agency and MLLS' Languaging Opportunities

Various aspects of Catherine's lesson hint at the benefits of having teachers engage with Design Principle 2. The blank grid between the robot and Dog Man served as a "secondary stimulus" (Vygotsky, 1980) and helped promote students' agency in their own learning by mediating students' engagement in discrete aspects of CT (e.g., algorithms). The grid productively constrained the options for students and allowed them to bring their own choices and ideas using familiar, universal symbols (e.g., arrows) to complete the grid and form a possible algorithmic solution. These grids then served as a referent for communicating the student's thinking with others. The Dog Man activity also called on students to derive one of many possible solutions and draw on multiple language resources when communicating their solution, enhancing their participation in class. Engaging multiple resources (e.g., the grid, gestures, and words) indicated the multimodality of students' CT practice and their capacity to use CT tools to support their own learning. Catherine also called on all the students in the class and noted their verbal contributions. Though her interactions with students followed an IRE pattern, she ensured that student voices were heard online, when the default was for all students to be on mute. In addition, students were given multiple modes to express their understanding of the material and were encouraged to go beyond the minimum expectations of the activity to find different solutions and simplify their instructions, setting them up for future CS learning on efficient paths and loops. Although Catherine supported students in having agency in their own learning through the tools she provided and multiple modes of engagement, it remains unclear to what degree MLLs saw themselves as having more control and authority over their own learning. The long-term aim of students becoming agentic learners—to support development toward becoming agents of change—underlies Design Principle 2. More research is needed to understand how this may unfold over time in conjunction with students' languaging and literacies. Emphasizing the need to intentionally support students in recognizing their own power for learning and beyond could prove valuable for teachers' design work and justice aims.

Exploring Design Principle 3: Building Content Coherently Supports Future Learning

While Catherine had the opportunity to implement only one lesson, her initial foray provided useful indicators of the direction her instruction might take over time and her own understanding at the time of features of Design Principle 3—namely, the notion of coherently building students' learning over time. Students' engagement with CT focused tightly around only one CT concept: algorithms. Because they had to grapple with only one concept, students could explain their solutions and receive verbal scaffolding to deepen their understanding and hear CT discourse in context. The experiences of students reflect an intentional planning choice by Catherine to have students engage with and build CT concepts over time—as opposed to oversaturating the lesson with new CT concepts and hence diluting students' opportunities for deep engagement. This choice aligned with plans by her cooperating teacher to develop a longer coherent sequence of lessons. While we saw some indication of how teachers may productively take up Design Principle 3 in lesson design—and hence positively direct students to trajectories that increase their capacity for using CT over time—we acknowledge that coherence is challenging to design for (Reiser et al., 2017). Longitudinal observations of teachers' uptake of Design Principle 3 would provide insights for how to tighten coordination among those providing support to teachers—mentor teachers, district specialists, and researchers—in order to design for coherence across multiple CT lessons (i.e., units).

Conclusion

Our study tested a set of promising design principles—derived from a conceptual framework that integrates ideas on CT, language development, and student agency—that can serve to orient researchers, teachers, and others in developing learning opportunities that empower MLLs to develop computing discourse and be recognized as knowledgeable contributors. Enacting the design principles has brought into focus promising aspects of the principles and surfaced possible challenges that teachers new to CT may face when taking up the design principles to develop language-rich CT opportunities.

Whereas prior work in informal spaces has integrated CS and social justice (Denner et al., 2015), this study points toward the substantial support that elementary teachers may require in formal spaces to support MLLs' development into agentic learners over time and toward being able to use CT with their existing strengths to address increasingly complex problems relevant to their lives and communities. To better support teachers in navigating the intertwining trajectories of CS, language development, social justice, and established standards and curricula, more work is needed to theorize and test the role of design principles in supporting such trajectories, perhaps borrowing strategies from research on learning progressions (National Research Council, 2007).

The results of Catherine's lesson offer useful strategies for classrooms engaging in distance learning with limited verbal participation structures available—as well as those engaged in in-person learning that follows a traditional model of didactic instruction—to better engage MLLs in computing discourse. Further research is needed, however, to explore how to best support the coherent integration of computing discourse within the often constrained instructional spaces of elementary classrooms. As we continue to test and refine the design principles put forth in this study, we invite others to test the utility of our principles and conceptual framework within different contexts. Through such dialogues, researchers will gain needed insights into how to organize more innovative design work and achieve more equitable and just opportunities in which MLLs can productively engage in CT that drives language development.

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1. The first two authors contributed equally to the work.
2. All proper nouns are pseudonyms.

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