London Review of Education

LONDON REVIEW OF EDUCATION

UCLPRESS

Special issue: ***Culturally responsive STEAM education***

Research article

Developing teachers' cultural competencies through co-design of robot-coding mathematics activities for Latinx and Black elementary school students

Irina Lyublinskaya,[1,*] Sandra Okita,[1] Erica Walker,[2] Xiaoheng (Kitty) Yan[2]

[1] Teachers College, Columbia University, New York, USA
[2] Ontario Institute for Studies in Education, University of Toronto, Toronto, Canada
* Correspondence: il2369@tc.columbia.edu

Submission date: 18 September 2023; Acceptance date: 28 February 2024; Publication date: 10 April 2024

How to cite
Lyublinskaya, I., Okita, S., Walker, E. and Yan, X. (2024) 'Developing teachers' cultural competencies through co-design of robot-coding mathematics activities for Latinx and Black elementary school students'. *London Review of Education*, 22 (1), 11. DOI: https://doi.org/10.14324/LRE.22.1.11.

Peer review
This article has been peer-reviewed through the journal's standard double-anonymous peer-review process, where both the reviewers and authors are anonymised during review.

Abstract

This year-long case study involved the professional development of teachers in New York City elementary schools, who co-designed with researchers culturally relevant robot-coding mathematics activities to advance teachers' understanding of culturally responsive mathematics pedagogy. Study findings indicated that co-designing culturally relevant robot-coding mathematics activities led to the development of teachers' cultural competencies, deeper understanding of culturally responsive mathematics pedagogy and their students' cultures, stronger agency, and ability to integrate culturally responsive pedagogy into their mathematics curriculum. Teachers also began to perceive the robot as a mathematical tool rather than a motivational add-on, and started to develop their own cultural lens while focusing less on school structure constraints. The study emphasises the importance of engaging teachers as active co-designers of culturally relevant coding curriculum in professional development programmes.

Keywords culturally responsive mathematics pedagogy; cultural competency; design thinking; elementary school mathematics; robot coding; professional development

Introduction

Research shows that students' mathematics knowledge is tied to their cultural practices, and that students perform better on tasks that are linked to their everyday experiences (Thanheiser and Koestler, 2021). In American schools, mathematics tasks are often placed in a real-world context that White, middle-class students are familiar with, but racial and ethnic minority students may not be (Tilleczek and MacDonald, 2022). The lack of connection between school mathematics and student everyday lives diminishes student interest in mathematics as early as in upper elementary grades (Putwain et al., 2018). This has an even larger impact on students from sociocultural groups who on average lag behind their peers (Edwards and Parada, 2022).

Schools need teachers who are aware of students' cultural norms and experiences in order to influence their learning. However, the notion of culturally responsive teaching does not always resonate with teachers, and when it does, they do not know how to teach their subjects from that pedagogical stance (Ladson-Billings, 2000). Culturally relevant pedagogy could address these areas of concern. However, few tools are available to explicitly support teachers' development of culturally relevant pedagogy competencies within their daily planning and implementing of mathematics lessons (Mark and Id-Deen, 2022).

There is increasing recognition in relation to the K–12 new standards in New York (NYSED, 2020) that introducing robot coding to children as early as kindergarten is desirable in developing students' computational thinking and digital fluency (Angeli and Valanides, 2019). Integrating robot coding into mathematics instruction in elementary school can help make this subject more engaging and relevant to students (Zhang et al., 2021). Supporting teachers in combining coding with culturally relevant pedagogy into standards-based mathematics classrooms has potential to improve students' content knowledge and attitudes towards mathematics. Such integrations are challenging, and they require professional development that engages teachers as co-designers to develop their knowledge, skills, confidence and sense of ownership (Kelter et al., 2021; Potvin et al., 2023). However, there are very few studies, if any, that examine how involving teachers in the co-design of culturally relevant robot-coding mathematics activities might influence their cultural competency.

To address this challenge, we developed a professional development programme that engaged teachers in co-designing (with researchers) robot-coding mathematics activities, linked to everyday interests and culturally informed prior knowledge of Black and Latinx students in urban elementary classrooms. In this article, we report findings related to the influence of this professional development programme on teachers' cultural competencies in mathematics pedagogy.

Background

Traditional approaches to teaching mathematics have been solely objective and culturally neutral (Matthews and López, 2019). The majority of mathematics teachers today continue to provide instruction that discounts students' cultural and linguistic strengths and to exclude diverse students in their learning process (Celedón-Pattichis et al., 2018). Mathematics teachers' cultural awareness impacts their perspectives on students' mathematical abilities, as well as their approach to instruction (Walker, 2012). There is a demand for culturally competent teachers who develop sociocultural contexts for teaching and learning mathematics that can maximise student learning potential (Abdulrahim and Orosco, 2020).

Teachers need professional development opportunities to develop their own cultural competence and to recognise that mathematics education does not occur in isolation of sociocultural context

(Nasir et al., 2008). Culturally competent mathematics teachers can bridge the divide between home and school with culturally responsive mathematics teaching practices that provide an instructional context for students that is supportive, engaging and challenging (Abdulrahim and Orosco, 2020). They can capitalise on students' cultural and linguistic knowledge and use these strengths as a platform to foster higher-level thinking skills (Gay, 2018). They can foster student engagement and agency by creating a learning context that responds to students' social, emotional and cognitive needs (Hammond, 2015). Culturally competent mathematics teachers can also provide mathematics instruction that challenges students to think critically and prepare them to use mathematics as an analytical tool (Williams et al., 2016). Mathematics education researchers define culturally responsive mathematics pedagogy (CRMP) to include three components: (1) developing critical mathematics thinking; (2) building on students' informal mathematics knowledge, and cultural and experiential knowledge; and (3) orienting to students' culture and experience (Averill et al., 2009). Integrating these elements of CRMP into teaching requires appropriate disposition, knowledge and skills.

Theoretical framework

Our study is framed by sociocultural theories of learning that define learning as experiential, situated and contextual. Mathematics knowledge in the situated perspective is understood as being co-constituted in a community within a context. It is the community and context in which the student learns mathematics that significantly impacts how the student uses and understands mathematics (Boaler, 2000). In this project, teachers co-designed a supplementary mathematics curriculum titled 'Birds and Bots: B-squared', situated in a culturally relevant problem-based learning environment. Our project therefore provided teachers with participatory learning experiences through the lens of two frameworks: culturally relevant pedagogy and design thinking (Rinke et al., 2016).

Culturally relevant pedagogy framework

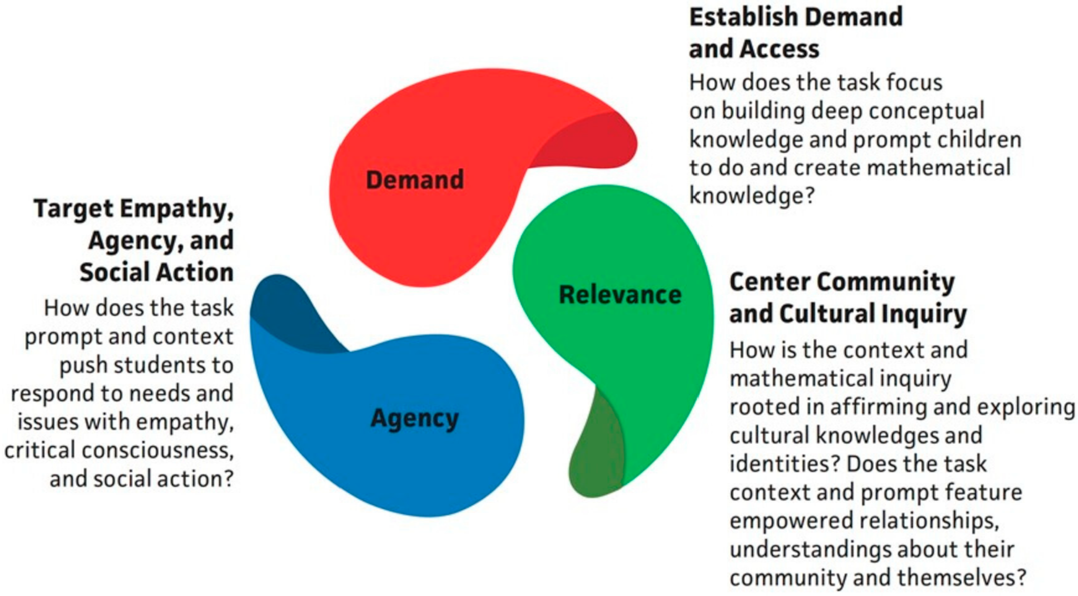
Incorporating culturally relevant pedagogy in mathematics classrooms can be a challenge for teachers (Leonard, 2018). Ladson-Billings's (1995: 483) seminal work with elementary teachers led to the conception of a culturally relevant pedagogy as teachers' 'ability to develop students academically, ... willingness to nurture and support cultural competence, and ... development of a sociopolitical or critical consciousness'. Furthermore, the culturally responsive-sustaining education framework (NYSED, 2018) suggests four key themes for teachers to consider when developing their instructional activities: welcoming and affirming environment; high expectations and rigorous instruction; inclusive curriculum and assessment; and ongoing professional learning and support (NYSED, 2018).

Specific to mathematics, culturally relevant pedagogy provides a powerful nexus between students' sociocultural experiences (found critical to learning and development) and classroom instruction, thus contributing to students' mathematics cognition (Abdulrahim and Orosco, 2020; Leonard, 2018). Providing students with a cultural frame of reference during mathematics teaching and learning enables them to bridge academic content with their family and community experiences to enhance their mathematical development.

Based on the work of Ladson-Billings and others, Matthews et al. (2022a) have developed a culturally relevant mathematics task-building framework to explore the core concepts of demand, relevance and agency (Figure 1).

These concepts, with their attention to meaningful and rigorous mathematics, aligned with the goals of our project and informed our work building authentic tasks to enhance student learning. *Demand* centres on the importance of building deep conceptual knowledge, and further entreats students to do mathematics and construct mathematical knowledge. *Relevance* is meant to 'centre community and cultural inquiry' (Matthews et al., 2022a: 41), in particular, affirming and exploring students' cultural knowledge and identities. *Agency* incorporates the concepts of empathy and social action. Tasks that incorporate this dimension push students to consider needs and issues of their community, both narrowly and broadly, and to respond with 'empathy, critical consciousness, and social action' (Matthews et al., 2022a: 41), all within mathematical contexts.

Figure 1. Culturally relevant mathematics task-building actions (Source: Matthews et al., 2022b)



Design thinking framework

Design thinking is a dynamic problem-solving framework that can empower educators to develop engaging and effective curricula (Brown, 2008). In educational contexts, design thinking emerges out of social processes and involves creation of knowledge. While various schemes have been proposed for the design-thinking process, Summerville and Reid-Griffin (2008) suggest that design thinking should be treated as a process in which social exchanges move ideas back and forth until these ideas are fully accepted by the team. Furthermore, according to Koh et al. (2015), design thinking can be used for teacher development. Through teachers' involvement in the design process, they can deepen their understanding of new and existing technologies and pedagogies, and enhance their understanding of the content they are teaching (Lyublinskaya and Tournaki, 2012).

Acknowledging the importance of culturally relevant pedagogy and teacher involvement in curriculum design, and noting that these elements are often missing from teachers' professional development experiences, we placed the co-design of culturally relevant robot-coding mathematics activities at the centre of our teacher professional development programme.

Methods

This case study explored the influence of the professional development programme on teachers' cultural competencies, and it was guided by the following research questions:

1. How does co-designing culturally relevant robot-coding activities influence teachers' perceptions of and competencies in CRMP?
2. What core concepts of CRMP, that is, demand, relevance and agency, are demonstrated by teachers in the robot-coding activities they co-designed with researchers?

Context of the study

This study was completed in 2022/3 as part of a larger four-year project. Case study teachers and researchers each took the lead in designing 25 activities, totalling 50 B-squared robot-coding mathematics activities that included culturally relevant scenarios. A culturally relevant context was selected for each curriculum topic, and all scenarios for that topic were designed within that context (Table 1).

Table 1. Curriculum topics and corresponding culturally relevant contexts

Curriculum instructional unit	Mathematics topic	Culturally relevant context	Number of activities
Place value and problem-solving with units of measure	Rounding to the nearest ten and hundred	All About Me!	3
	Two- and three-digit measurement addition using the standard algorithm	Fundraising	3
	Two- and three-digit measurement subtraction using the standard algorithm	Zoo Field Trip	4
Multiplication and area	Foundations for understanding area	My Block	4*
	Concepts of area measurement	Playground Architects	4*
	Arithmetic properties using area models	Our Lego Apartment	4*
	Applications of area using side lengths of figures	Pokémon!	5*
Geometry and measurement word problems	Solving word problems	The Brooklyn Public Library	3
	Attributes of two-dimensional figures	Take Out!	6
	Problem-solving with perimeter	Cultural Art Projects	2* 3
	Recording perimeter and area data on line plots	Minecraft	5*
	Problem-solving with perimeter and area	Roblox	1* 3

* *Activities that were led by the teacher team.*

All activities used BirdBrain Technologies' (https://www.birdbraintechnologies.com/) small wireless Finch Robot 2.0 (Heiner, 2018; Okita, 2014). The robot is compatible with multiple devices used in today's classrooms. It has unique characteristics that make it age-appropriate for use in elementary mathematics classrooms:

- The FinchBlox, a native coding app, is an icon-based programming environment allowing active engagement of students who are not yet fluent readers.
- The built-in sensors enable students to measure distances and determine the robot's orientation.
- The built-in buzzer and LEDs enable sound and light effects as ways of self-assessment and immediate feedback on completion of particular mathematics tasks.
- The line tracking, precise movement, compass and pen mount allow the robot to draw straight and curved lines given specific measurements.

Overview of the professional development programme

The professional development programme included a three-day summer retreat and co-design workshops conducted during the school year. In total, teachers participated in 18 hours of in-person professional development during the summer, and 18 hours of in-person and 15 hours of online professional development during the school year. In the summer, teachers were introduced to robot coding (Figure 2) and CRMP.

The summer workshops were led by faculty experts in mathematics education, educational technology, urban and minority education, and CRMP, as well as by professional staff – experts in curriculum development and robotics. During this time, teachers selected instructional units for supplementing the standards-based mathematics curriculum with robot-coding culturally relevant activities. During the autumn professional development, teachers explored how mathematics activities might incorporate culturally relevant pedagogy principles and robot coding. During the spring professional development, teachers in collaboration with the project team co-designed activities for the selected instructional units.

This work focused on: (1) following curriculum requirements; (2) developing culturally relevant context for the tasks; and (3) outlining ideas for the use of Finch for each task. Each activity went through a process of revision that included deepening cultural connections, expanding initial closed-ended problems to more open explorations, and making more explicit connections between the mathematics topic and the use of Finch. For example, for the *Playground Architects* theme, teachers developed four activities that focused on area measurements. In the *Sandbox* activity, students were asked to design a new school playground, and they had to figure out the possible widths and lengths of a rectangle of a given area. The *Basketball Court* activity asked students to divide the schoolyard of a given area in order to donate some space for a community basketball court. The *Slides* activity asked students to consider possible designs of slides for big kids and toddlers, given the areas that these slides could occupy in the park. In the *Jungle Gym* activity, students designed a playground that is wheelchair accessible. In all these activities, they coded Finch to draw their designs on square grid mats to check the area. The coding elements included movement and right-turn blocks, as well as the repeat blocks that enabled students to represent measurements using the concept of place value of two-digit numbers.

Figure 2. Teachers learning robot coding to draw plane shapes

Participants

Twelve teachers who taught in Integrated Co-Teaching (ICT) classrooms in two New York City Title I public schools participated in the project. (A Title I school is a school with large concentrations of low-income students receiving supplemental federal funds to assist in meeting students' educational goals.) In ICT classrooms a general education teacher and a special education teacher jointly provide instruction to a class that has students with and without disabilities. Due to the high turnover rate of teachers in New York City and changes in teaching assignments, only two teachers, Deja and Sharon (pseudonyms), teaching in the same ICT classroom, completed all parts of the professional development programme. For this reason, they were selected for this case study. In their school, 46 per cent of students are identified as Black and 49 per cent as Latinx, 24 per cent of students have disabilities and 93 per cent of students receive free lunch. Only 32 per cent of Black students and 18 per cent of Latinx students in this school demonstrated mathematics proficiency based on the 2022 state mathematics test.

Deja is a Black female general education teacher with 15 years of teaching experience. She earned her undergraduate degree in elementary education and her master's degree in early childhood special education. She also holds professional teaching certificates in early childhood (birth to Grade 2) and childhood (Grades 1–6) education. Sharon is a Black female special education teacher with 20 years of teaching experience. She earned her undergraduate degree in sociology and her master's degree in elementary education. She also holds professional teaching certificates in special education (all grades) and childhood education (Grades 1–6).

Data collection

Teacher focus group interviews were conducted in person during the summer retreat. The two case study teachers participated in separate focus groups. The data from these interviews included ethnographic notes. Individual teacher interviews were conducted online in January, about halfway through the study. These interviews were videotaped and transcribed. Ethnographic notes and robot-coding mathematics activities co-designed by the teachers and researchers were selected from the professional development workshops held in February and June.

Instruments and data analysis

All interviews were semi-structured and followed a pre-made script with open-ended questions. Focus group interviews included five questions about teachers' expectations from the project, their experiences in teaching mathematics and their students' experiences in learning mathematics. Individual interviews included four questions that focused on teachers' thoughts about CRMP and future implementation of the developed activities. The individual interviews also probed teachers' early professional development experiences in co-designing culturally relevant robot-coding activities.

The Codebook for CRMP Competencies was adapted from the framework for culturally responsive teaching (Muniz, 2020). The framework defines eight competencies critical in enacting culturally responsive teaching across grade levels and subject areas. Two of these competencies were beyond the study scope and were therefore removed. An additional three competencies were developed upon initial coding of data, resulting in nine competencies for CRMP (Table 2).

Table 2. CRMP competencies

Framework competencies	**Code**
Recognise and redress bias in the system	RB
Draw on students' culture to shape curriculum and instruction	SC
Bring real-world issues into the classroom	RW
Model high expectations for all students	ME
Promote respect for student differences	SD
Reflect on one's own cultural lens	OL
Additional competencies	**Code**
Acknowledge school style	SS
Recognise parents' background in mathematics	PMC
Acknowledge student differences in mathematics	SM

To assess coding for consistency, one excerpt from each focus group interview was selected for independent coding by two coders. In the process of establishing intercoder agreement, some codes were refined, until agreement was reached. The remaining transcripts and ethnographic notes were coded independently.

The CRMP rubric was developed based on Matthews et al.'s (2022a) curriculum-building framework to assess the co-designed activities. The CRMP rubric (Table 3) incorporates the three core aspects of demand, relevance and agency, with adaptations aligned to the template that the project team designed for the development of B-squared activities. In particular, we wanted teachers to incorporate all three core aspects when designing tasks, ensuring that rich and meaningful mathematical content was present, while attending to students' experiences, and providing opportunities for students to reflect on social action and equity within a mathematical context.

Each CRMP component is defined by several criteria, and the score is assigned based on the number of criteria met in the activity, with a maximum score of 3 for each component. After the B-squared activities were completed (but before implementing them in the classrooms), a team of three coders randomly chose several activities to discuss, review and revise the rubric. Then, each coder applied the revised rubric to five randomly selected activities to ensure consistency of the ratings. Once agreement was reached, the rubric was finalised, and researchers used the rubric to score all co-designed activities.

Table 3. CRMP rubric

CRMP components	Criteria
Demand	• Opening scenario is clearly written: mathematical question is clear and correct, even if open-ended • Mathematics required is at or above grade level • Task (either in the opening scenario or in the reflection) has an element that allows for meaningful student exploration and thinking OR extends the mathematics explored in the task to a new or novel situation
Relevance	• Scenario references a cultural or community or familial context, in a non-essentialist/non-stereotypical way • Scenario presents mathematics within the cultural/community/familial context in a meaningful, authentic way • Scenario affirms and/or reflects attention to students' identities within and/or beyond school • Scenario makes use of students' knowledge and experiences
Agency	• Scenario prompts students to think about taking action to benefit or contribute to others or society, either locally or broadly • Scenario prompts students to engage in empathetic thinking or reflects empathetic behaviour • Scenario prompts students to consider issues relevant to social consciousness, equity and/or justice

Findings and discussion

Focus group interview revealed that Deja initially distinguished between bias at the individual level and institutional racism (RB) through her perceptions of her students' needs: 'Because [of] our kids' demographic. They need so much assistance.' She also linked learning gaps to students' low reading comprehension that had a direct influence on mathematics achievement (RB): 'Cuz we found a lot of gaps last year … what I would say overall the issue is, comprehension. If you can comprehend in reading, then you're pretty OK for the most part with math.' Deja then continued to acknowledge student difficulties in mathematics performance (SM): 'If they're lacking in comprehension, then when it comes time to solve word problems, they're trying to figure out, "I need to add … I don't know if I need to subtract. I don't know if this is a one-step or a two-step problem."'

Deja demonstrated knowledge of her students' culture (SC) when describing how her students perceived mathematics as being 'game-like', and how this attraction could help students engage with mathematics: 'They definitely have an affinity toward math, more toward math than towards reading, and math becomes like a game to them.' Deja further described how students may experience different learning engagement with game-like mathematics, demonstrating her respect for student differences (SD). Deja's understanding of her students' interest in games is reflected in contexts of activities co-designed by her and Sharon, which included themes related to Lego, Pokémon and Minecraft.

While Deja worried about integration of the robot-coding activity with the standards-based curriculum, she indicated that successful integration of these activities in mathematics was possible and promising, which reflects Deja's thoughtfulness about teaching and the long-term development of her students: 'I would hope that it'd be different because it'll be like, you know, this is a benefit long term. This is what we are looking [for], this is where we're heading.' However, Deja was concerned about how school expectations and norms (SS) may limit culturally responsive instruction with robot coding. Within such school restrictions, Deja describes what needs to be clear for her (and other teachers) to better develop their own cultural lens (OL). She mentions how teachers need to understand the materials presented to them, and what to expect to better prepare and implement these activities.

Five months later, during an individual interview, Deja mentioned how professional development influenced her perceptions and attitudes toward her own mathematics learning and instruction, indicating development of her own cultural lens (OL):

> The workshops have been definitely helpful. I do feel that they are, I guess, stretching or expanding my thinking as far as like what math could look like in the classroom and just going from the traditional way of doing math to making it more hands-on, more engaging with the Finch, and just everything that we're learning.

Other recognisable differences included deeper understanding of student culture (SC) and specific statements on how this had influenced and shaped her mathematics instruction: 'To me, culturally relevant teaching is just making sure that your students see themselves and everyday math … So, I always make sure that my students see examples that reflect their own experiences.' However, Deja continued to have concerns about integrating the robot-coding activities into a rigidly structured curriculum (SS):

> At my school, like it's a very strict schedule. So, I feel that there's gonna be a lot of remodelling that's gonna have to take place, and that has to be done early on and not [at the] last minute … it can't be just, we're gonna do this here … it has to, the alignment has to fit in seamlessly.

She was also concerned about the impact of robot-coding activities on students' state test performance: 'Where I see the challenge lying is that when you're teaching a testing grade … this is the state test, you know, we gotta get them ready for the state test … but not seeing how it could be impactful.'

Similar to Deja, at the beginning of the project, Sharon demonstrated a variety of competencies in understanding student culture (SC), repeatedly stating that students 'enjoy working with manipulatives and hands-on activities'. She also emphasised the importance of bringing real-world connections into the classroom (RW), commenting that 'it [mathematics] needs to be brought to their attention more of how it's used in the real world or how it applies to their life'. At the same time, she demonstrated some deficit perspectives about her students, blaming students for their low academic performance (RB): 'Many students … don't really have a focus on mathematics. … things that you would think that they would know, even at such a small age, they don't have it, you know?' Sharon's comments during the group interview also demonstrated her perception of a lack of attention to mathematics in the families of her students (PMC): 'you get an aunt, uncle, whoever comes over, they're giving you money … math is everywhere, but they [students] don't recognise it or their attention is not brought to it'. While Sharon pointed out connections between student experiences with money at home (SC) and mathematics they learn in class, she did not recognise an opportunity to help students make this connection.

When discussing the challenges of integrating robot-coding activities into the standards-based curriculum, Sharon also referred to strict school policy on scheduling and time spent on specific subjects (SS): 'this programme sounds wonderful, but when you start to implement it in the requirements of the programme versus the requirements of the building, there can be a, you know, conflict'. She also had difficulty imagining how robot-coding activities could support student learning of the required curriculum (SS), as evident from her comments:

> I guess I'm still trying to see how it fits into the curriculum. Cuz I mean we looked at places, OK, maybe we can do it here, but how, what does that look like? … How do we use this to actually teach math to strengthen their skills in math?

Sharon also indicated her personal challenges, reflecting on her lack of confidence in using classroom technology and her own ways of learning (OL):

> I'm visual, but I'm also tactile … I need step by step for me to really see it. Because if I don't, if I already have low confidence in technology, you know my abilities in technology, if I can get a clear picture of how it is from step A to step Z, you know, then that, that works for me.

Five months later, Sharon's perceptions had changed significantly, as her comments reflect on her own learning (OL) of better understanding student culture, and how that can shape curriculum and instruction (SC):

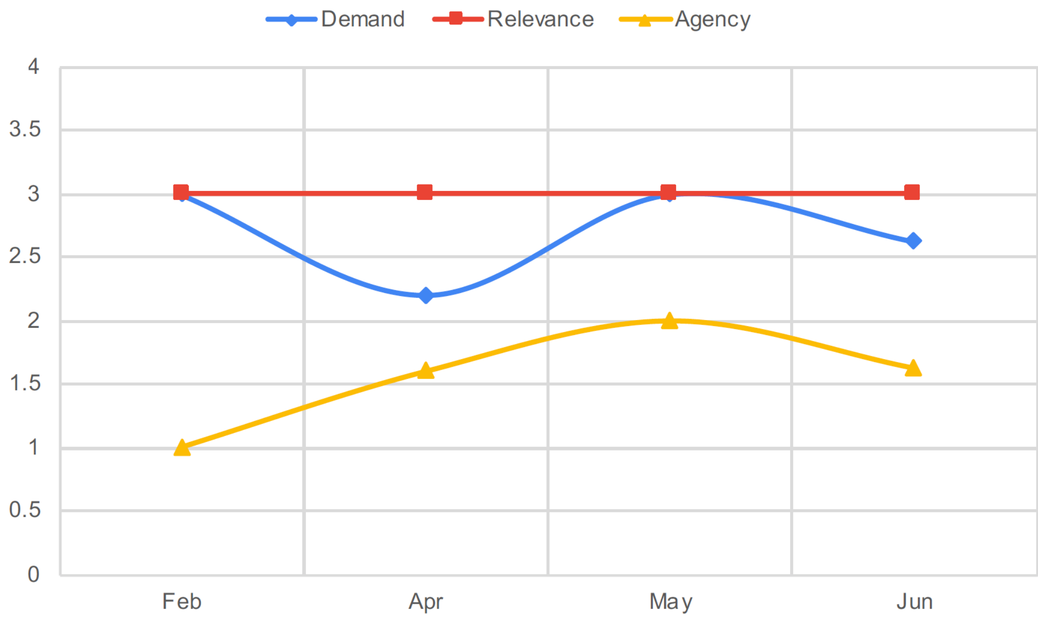
> I feel that with proper support and instruction and training, robotics can be effective in teaching math for our underserved students. I feel a lot of the work that we do can be more culturally relevant. I've never really thought about it in terms of mathematics. How can I change this curriculum so that it relates to their [students'] experiences?

Sharon's perceptions of her students' potential also started to change. While she recognised that some underserved students may have mathematical difficulties (SM), she now demonstrated belief in their success with proper teaching: 'The kids don't have this skill. What can I do? What strategy can I use to help them to understand this thing?' She no longer blamed students for low academic performance, but was looking for opportunities to support them, which represents her gaining competency in redressing bias in the system (RB). Sharon also started to see technology as part of student culture (SC) that can help them to get engaged in learning mathematics: 'I think for one, just the idea of the robot, you know, and the students being able to touch and manipulate and use the computer, the program and things like that. I think that it would build some excitement around mathematics.' Building on that, Sharon shared her beliefs in student abilities to explore mathematics with robots, demonstrating higher expectations of her students (ME): 'Because we want them to be able to explore, maybe find out things on their own about how it [robot] works and what to do with it. … so, I think it'll be a good entry point for, especially for those lower level students.' As the academic year progressed, Sharon and Deja continued to develop activities that drew on students' familial and community connections, in ways that extended beyond typical money and/or counting problems (PMC).

To facilitate the co-design process, the researchers designed an activity-planning template. In addition to common elements of mathematical tasks, such as objective, materials and procedure, the template also included several components unique to the B-squared activities: developing a scenario, incorporating a mathematical prompt and providing reflection questions for students. Scenarios, mathematical situations to be explored using the Finch robot, were to be engaging and of interest to students. For each scenario and accompanying mathematical prompt and reflection questions, teachers were to consider demand, relevance and agency, which are characteristic of rich, culturally relevant mathematical tasks (Figure 1). These three concepts, incorporated into the activity-planning template, and the corresponding rubric (Table 3) supported the teachers in the co-design process.

Deja and Sharon completed four activities in February, five in April, eight in May and eight in June. These activities were assessed using the CRMP rubric. Figure 3 shows the average monthly scores for demand, relevance and agency for these activities.

Figure 3. Demand, relevance and agency average monthly scores of activities developed by the teachers



As seen in Figure 3, all activities included scenarios that were relevant to the students, representing teachers' competency in student culture. The demand scores that indicate teachers' knowledge for teaching mathematics fluctuated, as teachers often used closed-ended problems that did not include meaningful explorations for students. These also reflect that teachers' ability to create high-demand scenarios depended on their facility and familiarity with the topic. The agency component was the most difficult aspect of culturally relevant pedagogy for the teachers.

To examine changes in teachers' competencies in designing culturally relevant tasks for Finch explorations, we analysed two activities, *Our Lego Balcony* and *Family Portrait*, developed in February and June 2023, respectively. *Our Lego Balcony* is part of a themed unit, *Our Lego Apartment*, which uses Lego bricks to build distinct features of New York City apartments. The choice of using Lego bricks reflected Deja's interest in connecting mathematics to toys, games and surrounding environments familiar to students. This activity was designed to help students explore arithmetic properties using area models. Deja and Sharon crafted the following scenario: 'Yeamin measures the dimensions of his balcony (12 metres by 5 metres) and uses this to find the area of his balcony. His friend Malachi's balcony has the same area but different measurements. What could his measurements be?'

Apartments with balconies are familiar features to students living in New York City. The balcony sizes in the scenario – 12 metres (approximately 39 feet) – may seem somewhat contrived, but it represents real New York City apartment balconies that run the width of the building with partitions that fit different apartment details. The open-ended nature of the question (possible measurements of Malachi's balcony) and the desire to have multiple solutions to the question (that is, different dimensions that would yield the same area of 60 square metres) allow for rich discussions. Using the CRMP rubric, this task scored medium on demand, noting that the task was grade appropriate, and that the scenario and mathematical question would be understandable to students. The activity had an open-ended nature, but the posed reflection question at the end was simply 'What is the area?', which was a missed opportunity and kept the mathematical demand level from being scored as high. The scenario reflected students' knowledge and experiences (that is, familiarity with New York City high-rise apartment balconies). It scored high for relevance. The attention to agency was missing from this scenario, resulting in a low score (demand: 2; relevance: 3; agency: 1).

The second activity, *Family Portrait*, was developed in June within a *Cultural Arts Project* theme. It addressed the mathematical topic of problem-solving with perimeters: 'Jason and Celeste are creating a [rectangular] frame for their family portrait. Celeste lets her big brother, Jason, paint the set of 8-inch parallel lines purple, while Celeste paints the 4-inch parallel lines yellow. What is the perimeter of the frame they have created?'

In this activity, students coded the Finch robot to draw geometric shapes and examine its properties. The details reflect Sharon's desire to link mathematics to students' families, draw on familial connections, and collaborate and share through creating a family portrait frame. Teachers thought carefully about the properties of geometric shapes and their dimensions, and how students might recognise mathematical shortcuts to adding up the four sides of the rectangular frame. This was evidenced in the reflection question for this task: 'If the shape was a square instead of a rectangle and one side measured 4 inches, how could you find the perimeter?' Therefore, the demand and relevance of this task were evaluated as high. Agency was also attended to in a meaningful way, as Celeste demonstrates empathetic behaviour, engaging her sibling in creating the frame. This task received a perfect score of 9.

These two activities showed Sharon and Deja developing capabilities of connecting rich mathematics and culturally relevant pedagogy in such a way that mathematics content was included and not obscured by the task itself. This is reflected in increased mathematical demand opportunities described in the two tasks. Furthermore, it should be emphasised that teachers are not unidimensional in their beliefs about their students and their potential. While teachers' views can sometimes be limited when it comes to perspectives about students' lives, support from their families, and communities for mathematical thinking, we also saw teachers' understanding of students' strengths, and how this could be leveraged for student engagement.

As the year progressed, we observed deeper understanding and ability to reference students' lives in the design of mathematical tasks, in ways that were affirmative and culturally centred, and not essentialist or stereotypical. Despite teachers' continuing concern about the influence of school structures (controlled by administrators) on this work, their efforts to infuse technology and culturally relevant pedagogy into the school mathematics curriculum, their high engagement and continuous growth in competencies, both in understanding their students and in developing rich mathematical tasks, were evident.

Conclusion

The objective of this study was to develop teachers' cultural competencies and deepen their understanding of CRMP as they co-designed culturally relevant robot-coding mathematics activities with researchers in a year-long professional development programme. In the earlier stages of professional development, teachers showed understanding of students' cultural background and experiences, but were uncertain how to integrate culturally relevant pedagogy into their mathematics curriculum. Early co-designed activities lacked connections between culturally relevant pedagogy and mathematics content, and teachers' dependence on researchers to make this connection was frequent. Existing literature similarly suggests teacher struggles in making connections between culturally relevant pedagogy and mathematics (Leonard, 2018). In addition, teachers initially saw the robot as a separate tool, and had difficulty connecting robot coding to the targeted mathematical concepts (Silk et al., 2010). Literature suggests that subject content knowledge in science, technology, engineering and mathematics (STEM) disciplines, in combination with higher teacher self-efficacy and confidence levels is crucial for successful implementations of educational robotics activities in classrooms (Dorotea et al., 2021). Similarly, our finding about difficulty in connecting robot coding to mathematical concepts suggests teachers' needs for more time and support from professional development programmes in building content knowledge, skills and confidence to use robot coding in K–12 mathematics classrooms.

Over time, the influence of the co-designing process became evident. Teachers showed a deeper understanding of their students' cultures and how to integrate culturally relevant pedagogy into mathematics activities. Teachers grew familiar with the key attributes of the robot, perceiving the Finch robot as a mathematical tool, and utilising its physical and coding features to design student tasks that focused on the meanings of the mathematical concepts. They also started to pay more attention to developing their own cultural lens, and focused less on constraints from school structures.

This study explored a new approach to professional development by co-designing and implementing culturally relevant robot-coding activities into standards-based mathematics. Doing so has led to the development of elementary school teachers' cultural competencies, deeper understanding of CRMP and their students' cultures, stronger agency and ability to integrate culturally responsive pedagogy into their mathematics curriculum. Implications include knowledge of how teachers' cultural competencies are affected by professional development experiences; the importance of co-design work to help teachers make connections across innovative pedagogies (that is, robot coding and culturally relevant teaching in elementary mathematics classrooms); and providing a framework for facilitating authentic connections between culturally relevant pedagogy and mathematics, a discipline where concrete examples for teaching are largely missing from the discourse and professional literature. Next steps will be to see how teachers' cultural competencies and culturally relevant pedagogy in mathematics may continue to evolve over the years, and across different early elementary school grade levels, and how that can influence students' mathematics performance and interests.

Funding

This study was funded by the National Science Foundation, award ID 2147699.

Declarations and conflicts of interest

Research ethics statement

The authors declare that research ethics approval for this article was provided by the Teachers College Institutional Review Board, protocol 21-172, and by the Institutional Review Board and Ethics Committee of New York City Department of Education, protocol 4306.

Consent for publication statement

The authors declare that research participants' informed consent to publication of findings – including photos, videos and any personal or identifiable information – was secured prior to publication.

Conflicts of interest statement

The authors declare no conflicts of interest with this work. All efforts to sufficiently anonymise the authors during peer review of this article have been made. The authors declare no further conflicts with this article.

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