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Rethinking Integrated Computer Science Instruction: A Cross-Context and Expansive Approach in Elementary Classrooms

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Rethinking Integrated Computer Science Instruction: A Cross-Context and Expansive Approach in Elementary Classrooms

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Abstract: This study examines how a rural-serving school district aimed to provide elementary-level computer science (CS) by offering instruction during students' computer lab, a class taught by paraprofessional educators with limited background in computing. As part of a research-practice partnership, cross-context mathematics and CS lessons were co-designed to expansively frame and highlight connections across – as opposed to integration within – the two subjects. Findings indicate that the paraprofessionals teaching the lessons generally reported positive experiences and understanding of content; however, those less comfortable with the content reported lower student interest. Further, most students who engaged with the lessons across the lab and classroom contexts reported finding the lessons interesting, seeing connections to their mathematics classes, and understanding the programming. In contrast, students who only learned about mathematics connections within the CS lessons (thus not in a cross-context way) reported significantly lower levels of interest, connections, and understanding.

Introduction

There is broad consensus among policy makers, educators, and researchers that it is essential for all students to have opportunities to learn foundational ideas of computer science (CS) and explore computational thinking (Vakil, 2018). Yet, many school districts face barriers in providing equitable and high-quality access to elementary-level computer science instruction given constraints in their local educational infrastructures. Common barriers reported include the lack of: 1) curricular time, 2) educator expertise in CS, and 3) 1-1 computing (Blikstein & Moghadam Sepi, 2019).

In this paper, we examine how one rural-serving school district, in the context of a research-practice partnership (RPP; Coburn et al., 2013), aimed to address these barriers as key problems of practice in their elementary schools. In particular, the partner school district decided to offer CS instruction in elementary school during students' weekly computer lab time, which is required and thus a part of all students' elementary experiences. In this district, computer lab instruction is led by paraprofessional educators who work part-time, often lack teaching credentials, and typically have little formal background in either CS or basic classroom instruction. To address this problem, a design team, comprised of teachers, paraprofessionals, district administrators, and researchers, collaboratively designed and tested an approach in which CS connections were highlighted and identified *across* subject contexts, as opposed to integrated *within* (National Research Council, 2014; Weintrop et al., 2016). The cross-context design was informed by the theory of expansive framing, in which disparate contexts are reframed into a single, unified frame so that ideas in one context are extended through the entire frame (Engle et al., 2012). Mathematics was chosen as the subject area for making connections by framing mathematics as a context to learn CS concepts.

As an RPP, we were interested in the implementation of the cross-context lessons from the perspective of the paraprofessionals who taught them across schools in the district. We were also interested in examining the cross-context approach as it applied in practice for elementary school students. We wished to address how critical it is for students to make the cross-context connections in both the mathematics and CS lessons or whether it is sufficient for them to only make connections during their computer lab instruction. In this paper, we present the results of implementing these lessons in two school contexts. In one school, the cross-context, students participated in the cross-context lessons during both regular mathematics classroom and computer lab instruction. In the remaining schools across the district, the CS-only group, lessons were only taught in the computer lab led by the paraprofessionals. The CS-only group received CS lessons that integrated mathematics; however, these lessons were only taught in the computer lab setting and not in mathematics classrooms. Our research was guided by three questions: *What were paraprofessionals' perceptions of their implementations? What were students' perceptions of the lessons in the cross-context classroom implementation? Did students' perceptions in the cross-context group differ from their peers in the CS-only group?*

In the following sections, we first describe the theoretical framework that informed our work, expansive framing. We then describe our cross-context lessons and how they were informed by the framework while also intentionally designed to fit within the constraints of public-school educational infrastructures. We then describe our research design followed by the findings, conclusions, and implications for practice.

Theoretical framework: Expansive framing

Expansive framing (Engle et al., 2012) is both an instructional approach and a theoretical framework to explain transfer of learning from a situated and sociocultural perspective. Expansive framing posits that broadly framing curricula across contexts (e.g., times, places, groups of people, roles, and topics) can foster expectations that content learned in one setting will be useful in other settings. The theory advocates for the importance of interleaving contextual features to promote transfer between the contexts. Additionally, framing expansively promotes student creation of and authorship in their own learning. This authorship requires students to draw upon their relevant prior knowledge, holds them accountable for their own learning, and portrays learners as independent knowledge generators in response to new problems (Engle et al., 2012). Use of this theory has been growing in educational settings, including CS education (Grover et al., 2014).

Table 1
Examples of Expansive Framing Principles Instantiated in Lessons

Expansive Framing Principle	Instantiation in Mathematics	Instantiation in Coding
Connecting contexts	Use conditional statements (a CS concept) to classify quadrilaterals	Embed math content in coding activity
	Script teacher statements with physical (mentions of computer lab) and temporal ("you *will*…use conditionals statements in the computer lab") references	Add educative elements to Scratch cards (Figure 1)
	Use images from coding activities to demonstrate math concept	
Promoting authorship	Think-pair-share math routines hold students accountable for their learning	Students create and code their own quiz
	Shape sorting activity allows for multiple correct answers and supports creative thinking	

In this study, we used expansive framing to inform the collaborative design of cross-context integrated CS-math lessons. Specifically, CS concepts were framed within the mathematics lessons through prompts that linked mathematics and CS ideas. Mathematics was also framed within lessons in the computer lab that reified conceptual understanding of mathematics topics and supported student creation through programming. Table 1 shows key principles of expansive framing and examples of how each principle was instantiated in classroom mathematics routines and lab coding activities. These features of the lessons that connected concepts across contexts and promoted student authorship were intended to foster transfer of content between settings.

Cross-context, expansively-framed CS-mathematics lessons

A design team comprised of two classroom teachers, three paraprofessionals, two school district administrators, and researchers collaboratively worked on an approach to address the district's aim to provide equitable and high-quality access to elementary-level CS instruction in ways that fit with the district's constraints.

Table 2

How RPP Work Addressed Constraints in the Problem of Practice

Constraints in District	Approach in Mathematics Class	Approach in Computer lab
Lack of time	Co-adapt mathematics routines aligned to existing math curriculum	Add CS instruction in weekly computer lab
	Highlight cross-curricular connections	Add co-designed CS lessons to existing curriculum
Lack of educator expertise	Highlight CS concepts in math topics	Use Scratch cards with educative elements (Figure 1)
Lack of 1-1 computing	Unplugged	Plugged

Mathematics was identified as an ideal subject area for making connections with CS concepts as there is a history investigating such synergies (Fisler et al., 2021; Papert, 1980; Shumway et al., 2021; Strickland et al., 2021; Weintrop et al., 2020). Further, a recent review (Shehzad et al., 2023) of studies of CS-math integration (E.g., Israel & Lash, 2020; Weintrop et al., 2020; Wong & Cheung, 2020) found that connections between math and CS concepts need to be made explicit through instruction. Thus, the proposed solution involved identifying and highlighting CS connections across (as opposed to only integration within) subject contexts in mutually supportive and expansively-framed ways (Engle et al., 2012).

Table 2 shows three key constraints identified in the partner school district and how design elements of the expansively-framed curricular approach offered solutions. The constraint of *lack of curricular time* led the partner district to add CS instruction to students' weekly computer lab time, taught by paraprofessionals. CS instruction in the mathematics class occurred through brief mini-lessons that were embedded into existing standards-aligned mathematics routines with an emphasis on highlighting computing concepts. These expansively-framed mini-lessons also helped classroom teachers see and articulate mathematical connections to CS ideas, an important goal in efforts to create cross-context connections (Fisler et al., 2021).

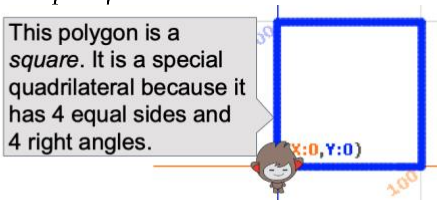
To address the *lack of a 1-1 computing* infrastructure in schools, we used an unplugged-to-plugged approach to support expansive framing of concepts across instructional contexts (mathematics and computer lab classes). The mathematics routines were unplugged to help students focus on conceptual ideas while in the plugged computer lab activities, students programmed these ideas using Scratch.

The teachers and paraprofessionals also lacked time to design new CS and mathematics lessons. Hence, the design team engaged in incremental *co-adaptation* (Debarger et al., 2017) rather than co-design of instructional activities. In particular, the teachers and paraprofessionals identified challenging topics for students and worked together to determine where tasks or activities in the existing curriculum could be adapted to add synergistic CS/mathematics concepts. Researchers then designed first drafts of instructional lessons which were iteratively refined through cycles of brainstorming, implementations, and reflections with the design team.

Another constraint was lack of teacher and paraprofessional expertise, as CS concepts are typically new territory in elementary education (Delyser et al., 2018). To support the paraprofessionals, the lessons were designed using a familiar (to them) instructional routine, Scratch cards (Rusk & MIT Scratch Team, 2017). Further, these cards were annotated with educative elements (Davis & Krajcik, 2005) to help both paraprofessionals and students understand the connections to mathematics (see example in Figure 1). The Scratch cards supported students as they engaged in programming activities that reified mathematics concepts. For example, in the geometry lesson, students programmed various shapes discussed in the mathematics class and designed short quiz-like game that asked game users to recognize differences between shapes. This authorship component was intended to further students' understanding of cross-context connections.

Figure 1

Example of Educative Elements Embedded in a Scratch card.



To support teachers in their mathematics classes, we developed a series of mathematics routines, a typical part of these teachers' math lessons, that connect to CS concepts. For example, in one mathematics routine, teachers used programming if-then-else conditional logic within the following kinds of prompts to help students recall their knowledge of quadrilaterals: "if a quadrilateral is regular, then it has four **<blank>** sides, else it is not regular." The correct answer was congruent, or equal. The goal was thus to expansively frame CS and mathematical concepts rather than learning to program in Scratch in isolation (Grover et al., 2014).

Table 3

Cross-Context and Expansive Framing of Mathematics and Computer Science in Geometry Unit

Math Topic	Math Big Ideas	Computing Big Ideas	CS-Math Connections
Quadrilaterals	Reasoning with polygons Classifying shapes	Conditionals, variables, abstraction	Use conditional statements to reason about polygons and attributes
Triangles	Classifying triangle types	Conditionals, variables, loops	Program shapes with exterior angles

While we co-designed two units (see Beck et al., 2022), the present study focuses on the geometry unit. The mathematics unit was designed as a menu of six mathematics routines that teachers could choose from as a warm-up to typical mathematics lessons in their geometry unit. The CS lessons were designed as extension activities to existing instruction and contained two math-integrated lessons. Table 3 summarizes topics covered in the geometry unit, specifically the two lessons on quadrilaterals and triangles.

Methods

Participants and context

This research took place in a rural-serving district in the western United States. Fourteen elementary school-based paraprofessionals in the district (92% female) participated in the study. Nine (64%) of the paraprofessionals were new to the job, having worked in their role for less than three years. Six of the paraprofessionals held bachelor's degrees and three held associate's degrees. Only four paraprofessionals (28%) reported prior teaching experience with only one reporting prior programming experience.

While most of the paraprofessionals across the school district taught the integrated CS lessons (N=14), we only collected student data in three elementary schools. In School 1, the math lessons were taught during regular math time by two classroom teachers and the CS lessons were taught during computer lab time by the school's paraprofessional (the cross-context group; N=57 students). In the other two schools, only the CS lessons were taught by the two schools' paraprofessionals (CS-only group; N=172 students). Figure 2 shows the number of teachers, paraprofessionals, and responses from students who participated in the study.

Data Sources

Paraprofessionals

Before the implementation, a district administrator led professional development sessions with the paraprofessionals, introducing them to the cross-context CS lessons. The geometry unit consisted of two lessons: quadrilaterals and triangles (see Table 3). The two lessons were taught during a computer lab session (2 total) in all schools in the district. Many schools have multiple fifth-grade classes thus, a total of 36 classes were taught by these paraprofessionals.

After teaching the two lessons, paraprofessionals completed a five-item feedback survey, addressing their perception of the lessons, their understanding of the content, and perceptions of their students' interest and ability to make connections (see Table 5). These questions were answered on a Likert scale (1 “strongly disagree” – 6 “strongly agree”). An optional open-response question solicited additional feedback.

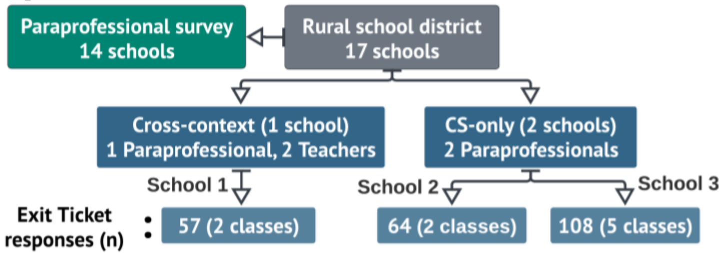
Students

Immediately following each lesson in the computer lab, students completed a short three-question exit ticket survey about their perception of the lesson. Table 4 shows the constructs addressed and questions asked of students in these exit tickets. Students were asked to either respond with “yes” or “no” to each statement. Figure 2 shows the number of student responses collected per school.

Table 4
Exit Ticket Items. Students Responded Either Yes/No

Construct	Exit Ticket Question
Interest	I found today’s computer lab lesson interesting.
Connection	Today’s computer lab was related to what I do in math class.
Understanding	I understood what we did in computer lab today.

Figure 2
Number of classes, teachers, paraprofessionals and exit tickets collected by lesson, implementation, and school



Analysis

To address the first research question, we complied descriptive statistics for items on the feedback survey. We analyzed the open-ended feedback to identify emergent themes. For research questions 2, we compiled descriptive statistics of exit ticket responses. For RQ3, as students’ responses were binary (yes/no), we compared the differences between responses of the cross-context students to the CS-only students using a three-level logistic regression model where survey items were treated as level-1 units, individual students were treated as level-2 units, and individual classes were treated as level-3 units. The CS-only group was treated as the reference group.

The study comes with limitations. First, we had to work with unidentified student data, thus we could not match student data collected across the two lessons, resulting in loss of power and inability to take student specific differences across lessons into account. Second, the surveys used self-reported measures, which may suffer from bias due to respondents’ subjective frames of references (Biernat, 2003). The student survey also contained yes/no items, which can bias the respondents toward agreeing with the statements (Yeager et al., 2013). In addition, predictor variables were measured using single items which can be a threat to construct validity (Cook & Campbell, 1979). Despite their limitations, single item measures are increasingly being used in implementation research in education (Yeager et al., 2013) due their simplicity and ease of administration. We hope that the study’s findings motivate further work examining the effects of context on learning and transfer in the complex settings of school-based implementation research.

Findings

Research question 1: Paraprofessionals’ perceptions

Our first research question focused on paraprofessionals’ perceptions of their implementation of the lessons. Table 5 shows the means and standard deviations for their responses on each question on the feedback survey.

Only one of the paraprofessionals reported any prior programming experience and nine were somewhat new to their teaching roles; hence, we expected some difficulty with their implementations despite carefully designed supports and scaffolds. However, as shown in Table 5, the majority reported positive experiences teaching the lesson and understanding the content. Note that three (21%) participants did not think their implementation went well, and of those three participants, two participants reported that they did not understand the mathematics content. This suggests a possible link between the importance of having sufficient cross-content knowledge to effectively teach the lessons.

We also asked the paraprofessionals to indicate how interested they thought their students were in the lessons and whether they thought their students made the connections to their mathematics class instruction. Prior studies have shown that teachers have considerable sensitivity in appraising classroom conditions and outcomes (Kelly & Abruzzo, 2021). As these lessons were implemented later in the school year, the paraprofessionals had already developed a sense of their classes and how their students responded to different activities.

The majority of the paraprofessionals also reported positive perceptions of student interest in the unit and indicated that their students were able to make connections between CS and mathematics in the lessons (Table 5). However, five (35%) of the paraprofessionals did not agree with the statement that their students showed interest. Note that three of these five paraprofessionals were also ones who indicated that they were not comfortable with the mathematics content. Two paraprofessionals also did not think their students were able to make connections to the mathematics; again, one of these respondents indicated low comfort with the mathematics content. Taken together, these findings suggest the importance of developing the paraprofessionals' mathematics content knowledge and confidence in teaching in order to help students make connections.

Table 5
Paraprofessional survey descriptive statistics, (N=14) (Scale:1"strongly disagree" 6 "strongly agree")

Construct	Survey question	Mean	Std Dev
Outlook	My implementation of the quadrilaterals and triangles lesson went well.	4.29	0.99
Math	I understand the underlying math in the quadrilaterals and triangles lesson.	4.57	1.22
CS	I understand the underlying CS concepts in the quadrilaterals and triangles lesson.	4.86	0.95
Interest	My students showed interest during the quadrilaterals and triangles lesson.	3.57	1.40
Connection	My students made connections to the math content during the implementation of the quadrilaterals and triangles lesson.	4.00	1.11

To further examine paraprofessionals' experience teaching the cross-context lessons, we examined the open-response feedback they provided. A major theme in their feedback was that the lessons were too long and there was not enough time to adequately teach them. One paraprofessional wanted "more time to go through the why's of what we were doing to helped [sic] with understanding" whereas others just wanted more time for students to complete the lessons. Having additional time would allow the paraprofessionals time to lead discussions about connections between CS and mathematics, as well as enable students to engage in more creative choice in their coding (Lytle et al., 2019).

There were only two comments about students struggling with content. One paraprofessional mentioned students struggled with the way Scratch uses exterior angles to draw triangles while mathematics typically uses internal angles to describe triangles. This required a conversion between the two angle measurements. Another mentioned that some students struggled with understanding the conditional blocks. In terms of whether students found the lessons interesting, the paraprofessionals' feedback was mixed. Some said the students were interested whereas others said their students found the lessons "boring." One paraprofessional mentioned that they would "like to see the lesson create something that the kids would be excited about going home and playing with." Several spoke positively about the cross-context nature and the benefits for students.

Finally, two comments suggested we did not fully explain to the paraprofessionals the purpose behind the cross-context lessons. One paraprofessional wrote: "I don't remember being told why we were teaching these lessons other than they were being taught during the same time these shapes were taught in their math time." This feedback highlights the challenge of cross-context integration in an entire school district. As mentioned above, the design team included two fifth-grade teachers and three paraprofessionals who worked together to create both the mathematics lessons and the CS lessons. Thus, there was an implicit assumption that the CS and mathematics lessons would mutually support the big ideas (see Table 3) across contexts. A further assumption was that in each participating school, the teacher and paraprofessional would communicate with and talk about the cross-context lessons. Students would then explore the math concepts of geometry in the math classroom before the cross-context lessons were taught in the computer lab.

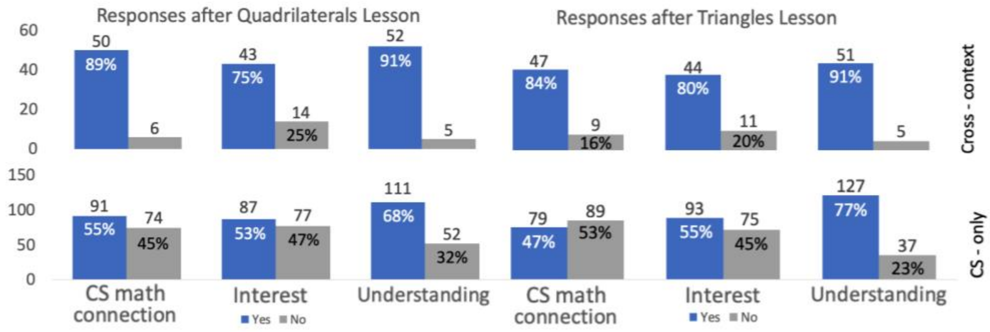
However, to our knowledge, this was not a common occurrence. Like other instructional innovations that are scaled to a district-level, there were several differentiating factors between each school, e.g., some schools had less opportunities for teachers and paraprofessionals to collaborate than other schools. It is thus possible that the lack of cross-context collaboration in some participating schools made it less conducive for students to make the important connections between the mathematics and CS.

Research questions 2 and 3: Students' perceptions

The second research question focused on the students from one elementary school in the cross-context implementation group where lessons in the math classes were expansively framed and integrated in both the regular math instruction and the CS lab (N=57).

Figure 3

Observed percentages and counts of student "yes/no" responses for the computer lab lessons



Exit ticket responses showed that a large majority of students reported that they found the quadrilaterals and triangles lessons interesting, saw connections to their mathematics classes, and understood the programming involved (see top part of Figure 3).

The third research question contrasted the perceptions of students in the cross-context group to students in two other schools where the CS-math connections were only taught in the CS lessons during computer lab time (CS-only group; N=172). Across both the quadrilateral and triangle lessons and compared to their peers in the CS-only implementation, more students in the cross-context implementations found the lessons interesting, saw connections to their mathematics classes, and understood the programming (see bottom part of Figure 3). Results from a three-level logistic regression model with random intercepts across students (level-2) and classes (level-3) found that these differences were significantly higher (see Table 6), as explained next.

Table 6

Multilevel Logistic regression probabilities of responding "yes" to items across groups and lessons

	Quadrilaterals Lesson		Triangles Lesson	
Construct	CS-Only	Cross-context	CS-Only	Cross-context
CS math connection	58%	94%***	47%	90%***
Interest	55%	83%**	58%	85%**
Understanding	75%	94%**	83%	96%**

*** p<.001, ** p<.01, p-values were adjusted using the method of false discovery rate

On the question related to *perceived connection between the CS lesson and their mathematics* class, the average probabilities of responding "yes" by the cross-context students were 94% and 90% for the quadrilaterals lesson and the triangles lesson respectively, and were significantly higher than their peers in the CS-only group. This suggests that encountering CS and mathematics content in both the classroom and the computer lab helped students more effectively see the connections.

On the question related to *perceived interest in the lesson*, the average probabilities of responding "yes" by the cross-context students were 83% and 85% for the quadrilaterals lesson and the triangles lesson respectively, and were significantly higher than their peers in the CS-only group.

On the question related to *perceived understanding of the lesson*, the average probabilities of responding "yes" by the cross-context students were 94% and 96% for the quadrilaterals lesson and the triangles lesson respectively, and were significantly higher than their peers in the CS-only group.

Conclusion and implications

This paper describes the collaborative design of fifth-grade cross-context mathematics and CS lessons. By situating this work within a research-practice partnership (RPP), the approach enjoyed significant district support and resulted in curriculum intentionally designed to fit within the constraints of its elementary schools. In this way, this work contributes to understanding how RPP structures can support the equitable integration of CS by working in elementary schools that historically have offered few CS learning opportunities.

The approach involved identifying and highlighting CS connections across mathematics and CS contexts in expansively-framed ways. This work thus contributes to a reconsideration of what CS integration can look like in elementary schools. While the many synergies between the disciplines of mathematics and CS have previously been identified, elementary teachers and paraprofessionals are not always equipped with resources to make these connections apparent to their students. The lessons drew upon teachers' and paraprofessionals' established instructional routines in order to support their understanding and teaching of the cross-context instruction.

The paper also reports findings examining paraprofessionals' and students' experiences of these lessons. While many paraprofessionals provided positive feedback, there were some who commented that their students were not able to see mathematics and CS connections. This feedback is important to our co-design process because it indicates that the designed supports in the lessons (e.g., educative components in the Scratch cards) were not sufficient support for some of the paraprofessionals. Further iterations of the lessons should consider other kinds of supports to foster their understanding and comfort with teaching mathematics content, such as video or other modes that can provide deep but quick reviews of the mathematics content.

We also found that a majority of the students in the cross-context group reported that they found the lessons interesting, saw connections to their mathematics classes, and understood the programming; these differences were significantly higher than those in the CS-only groups. These findings show the value in building connections into classroom lessons and the importance of making and highlighting the connections, as suggested by the theory of expansive framing, between both the CS and mathematics contexts. While not the focus of the present study, helping students see the connections between mathematics and CS also has the potential to help them more deeply understand the content in both disciplines.

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