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Co-Designing Elementary-Level Computer Science and Mathematics Lessons: An Expansive Framing Approach

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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 time. 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 indicated that 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, a three-level logistic regression model showed that students who only learned about mathematics connections within the CS lessons (thus not in a cross-context way) reported statistically significant 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.

In this paper, we describe how one rural-serving school district 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. To address this problem, a design team, comprised of teachers, paraprofessional CS educators, 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.

In particular, we examine the cross-context approach as it applied in practice for upper elementary school students. We 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 elementary school contexts. In one school, the cross-context group, students participated in the cross-context lessons during both regular mathematics classroom and computer lab instruction. In two other schools in the school district, the CS-only group, lessons were only taught in the computer lab led by the paraprofessionals. Thus, the CS-only group participated in the CS lessons that integrated mathematics; however, these lessons were only taught in the computer lab setting and not also in the regular classrooms. Our research was guided by the following question: *Did students' perceptions in the cross-context group differ from their peers in the CS-only group?*

Theoretical framework: Expansive framing

Expansive framing is both an instructional approach and a theoretical framework to explain transfer of learning from a situated and sociocultural perspective (Engle et al., 2012). Expansive framing posits that broadly framing curricula across contexts (e.g., time, place, people, role, and topic) 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 helps promote student creation of and authorship in their own learning by inviting students to draw upon their prior knowledge, holding them accountable for their own learning, and portraying them as independent knowledge generators (Engle et al., 2012). Use of this theory has been growing in instructional settings, including CS education (Grover et al., 2014).

In this study, we drew upon expansive framing to inform the collaborative design of cross-contextual 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.

Cross-contextual, expansively framed CS-mathematics lessons

For the design of the instructional unit, mathematics was identified as an ideal subject area for making connections with CS concepts as there is a long history investigating such synergies (e.g., Papert, 1980; Weintrop et al., 2020). Further, a recent literature review (Shehzad et al., 2023) of CS-math integration found that connections between math and CS concepts need to be explicitly made through instruction. Thus, the proposed solution involved identifying and highlighting CS connections across subject contexts (as opposed to only integrating CS in math lessons) in mutually supportive and expansively framed ways. Thus, math-integrated CS instruction was added to students' weekly computer lab time; CS instruction also occurred in the mathematics class through 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-contextual connections (Fisler et al., 2021).

Lessons were designed to build connections between math routines in class and CS instruction in the computer lab. For example, in one math routine, teachers used 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 math concepts rather than learning to program in Scratch in isolation (Grover et al., 2014). Table 1 shows key principles of expansive framing and examples of how each principle was instantiated in classroom math 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.

Table 1
Examples of Expansive Framing Principles Instantiated in Lessons

Expansive Framing	Instantiation in Mathematics	Instantiation in Coding
Connecting contexts	Use conditional statements (CS) to classify quadrilaterals (math)	Embed math content in coding activities
	Script teacher statements with physical and temporal references	Add educative elements to Scratch cards
	Use images from coding activities to demonstrate math concept	
Promoting authorship	Engaging in think-pair-share math routines hold students accountable for their learning	Students create and code their own quiz
	Engaging in shape sorting activity supports multiple correct answers and creative thinking	

While we co-designed two instructional units, the present study focuses on the geometry unit. The mathematics unit was designed as a menu of six math 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 2 summarizes topics covered in the geometry unit, specifically the two lessons on quadrilaterals and triangles.

Table 2
Cross-Contextual and Expansive Framing of Mathematics and Computer Science in Geometry Unit

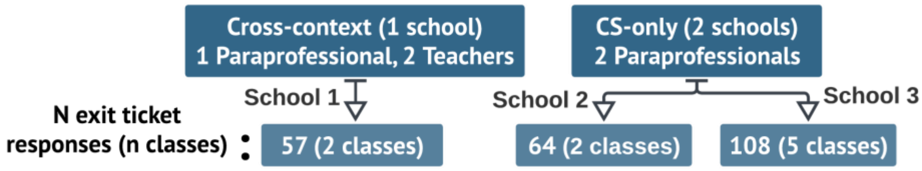
Math Topic	Math Big Ideas	Computing Big Ideas	CS-Math Connections
Quadrilaterals	Reasoning with polygons Classifying shapes	Conditionals, variables, abstraction	Use conditional statements to reason about polygons and attributes
Triangles	Classifying triangle types	Conditionals, variables, loops	Program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

Methods

This research took place in a rural-serving district in the western United States. We 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 1 shows the number of teachers, paraprofessionals, and responses from students who participated in the study.

Figure 1

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



Immediately following each lesson in the computer lab, students completed a short three-question exit ticket survey about their perception of the lesson. Table 3 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.

Table 3

Exit Ticket Items. Students Responded Either Yes or No

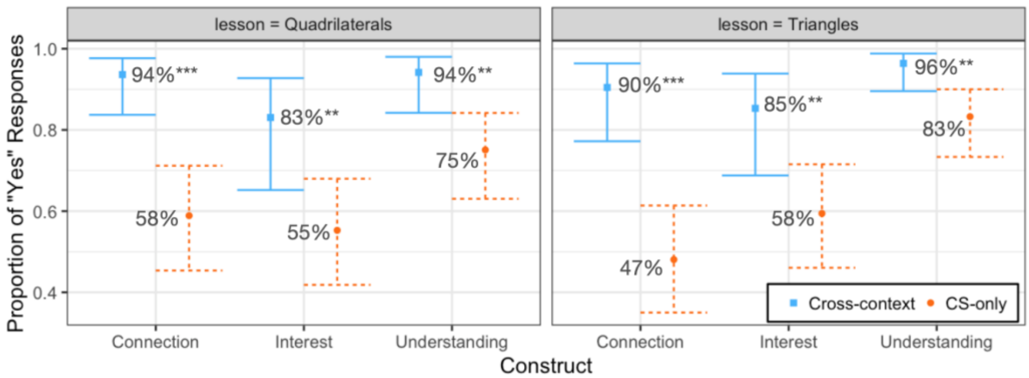
Construct	Exit Ticket Prompt
Interest	I found today's computer lab lesson interesting.
Connection	Today's computer lab was related to what I do in math class.
Understanding	I understood what we did in computer lab today.

As students' responses were binary (yes/no), to address the research question 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 were working 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. Despite these limitations, exit ticket measures are increasingly being used in implementation research in education (Yeager et al., 2013) due their simplicity and ease of administration.

Figure 2

Estimated marginal means of "Yes" responses modelled using multilevel logistic regression



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

Findings

To address our research question, we 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. Results from a three-level logistic regression model with random intercepts across exit ticket items (level-1), students (level-2), and classes (level-3) are presented in Figure 2. 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, and these differences were significantly higher. For example, 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 better see the connections. The average probabilities of responding “yes” were also significantly higher for students in the cross-context group on the questions related to *perceived interest in the lesson* and *perceived understanding of the lesson* (see Figure 2).

Conclusion and implications

This paper describes the co-design of fifth-grade cross-contextual mathematics and CS lessons. 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.

The paper also reports findings examining students’ experiences of these lessons. Most students in the cross-context group reported that they found the lessons interesting, saw connections to their mathematics classes, and understood the programming; moreover, these perceptions were significantly higher than students 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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