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Exploring Elementary Teachers' Perceptions of Teaching a Science, Engineering, Mathematics, and Computer Science Project

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Abstract: While national frameworks call for the integration of science, technology, engineering, mathematics, and computer science (STEM+CS) in K-12 contexts, few studies consider elementary teachers' perceptions of implementing STEM+CS projects in science classrooms. This single case study explores elementary science teachers' perceptions of enacting STEM+CS curricular materials. Survey and interview data were collected over the four-week project and qualitatively coded. Findings demonstrate teachers' reported struggles to implement unfamiliar disciplines and leverage students' prior knowledge in familiar disciplines as well as unanticipated consequences of instructional decisions based on perceived student engagement and pacing. Results underscore the value of teacher voice for curricular and professional development and highlight the need for further investigation of how teachers' perceptions may influence enactment of STEM+CS curricular materials.

Introduction and background

Interdisciplinary science, technology, engineering, mathematics, and computer science (STEM+CS) curricular activities involve deeply integrated practices for developing knowledge. National frameworks in the United States describe a STEM+CS vision involving students developing science knowledge and engineering design solutions by using mathematics and developing computational models to solve authentic problems and create scientific arguments and explanations (i.e., ASEE 2020; K-12 Computer Science Framework, 2016; National Research Council, 2012). In the elementary grades, implementing interdisciplinary STEM+CS projects includes integrating mathematics, computational thinking, and engineering concepts and practices into science classrooms where students define problems, analyze and interpret data, model solutions and science phenomena, and develop, test, and communicate solutions while considering constraints (NGSS Lead States, 2013).

Teaching this type of interdisciplinary curricula is challenging (Fulmer et al., 2018), especially for elementary teachers who may have differing amounts of knowledge of each individual discipline. For example, elementary teachers report feeling well prepared to teach mathematics and science but not engineering and computer science (Plumley, 2019). Although elementary teachers typically teach multiple disciplines to their students, interdisciplinary curricula require making connections across disciplines. As teacher education programs largely focus on siloed domain approaches to disciplines, teachers may need support to implement interdisciplinary approaches effectively in their classrooms. For instance, teachers may perceive content from integrated disciplines as skills instead of content, which may then affect how these disciplines are integrated and taught (Estapa et al., 2017). For example, mathematics can be implicitly integrated in STEM+CS activities (Lilly et al., 2021) and often takes the form of calculations or data representations (Baker & Galanti, 2017). However, making mathematics more explicit could change the student perspective from only focusing on a contextualized problem to a more explicit use of mathematics and disciplinary epistemologies (Fitzallen, 2015). In engineering, it may be challenging for elementary teachers to center engineering practices when they feel like they must prioritize the logistics of implementing engineering activities (i.e., Diefes-Dux, 2004). Additionally, elementary teachers may also be challenged in supporting students when content and practices are unfamiliar (Lilly et al., 2022). For example, elementary teachers may not be familiar with engineering analysis and so struggle to respond and guide students' varied design ideas to meet project constraints (Brophy et al., 2008).

This study then investigates how elementary science teachers perceive enactment of a STEM+CS project and aims to privilege the teachers' own voices to provide insights into their perceptions of challenges and necessary supports for the consideration of curriculum designers and professional development facilitators.

Methods

This study uses an embedded, single case study methodology (Yin, 2018) to examine teachers' perceptions of implementing a STEM+CS project in a public elementary school in the southeastern United States. The project challenged fifth-grade students to engineer a design solution to solve the authentic problem of water runoff at their school grounds by developing scientific models of runoff and absorption and using mathematics and computational thinking to develop computational models to test different engineering solutions. We define the case as two fifth-grade teachers, pseudonyms Mr. Skelton and Ms. Banet, who implemented the project in their two co-taught classrooms. We focus on this specific case as these teachers both hold an undergraduate science degree and thus have atypical content knowledge for elementary teachers. Further, both teachers have more than five years of teaching experience. Both teachers also have knowledge of project goals and educative supports as co-developers of the project who implemented a pilot version of the project the previous year.

Over the four-week project, both teachers answered open-ended questions on daily written surveys and weekly face-to-face interviews. Two researchers worked together to inductively code (Miles et al., 2020) the data through first and second level coding. First, the researchers identified if a teacher's answer demonstrated (1) perspectives about STEM+CS disciplines or (2) implementation of the STEM+CS project and then coded these statements for challenges, changes made to support student engagement, and additional supports that teachers perceive as necessary for equitable facilitation of STEM+CS activities. The researchers then looked across coded statements for patterns and wrote analytic memos (Miles et al., 2020).

Results

Teachers reported challenges with supporting computational modeling and mathematics and customizing and adapting the activities. First, both teachers discussed challenges with supporting students in computational modeling, including technical aspects of how to access and save students' computational models. For example, Ms. Banet discussed the difficulties that students faced saving and accessing their code within the computational modeling environment, "Explaining to the students how to save your computer, just in case something happens. That's pretty key. Because that kept happening, it kept disappearing." Ms. Banet also reflected how they could have addressed these difficulties by having more whole-class demonstrations of these problematic areas, "We should have done it at the beginning, showing how to shrink and enlarge the stage … That was a struggle."

The teachers also reported struggling with using pedagogical strategies for computing, such as debugging students' programs and supporting students to understand computing concepts such as variables. For example, Ms. Banet stated, "Students' programs were malfunctioning, I didn't know how to help other than having them close out their program and bring up a whole new copy … they ended up having to start over because I didn't know what to do." Here Ms. Banet reported on one debugging strategy that she used, starting over from scratch, but also recognized that she did not use any other strategies like stepping through each block together or asking the students to explain their code. Similarly, Mr. Skelton stated, "I also struggled to predict the sorts of observations kids make about their models and thus transition from those observations to useful questions that students could answer." In this comment, Mr. Skelton discussed his challenges for appropriate questioning strategies with the computational model. Teachers also found it challenging to support students using terminology or concepts from mathematics in science contexts. For example, Ms. Banet said, "A lot of students struggled with the word *relate*. They don't understand 'How does hourly rainfall relate to total amount of water'. And I don't know how to simplify that myself." Furthermore, even though Ms. Banet also taught mathematics classes, she reported struggling to support all students to use the mathematics concept of *ratio* with the science phenomena of absorption and run-off.

The teachers reported modifying the project to attend to these challenges. First, teachers reported adapting activities to maintain student engagement. For example, teachers reported adding an activity that was not in the curriculum in which students went outside to take pictures of their water runoff problem. The teachers considered the lesson to positively impact student engagement, as students "were able to connect pieces of the curriculum", the activity "reminded them of why we are doing all this in the first place", and it "sparked so much creativity." Adding this lesson enabled the teachers to see students that they perceived would struggle more with these lessons as capable of making connections within the curriculum. Additionally, the teachers reported altering activities as a result of time constraints. For example, Ms. Banet reflected that, "Due to time, we cut out all the math … so the kids didn't do pages, the last page we did was 18 and then we had them skip to page 26." When faced with pacing concerns, the teachers often chose to remove mathematics. However, teachers also acknowledged difficulties that may have emerged from their choices to skip parts of the project. Ms. Banet said, "I struggled to rush through the lesson without having students really understand why we were developing this model. Many students have lost interest … there's a disconnect between the hands-on experiments and how this relates to the computational model." As the mathematical tasks were designed to serve as connections from the hands-on activities to the computational modeling activities, Ms. Banet noticed the consequences of skipping activities.

Discussion and conclusions

This study focused on teachers' perceptions of challenges when implementing a STEM+CS project (i.e., Johnson et al., 2020; Pleasants et al., 2019). Even in this unique case, where both teachers have science degrees and extensive curricular knowledge of the STEM+CS project, teachers discussed a range of challenges during classroom enactment. Teachers reported struggling with integrating disciplines with which they had more experience (i.e., mathematics into science) as well as disciplines with which they had less experience (i.e., computer science through computational modeling). For example, teachers noted the difficulty with mathematics terminology and concepts in science contexts. Results highlight how teachers may need support not only to integrate more unfamiliar disciplines like engineering and computer science into familiar disciplines of mathematics and science, but also to integrate mathematics and science content and practices.

Enacting STEM+CS curricular materials requires teachers to have pedagogical knowledge about each individual discipline (i.e., Johnson et al., 2017), and how pedagogical strategies in one domain (e.g., debugging in computing) may relate to pedagogical strategies in other domains (e.g., problem solving in mathematics) or how to use pedagogical strategies across domains (e.g., questioning). Teachers reflected on struggling with the broader, interdisciplinary nature of the curriculum in terms of recognizing how to enact such strategies across disciplines. Specifically, they did not feel as if they had the pedagogical content knowledge to make in-the-moment instructional decisions. Future research should explore how the kinds of pedagogical knowledge and strategies that teachers utilize for enacting STEM+CS curricula may affect student outcomes.

The teachers also reflected on their concerns about pacing and how to adapt the project to stay on pace (e.g., what to cut or what to focus on if students struggle). Although teachers reported challenges that stem from students' lacking foundational skills from integrated disciplines, they did not make connections about how their customization of the project may have compounded these challenges. For example, teachers reported students struggled with implementing their coding but did not make a connection as to how altering their project by cutting mathematics from early activities might have impacted later activities in which students were expected to code conceptual models. Specifically, without recognizing how knowledge would build and the importance of specific activities for students to understand concepts and engage in activities later in the project, the teachers may have cut important activities due to their beliefs about their students' abilities to engage in those activities in face of pacing concerns. This demonstrates unintended consequences in teachers' adapting an STEM+CS curricula without support to understand how practices and concepts may build across disciplines and supports prior research of teachers' challenges in STEM+CS contexts (Baker & Galanti, 2017). An implication is that curriculum developers need to support teachers' knowledge about how concepts and practices will progress throughout a STEM+CS project so that students are able to successfully engage in activities across disciplines.

Further, teachers used the challenge of implementing ratios to recognize that they must safe-guard against allowing students' abilities and individualized needs, as well as teachers' beliefs about students' abilities in mathematics, to dictate students' opportunities to engage in science activities. For example, the teachers reflected on the challenge of leveraging students' prior mathematics knowledge and attempted to differentiate for students with different prior mathematics knowledge to equitably support all students to engage with this challenging interdisciplinary curriculum. However, although they also recognized that students' prior experience with coding affected their ability to engage in computational modeling, the teachers reported being unsure of how to support struggling students. Throughout the data, the teachers did not consider how or if their beliefs about students' abilities or individualized needs may have filtered students' opportunity to engage in engineering or computer science. Teachers may then need additional support to consider how to differentiate activities across disciplines to attend to differing levels of prior knowledge and equitably support all students.

By giving a voice to teachers and sharing their perspectives, we hope to help curricular makers to support teachers in their ability to adapt STEM+CS curricula to meet students' needs. This is particularly important as our results show that the teachers reported struggling more to adapt activities to resolve a challenge when implementing less familiar disciplines and suggested that they may need additional support in predicting, responding, and evaluating students' ideas (Brophy et al., 2008) and attending to technical difficulties that students may have (Diefes-Dux, 2004) across different disciplines. However, our results also highlight ways in which teachers adapted interdisciplinary activities, such as teaching students mathematically about ratios and then drawing connections to absorption ratios in science. This enabled the teachers to integrate mathematics into science and support the epistemic understanding that mathematics is part of real-world, science experiences in line with prior literature (e.g., Fitzallen, 2015). Such examples demonstrate that the teachers were capable of modifying the project to support students' needs. Thus, it is important to ensure that teachers have the support that they report is necessary to equitably implement STEM+CS projects across disciplines.

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