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Implementing Computer Science in Elementary Science Classrooms: An Elementary Teacher's Perceptions Over Four Years

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Abstract: As computer science (CS) is integrated in elementary science curricula, it is important to consider teachers' perceptions in how they access CS and support students to engage in CS skills and standards through NGSS-aligned activities. This single case study utilizes the Interconnected Model of Professional Growth (IMPG) to examine teacher change and explore the perspectives of a teacher, through semi-structured interviews, as he implements an NGSS-aligned, project-based CS unit over the course of four years. Findings indicate that the teacher perceived that changes in his practice helped inform changes in student outcomes and the curriculum and, in turn, these changes in outcomes further informed his teaching practice in the next iteration of the unit. Results highlight the importance of reflection and feedback as a way to impact the teaching practice of integrating CS in elementary science education.

Introduction and background

National frameworks such as the Next Generation Science Standards (NGSS) and the Framework for K-12 Science Education were designed to enable teachers to integrate computer science (CS) in elementary science curricula and provide authentic CS-integrated science experiences for their students (NGSS Lead States, 2013; National Research Council [NRC], 2012). NGSS was designed to enable teachers to provide authentic CS-integrated science experiences for their students, which is particularly important at the elementary level (Fluck et al., 2016). Through NGSS-aligned, CS-integrated science units, teachers can provide their students with personally meaningful learning experiences that enhance their engagement in school (Gannon et al., 2022; Ozturk et al., 2018; Rich et al., 2021) and richer problem-solving concepts (Fofang et al., 2020) to solve issues in an evolving technological society (e.g., K–12 Computer Science Framework, 2016).

As elementary teachers are tasked with implementing CS in their classrooms (Madkins et al., 2019), they often need support to develop and embed CS pedagogies, lessons, and skills in their classrooms (Yadav et al., 2016) as many elementary teachers do not have previous experience learning or teaching CS (Hansen et al., 2016; Harlow et al., 2016). Prior research has shown that teachers can develop CS content and pedagogical knowledge, as well as increased self-efficacy in CS, through extended PD opportunities that focus on teachers designing unique CS lessons for their specific classrooms and content areas (Ivy & Franz, 2017). Participation in a research-practice partnership (RPP) is one opportunity for teachers to engage in extended PD. RPPs are long-term partnerships between teachers and researchers who collaboratively focus on problems of practice and disseminate their findings (Coburn et al., 2016). RPPs focused on CS can empower teachers to integrate CS in their own classrooms as they develop their own CS skills (e.g., Christian et al., 2021) as well as increase their confidence in supporting students with CS (Rich et al., 2021).

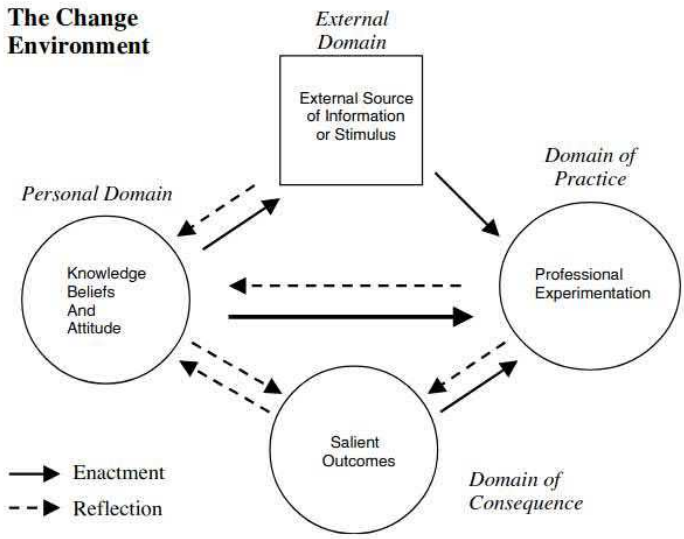
As RPPs are long-term, they can also offer opportunities for teachers to reflect upon their implementation of activities and contribute to changes in future iterations of CS-integrated activities. Reflective practices are important as they can support teacher growth in CS over time (i.e. Hu et al., 2021) and help teachers make use of their daily experiences teaching to bolster formal learning like PD (Mathew et al., 2017). Teachers that practice reflection often are able to quickly and effectively adjust to student learning needs during instruction (e.g., Gess-Newsome, 2015; Lilly et al., 2023; Rodgers, 2002). Understanding teachers' perceptions are also important as they can provide insight into teachers' instructional decisions which can affect how and what kinds of activities they use in the classroom (e.g., Remillard, 1999). Further, teachers' reflections between enactments have the potential to influence curriculum developers and researchers in creating new iterations of integrated CS curricula (i.e., Lee et al., 2020).

As CS is integrated in elementary science curricula, it is important to consider how teachers reflect on their experiences in how they access CS and support students to engage in CS skills and standards through NGSS-aligned activities (i.e., Ketelhut et al., 2020; Lilly et al., 2024; Sands et al., 2018). The purpose of this study is to investigate teacher opportunities for reflection and feedback (Peel et al., 2020) and consider the teacher's perceptions of co-designing and implementing an NGSS-aligned, CS-integrated unit with an RPP over four years.

Framework

In this study, we look at ways in which teachers perceive that changes in their teaching practice of CS in science classrooms can help inform the design of CS tools, practices, and curricula as we apply the Interconnected Model of Professional Growth (IMPG; Figure 1) to examine teacher change (Clarke & Hollingsworth, 2002). Specifically, we explore how a teacher perceives that their practice interacts with areas of their experience and perceptions of educational outcomes as we follow a Science, Technology, Engineering, and Mathematics (STEM) teacher's implementation of an NGSS-aligned, project-based CS unit over the course of four years. The teacher was given the opportunity to reflect after each annual implementation of the NGSS-aligned unit. Researchers and unit designers employed his feedback in making changes to the unit for the next implementation and considered the ways in which the teacher perceived that these changes impacted their practice, student learning, and/or use of CS tools in enactment.

Figure 1
Interconnected Model of Professional Growth (Clarke & Hollingsworth, 2002)



We chose to consider the teacher's perceptions as IMPG suggests that change occurs through the processes of enactment and reflection. Enactment is taking action, or the translation of change into action, while reflection is modification through deliberation on a change, or the impact of change. Further, in the IMPG, change occurs in four domains: the personal domain, the domain of practice, the domain of consequence, and the external domain (Clarke & Hollingsworth, 2002). The personal domain includes teachers' knowledge, beliefs, and attitudes. This could refer to teachers' knowledge, beliefs, and attitudes about the curriculum, the content (e.g., science, engineering, mathematics, or computer science), or the students (e.g., the perceived skills and abilities of the elementary students in the classroom). The domain of practice refers to classroom experimentation. For example, in this study, the domain of practice refers to changes in practice through the implementation of the CS-integrated science unit. The domain of consequence includes teachers' perceptions of outcomes. For example, in this study, the domain of consequence might refer to teachers' perception of students' learning of, or engagement with, CS. Finally, the external domain refers to interactions that occur outside of the professional world of a teacher, while the personal domain, domain of practice, and domain of consequence make up a teacher's professional world of practice. For example, in this study, the external domain included interactions with the researchers and curriculum developers. Change in these four domains are related through enactment and reflection, in that change in a single domain can translate to change in another domain. We specifically use Peel et al., 2020 as a model to examine the professional growth of a teacher implementing a CS-integrated science unit.

We believe that considering teacher feedback about the implementation of a CS-integrated science unit can help inform how to support teacher development and student learning. We consider the following research questions: (1) How does a teacher report that their practice of implementing CS-integrated science activities has developed over multiple iterations of an NGSS-aligned, project-based CS unit? (2) In what ways does a teacher report that providing feedback on their teaching experience of the unit has informed the design changes of the unit and the teacher's future teaching practices?

Methods

This single case study (Yin, 2009) focuses on the perspectives of an elementary STEM teacher, Mr. Skelton (pseudonym), as he implemented an NGSS-aligned, project-based CS unit in collaboration with fifth-grade science classroom teachers. We chose to use case study methodology as our research questions asked "how" and "in what ways" and considered a bounded context (Miles et al., 2020). Further, we believe that Mr. Skelton represents an unusual case in an elementary STEM teacher implementing an NGSS-aligned, project-based CS unit with elementary science teachers (Yin, 2018). Specifically, Mr. Skelton was a co-designer of the unit and was knowledgeable about the unit's goals and embedded educative supports, he implemented the unit four times, and he was involved in the co-design process to make changes to the unit in between implementations. Utilizing a longitudinal approach by focusing on four years of a teacher's journey in co-designing and implementing CS-integrated science activities is also unique for providing new knowledge for the field through IMPG and co-design. Thus, beyond Mr. Skelton's expertise, his sustained collaboration with the research team in co-designing and iterating on this unit exemplifies the potential for this type of work and contributed to his selection as the focal case.

Participant

At the beginning of this study, in 2018, Mr. Skelton had over five years of teaching experience and an undergraduate degree in science. He also was a co-developer of the CS unit and attended professional development that consisted of three days each summer and monthly meetings during each school year focused on the NGSS, computational modeling, and understanding curricular materials and teacher supports.

Mr. Skelton co-taught the NGSS-aligned, CS-integrated science unit in Spring 2018, 2019, 2020, and 2022 with science classroom teachers. An implementation did not occur in Spring 2021 due to the COVID pandemic. After each implementation, the unit was modified based on student outcomes and feedback from the teachers. In the unit, Mr. Skelton supported students to create conceptual models of the scientific phenomenon of water runoff, build computational models of water runoff at their school, and then use their computational models to test their engineering designs of their school grounds (i.e., Lilly et al., 2022). He also supported his co-teachers, particularly those new to the unit, by helping them to access the practice-based science curricula through a teacher's guide. The teacher's guide outlined the science and engineering practices (SEPs) for each practice-based lesson. Within the teacher's guide were student activities with corresponding practice-based science pedagogical strategies that were linked to the specific SEPs for each lesson. Using this guide, and his past experiences implementing the unit, Mr. Skelton was able to offer suggestions for how the teachers could enact the SEPs across the CS-integrated activities.

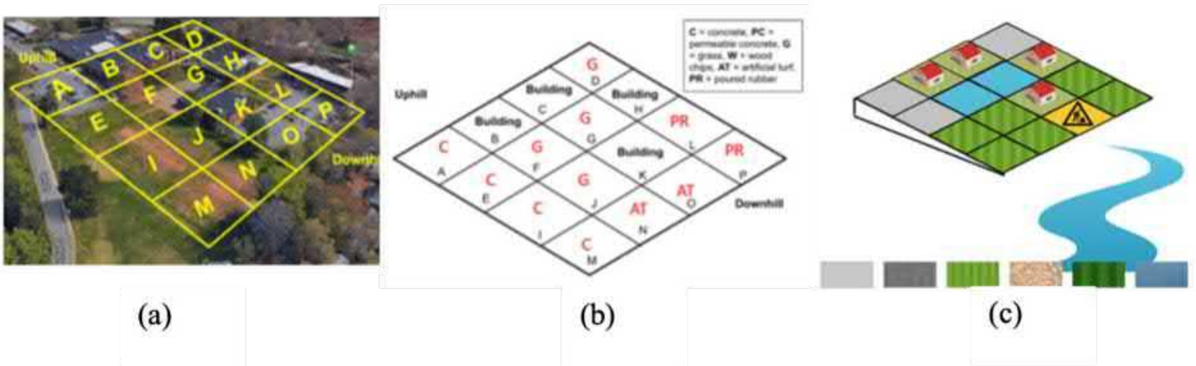
NGSS-Aligned, CS-integrated science unit

For each class section, Mr. Skelton implemented a NGSS-aligned, CS-integrated science unit called the Water Runoff Challenge (WRC) during 15 class periods across 3 weeks, with each class period being 50 minutes long. To begin the WRC, the teachers would show students a video of their principal giving them the challenge to redesign their school grounds so that their play areas would not be negatively affected by water runoff. Mr. Skelton and his co-teacher would then support their students to utilize their knowledge that their school play areas had a flooding problem that often led to recess being canceled after a storm to define the problem. They then supported students to carry out investigations to learn about the relationship between surface materials and water absorption and construct explanations about their findings. Through these investigations, students developed conceptual models and explanations for several different types of surface materials including artificial rubber, concrete, grass, permeable concrete, and poured rubber.

In the next part of the WRC, Mr. Skelton and his co-teacher supported their students to generate and compare multiple engineering designs using their conceptual models and explanations while specifying that the goal of these engineering designs was to reduce the water runoff on the school grounds within specific unit criteria (e.g., having areas accessible for students with physical disabilities and cost of materials). To create their engineering designs, the teachers gave their students a 16-square grid overlaid on their school grounds (Figure 2). For each square, the students decided on a purpose (i.e., grassy field, play area, school building, parking lot) and a corresponding surface material (i.e., grass, mulch, concrete, asphalt).

The teachers then supported their students to translate their engineering designs to computational models and test each to determine the design that would most closely meet the different unit criteria. Their computational model calculated the total rainfall and total water absorbed, which the students would then interpret as they tested each model's output. Students then communicated information about their optimal design solution to their classmates during in-class presentations.

Figure 2
The WRC Used (a) a Grid Overlaid on a Map of Their School to Use as a Basis for (b) Students' Designs and (c) the Computational Model



Analysis
Data sources include four semi-structured interviews in which Mr. Skelton and the corresponding science teachers were asked about the implementation of each unit following its completion. The open-ended interview protocol was developed with feedback from the RPP and experts in science and CS education. The interview protocol included questions that prompted teachers to reflect on their perceptions of the successes and challenges that they faced in planning and implementing the WRC; their self-efficacy with pedagogical strategies, content, and design processes for STEM+CS; the in-the-moment instructional decisions that they made through implementation; any changes to their instructional practice during or after implementation; the possible modifications to the WRC that they would suggest to support teachers and/or students; their students' successes and challenges in engaging with the WRC; and any comparisons between student engagement and teacher planning and implementation for iterations of the WRC.

Each interview lasted at least 30 minutes and was audio recorded and transcribed. Researchers used a priori codes (Miles et al., 2020) derived from the domains within the IMPG framework (Clarke & Hollingsworth, 2002) to analyze the interview data. During the coding process, each response to interview questions was team coded (Miles et al., 2020) by three researchers to identify domains. Responses could receive multiple domain selections. For each year's interview, the three researchers grouped responses by individual domain for responses that received a single domain code and intersecting domains for responses that received multiple domain codes. They then looked across years to consider patterns for each individual domain as well as each set of intersecting domains and wrote analytic memos which were used as the basis of the findings below.

Results
In this paper, we share how the domain of practice intersects with each of the other domains and include supporting quotations from Mr. Skelton's interviews.

Consequence and practice
Mr. Skelton reported ways in which he believed that the changes that teachers made in their practice, in reaction to modifications made to the WRC in between implementations, affected student outcomes. For example, in his 2022 interview, Mr. Skelton said:

> I just felt like it worked out better this year. I'm doing a better job of explaining this, developing an understanding of what our baseline rate event was. And [when students get] that, and then can create these rules for the computer to understand, and then we have to build out those rules. Then linking it back to the dice game … and doing the test cases were so helpful.

In this example, Mr. Skelton discussed how his improved implementation of the unit, specifically how he changed the ways in which he explained a scientific term, enacted new activities, and supported students to make connections between those activities and the scientific term, then supported student understanding.

Mr. Skelton also discussed how the teachers utilized their reflections on consequences to make changes in their practice or to anticipate future changes for the next implementation. Further, Mr. Skelton was able to consider how wanting to change a consequence led him to change his practice and then how this change in practice led to a change in consequence. For example, in the 2018 implementation, teachers had identified vocabulary as a challenge for students (Lilly et al., 2022) which led to changes being made to the unit. In the 2019 interview, Mr. Skelton reported that "I think adjusting the actual vocabulary words in the lessons was probably the most helpful, because then we didn't have to go over new concepts very much." In this example, Mr. Skelton was able to reflect upon how teachers' practice had been changed and how this affected student understanding throughout the unit.

External and practice

Mr. Skelton discussed ways in which the external domain affected his practice through changes in the resources between implementations. During these responses, Mr. Skelton focused on how teachers felt enacting the unit rather than their views of student consequences. For example, Mr. Skelton reported in his 2020 interview that having more hands-on activities before the main series of water investigations made that activity easier to implement. Mr. Skelton also suggested ways in which reflecting on his practice led him to make suggestions to the researchers. Specifically, he wanted to change the resources that were available to teachers. For example, Mr. Skelton discussed how the teachers wanted to make a change in how they taught the concept of initializing variables. He requested clearer instruction for how teachers should explain the need to create variables to help the computer understand that absorption limits are different for each material and to support teachers to help students to program broader rules instead of considering each material as a separate case. In the 2020 interview he said:

> So, we've got to be able to program it to have some rules, I think there's ways to do it. I'd like to explore in the future, because I do think that's an important aspect of coding.

In these responses, Mr. Skelton discussed how implementing this project multiple times in conjunction with researchers enabled him to make suggestions to the WRC that he could then implement in the next iteration. Mr. Skelton's focus was not just on changing the WRC for his classroom, but in helping other teachers who may implement this unit. Across interviews, Mr. Skelton discussed the importance of reflection for both students and teachers.

Personal and practice

Comparing Mr. Skelton's responses across interviews, he reported different ways in how his personal domain affected his practice. In the 2020 interview, Mr. Skeleton reported ways in which his formed beliefs about students in-the-moment then affected his practice as he considered how to meet students' needs. For example, he said:

> We changed [whole class discussions] a little bit because we realized.... We couldn't just have a class discussion where one kid was bouncing ideas off another kid. I would love to get to a point where they were like asking each other questions, but that's high-level stuff.

Mr. Skelton continued to explain how his beliefs about students led him to make in-the-moment instructional decisions to shift the intended student-led discussions to teacher-led discussions. In the 2022 interview, Mr. Skelton reported ways in which his increased understanding of the WRC and his ability to recall activities in which students had previously struggled affected his practice as he anticipated student struggles and planned supports to meet their needs.

Consequence, personal, and practice

Mr. Skelton also described how his own personal beliefs about his students and different teaching strategies affected his practice and, in turn, his students' experience. For example, in his 2018 interview, he stated, "And so whenever there's behavior issues, you tend to go for the essence of the lesson and not work on the fine details. And then students didn't have the connections in later activities". In this interview, he relayed how his personal domain experience with classroom management directly impacted his implementation of the WRC and students' access to the curriculum. Similarly, in the 2022 interview, he said:

> The last times, we just gave them the rules, because there were so many kids that were behind, we were just trying to get through it. This time, I felt it was much more meaningful and intentional, about why we're doing these computational thinking exercises, and everything just flowed much better.

In this interview, he continued to share how his personal beliefs about the importance of staying on pace changed to focus instead on ensuring students' understanding of the CS concepts and skills that would be needed throughout the unit. Further, Mr. Skelton shared how he was thinking about integrating CS into his curricula in the future. For example, he said:

> I feel like kids got a lot. I've gotten a lot out of this unit. I'd love to do more things like if we can tackle other dynamic problems, other ecosystem level problems, with computational modeling and conceptual modeling in science. We're on the right track.

In this quote, Mr. Skelton shared his perceptions of how student outcomes within the domain of consequence, as well as his personal domain feelings of benefiting in this implementation of the WRC, informed his decision to develop future NGSS-aligned units.

External, personal, and practice

Connecting the external, personal, and practice domains, Mr. Skelton reported being able to consider a different way of doing science through CS after interacting with the unit. For example, in his 2019 interview, Mr. Skelton said, "I appreciated the scientific modeling inclusion. I think that doesn't reflect as much of the kind of pedagogy that I do, but I know it's good instructional practice to have students work through modeling on a regular basis." This example showed how enacting the WRC gave Mr. Skelton access to different teaching strategies. Mr. Skelton went on to further consider how he could utilize conceptual modeling to support student engagement with other science standards.

Mr. Skelton also reported ways in which having access to this WRC and professional development resources, as well as his experiences enacting the unit, affected his personal views and attitudes. Specifically, Mr. Skelton reported a change in his understanding of what students need to engage in his science classroom as well as his attitudes about science and practices in teaching problem solving in science. For example, in his 2022 interview, Mr. Skelton said:

> This is a vast departure from how normal teaching happens. When you facilitate discussion and feedback, looking at data and analyzing data, those types of things that are part of what scientists normally do, I think it is challenging for kids. It's much easier for them if you look at the graph and tell them what it says … I think being comfortable with that messiness is what makes the unit really successful and appealing to me.

These examples show how changes in a teacher's personal domain, and their beliefs or attitudes towards how science should be taught, can then affect future practice.

Discussion

NGSS was designed to enable teachers to provide authentic CS-integrated science experiences for their students, which is particularly important at the elementary level (Fluck et al., 2016). The results of this study highlight the importance of considering teachers' perceptions of implementing NGSS-aligned units (i.e., Ketelhut et al., 2020; Sands et al., 2018) as well as offering teachers opportunities for reflection and feedback (Peel et al., 2020) as a way of impacting the teaching practice of integrating CS within elementary science education. Specifically, findings indicate that Mr. Skelton perceived that changes in his practice helped inform changes in student outcomes and the curriculum and, in turn, these changes in outcomes further informed his teaching practice in the next iteration. These results are in line with prior research showing that teachers' instructional decisions can affect how and what kinds of activities are used in the classroom (e.g., Remillard, 1999) by adapting curriculum materials to respond to students' in-the-moment needs and planning additional student supports (e.g., Gess-Newsome, 2015; Lilly et al., 2023).

As Mr. Skelton taught and gave feedback on multiple iterations of the unit, he reported ways in which the domain of consequence affected his teaching practice based on his perceptions of enacting the WRC and of student learning. After reflecting on the unit, Mr. Skelton was able to propose changes and then adjust his practice to these changes. This process of reflection and enactment of the WRC between these domains can help researchers to develop science curricula that integrate CS concepts (i.e., Lee et al., 2020).

This single case study of a STEM teacher integrating CS within an NGSS-aligned WRC over multiple years shows the development the teacher reports with his own practice through the enactment of the unit. The teacher's responses help provide insight into teacher feedback on CS integration design as well as growth through teaching a CS-integrated science unit. In this case, Mr. Skelton was able to see himself as a part of the iterative co-design of the unit as he saw how his suggestions to the curricula designers were being implemented. Seeing his changes to the WRC may have also impacted his growth and commitment to implementing the unit. Particularly in this study, where the STEM teacher has implemented the unit multiple times and is also a teacher-leader supporting other teachers to implement the unit, his knowledge and suggestions are invaluable to curricula designers and researchers in the RPP. We believe that over time, as teachers use CS tools and integration in content areas, their experiences and growth should help inform the design of the curriculum and tools. We also believe that through reflection and enactment of CS-integrated science units, teachers will continue to develop their understanding of CS concepts to enhance the student learning experience in NGSS-aligned units.

Implications from this study include that curricula designers and researchers may need to consider different strategies for how to support elementary teachers with the content and pedagogical skills needed to teach CS-integrated science curricula by offering them repeated opportunities to practice implementing these skills in low-stakes contexts with their students. For example, in addition to practicing skills within professional development contexts, curricula designers could create a series of short CS-focused activities (e.g., warm-up, centers) that teachers could use as repeated practice teaching specific skills to their students before implementing a unit. Curricula designers could also offer shorter CS-integrated units over the course of a semester or school year in preparation for a larger unit. These options would give teachers an opportunity to reflect upon their teaching of CS and make adjustments sooner rather than after a full school year. In each case, researchers could consider how the teachers' personal growth might lead to changes in the co-design process and report back any necessary changes to both curricula designers and the teachers for the next activity/project/unit iteration. This work shows the importance of the continued relationships between teachers, researchers, and curricula designers in RPPs in which teachers are supported to implement units multiple times and reflect in between for teacher growth, and researchers and curricula designers are committed to centering the teachers' perceptions and suggestions for each iteration.

Conclusions

The opportunity to look at a teacher's perceptions of their practice while implementing an NGSS-aligned, project-based CS unit over multiple years provides insight into how teachers' perceptions may change as they integrate CS within elementary science classrooms. We believe that supporting teachers to reflect on teaching a CS-integrated science unit can help teachers to develop their teaching practice. For example, Mr. Skelton may have shown a sense of empowerment and ownership of the unit through his teaching practice because of his perceived ability to add value and make adaptations to the unit. His feedback of, and changes to, each iteration of the unit led to researchers and designers making changes in the curriculum materials as well as offering additional support through further professional development so that there was more opportunity for Mr. Skelton to enact his change in practice. This study then also puts forth a need for additional research to better understand what kinds of support teachers need to be able to integrate CS within their elementary science classrooms through NGSS-aligned curricula.

We believe that highlighting the importance of considering a teacher's perceptions of how their practice changes through iterations of a science unit containing embedded CS skills will enable teachers to professionally grow in their ability and efficacy in integrating CS and science as well as have agency in the curriculum creation and implementation cycle. The findings of this study point to the value of teacher co-design and reflection for professional growth across IMPG domains as well as for iterative improvement of curricula. As teachers access CS through NGSS-aligned curricula, it is important to continue to investigate how teachers develop, interact with, and implement CS in elementary science classrooms to enhance their practice as well as their students' experiences.

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