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Designing learning environments with iterative conjecture mapping to support teachers' computational thinking learning

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Abstract: One way to help develop foundational computational literacy skills for K-12 students is to integrate computational thinking (CT) into science and math, but teachers have struggled to implement CT. This work investigates secondary science and math teachers' CT outcomes as they engaged in a four-week summer institute. This study uses conjecture mapping to inform iterative design, implementation, and evaluation of the institute over two years. This paper characterizes teacher learning outcomes and the specific aspects of the institute design that led to those outcomes. Findings suggest the institute's design led to increased CT knowledge and confidence in CT. Specifically, teacher outcomes were supported by teachers' engagement as learners in discussion, reflection, and interaction with computational tools. Challenges encountered were used to inform redesign and a second implementation.

Purpose

Computational tools and methods are increasingly important in STEM disciplines. As such, it has become important to include computing in K-12 science education, both to enable students to understand the science, and to develop foundational computational literacy (Wilensky et al., 2014). One way to achieve this is to integrate computational thinking (CT) into core classes, such as science and math. CT, as conceptualized by Papert (1980), described the process of thinking about a phenomenon through using, creating, and constructing computational tools. While the potential benefits of CT integration with science and math are evident, teachers have struggled to design and implement CT in their classrooms. Several barriers impede CT's uptake such as lack of appropriate technology and infrastructure, teachers' limited experience with CT and computing, limited time to teach content, and limited professional development resources (e.g., Aljowaed & Alebaikan, 2018). Thus, it becomes increasingly important to support teachers in learning about and implementing CT. Our research team has worked with teachers to integrate CT into science and math classes for several years. Our approach has evolved from researcher-designed units to complete co-design with teachers. This co-design took place in 2019 during a four-week summer institute (CTSI), which also included workshops to support learning about CT, how to integrate CT, and how to teach CT. The research is guided by the following research questions. After a four-week summer institute where teachers engaged in workshops and co-design, 1) What were the teacher learning outcomes? And 2) How did the summer institute's design mediate teacher outcomes?

Framework

Table 1
Initial PD Conjecture Map About the Design of the 2019 PD

Conjectures	Embodiment	Mediating Processes	Outcomes
Teacher engagement in workshops and co-design will lead to learning about CT and how to integrate CT.	Workshops in which teachers participate in lessons about CT. Co-design in which teachers worked with researchers.	Interacting with computational tools Designing and creating computational tools	Learning about CT & computational tools Learning about how to integrate CT

Conjecture mapping was used to investigate how the design of the summer institute led to teacher learning outcomes (Sandoval, 2014). Elements of a conjecture map specify how the design of a learning environment enables desired outcomes. Conjecture maps consist of high-level conjectures (initial ideas about supporting learning through the learning environment), embodiment (the learning environment design elements), mediating processes (the activities and/or interactions connecting the embodiment and desired outcomes), and outcomes (the desired outcomes of the learning environment). Project researchers made an initial conjecture map before data analysis, which was then used to test design ideas, and data was used to refine the conjecture map. Table 1 depicts the initial conjecture map of hypothesized connections between design and outcomes.

Methods

The summer institute

The summer institute was four weeks with eight teacher participants. During the first week, teachers participated in workshops aimed to help them understand CT and its integration. Workshops included engaging the teachers as learners in several exemplar CT integrated lessons. The subsequent three weeks were dedicated to co-design where each teacher worked with one researcher to design new CT-integrated science and math units. More details about the summer institute are described elsewhere (Wu et al., 2022).

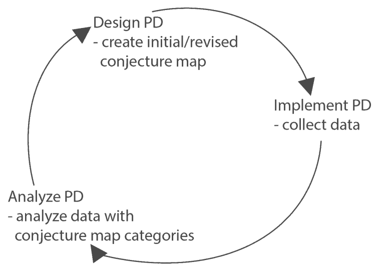
Data sources

Multiple data sources were collected throughout the summer institute. At the end of each week, the teachers filled out a reflection form to provide feedback. The group also discussed aspects that went well, aspects that were challenging, and goals for the next week, which was followed by a weekly exit ticket that each teacher filled out. At the end of the summer institute, teachers completed a post survey and a 45-minute semi-structured interview where they discussed their experiences. Audio and video recordings of the workshops were also collected.

Analysis

We utilized conjecture mapping design cycles to first identify desired professional learning outcomes and then to guide the design, implementation, data collection, analysis, and revision of the learning experience (Figure 1). We developed an initial conjecture map to plan and design the learning experience (Table 1). This qualitative study to investigate the how the learning experience contributed to outcomes took place through several rounds of inductive and deductive coding with triangulation between data sources (Miles et al., 2014). In the first round of coding, we investigated data sources to identify outcomes. Next, authors one and two coded data for connections between the identified outcomes and specific design elements (embodiments) and how they led to the outcome (mediating processes). These findings were used to modify the conjecture map to represent the actual learning experience implementation. A third round of coding was implemented to identify issues and areas for improvement that arose during the learning experience implementation. The refined conjecture map based on implementation data was used to redesign the learning experience.

Figure 1
Conjecture Mapping Design Cycle



Results

Teacher learning outcomes

Three categories of teacher self-reported outcomes were identified through the qualitative analysis: 1) Learning about and how to use CT tools, 2) Learning about pedagogy to support CT integration and scaffolding, and 3) Changes in values and attitudes regarding CT. Table 2 shows examples coded for each outcome. These results indicate the summer institute led to positive outcomes in teacher learning and shifts in values and attitudes.

Table 2
Teacher Learning Outcomes

Outcome	Quotation Example
Learning about and how to use CT tools	"I learned a lot about how to program NetLogo, as well as how to use various computational tools effectively in instruction" (Derick, Post CTSI Survey).
Learning about pedagogy to support CT integration and scaffolding	"Brainstormed new ideas for modeling the unit, interesting ideas for models that I wouldn't have thought of, like pulling in the data snapshots to model and having students place sensors" (Lacey, Post CTSI Survey).
Changes in values and attitudes regarding CT	"I have really learned a lot and will be more confident using CT with the students. I think I may even be able to do a little trouble-shooting and be less reliant on the team that observed my classes." (Tracy, weekly reflection 7/25)

Design mediated outcomes

The initial conjecture map was refined based on teacher responses, and then used to investigate the connections between outcomes and the summer institute design (Table 3). The Embodiment column describes the workshops and co-design teachers engaged in during the summer institute. The Outcomes column shows the outcomes identified from the data in the prior section. The Mediating Processes column describes the processes teachers engaged in during the embodiment that led to the outcomes. For example, when teachers engaged as learners in a workshop session (embodiment), they interacted with computational tools (mediating process), which led to learning about CT and computational tools (outcome).

Table 3

Conjecture Map for the design of the 2020 PD

Conjectures	Embodiment	Mediating Processes	Outcomes
Teacher engagement in workshops as learners followed by explicit reflection leads to learning about CT and changes in perceptions of CT.	Workshops in which teachers engaged as learners.	Answering questions in the CT-STEM units	Learning about and how to use CT Tools
	Workshops in which teachers reflected on pedagogy, CT content, science content, and planned their unit design.	Interacting with computational tools	Learning about pedagogy to support CT integration and scaffolding
Co-design allows for learning about CT and changes in perceptions of CT.	Feedback from other teachers and STEM experts.	Discussions	Changes in values and attitudes regarding CT
	Co-design in which teachers worked with researchers.	Designing and creating computational tools	CT-integrated units

Four mediating processes were identified within the data: 1) Answering questions in the CT-STEM units, 2) Interacting with computational tools, 3) Discussions, and 4) Designing and creating computational tools. The video data provided evidence of connections between mediating factors and outcomes, thus triangulating the various data sources. The connections between mediating processes and outcomes suggest the design of the summer institute led to teacher learning and changes in values and attitudes regarding CT. The overall conjecture map led to the development of two major conjectures about the design of the summer institute. First, teacher engagement in workshops as learners followed by explicit reflection leads to learning about CT and changes in perceptions of CT. Second, co-design allows for learning about CT and changes in perceptions of CT.

Although the 2019 summer institute led to several important outcomes, teachers did experience challenges and tensions. Some teachers felt unprepared to pick a unit topic after the first week. Teachers felt that workshops and design time could have been better interwoven to allow for reflecting on how to incorporate the ideas in their context. The red text in Table 3 represents new additions to the PD for the following year (2020). To address challenges, we began co-designing and planning earlier in the PD and allowed for reflection and planning with each workshop. To facilitate discussion and feedback, we added several sessions where teachers discussed their units with each other and with STEM professionals outside the project.

Findings presented elsewhere showed the 2020 teacher participants experienced similar outcomes, such as learning about CT practices, CT tools, and how to teach with integrated CT (Wu et al., 2021). Teacher's 2020 workshop reflections indicate they appreciated receiving feedback from STEM professionals. "Loved the feedback from the three-four people I spoke with. Loved connecting with a post-secondary professor to discuss some missing pieces when vertically building awareness in skill and content planning" (Matthew, 2020 Workshop Reflection). Similarly, teachers valued feedback from other teachers in the institute. "The team feedback and cross-team feedback were incredibly valuable" (Kathy, 2020 Post CTSI Survey). After the first week of the institute teachers were asked what went well, and several teachers indicated the time spent brainstorming along with workshops was beneficial. "I feel very accomplished with the brainstorming that [Jack] and I have begun. Looking forward to getting started next week!" (Jeremy, Week 1 Exit Ticket). These responses indicate the modification to include planning time earlier in the institute was helpful for teachers. Teacher participants in both summer institutes (2019 and 2020) successfully co-designed and implemented CT-integrated science and math units. Full units are available on the project website (ct-stem.northwestern.edu).

Discussion

Our research builds on and extends existing literature (Hestness et al., 2018, Yadav at al., 2014) by connecting the design of a learning environment with teacher outcomes through specific embodiments and mediating processes, adding to the literature knowledge about how to support teachers in learning about CT and feeling confident with teaching CT. Significant outcomes identified in this research also suggest that the summer institute addressed some of the barriers to implementing CT in schools, such as limited computing experience and limited professional development resources. Findings suggest the workshop design (engaging as learners, discussion, reflection, interaction with computational tools) led to increased CT knowledge and confidence in CT, which prepared the teachers for co-design. Co-design of new CT integrated units supported learning about CT tools and how to integrate them and increased confidence with CT through discussions, interactions with computational tools, and the design and creation of computational tools. Co-design pathways and cases of specific co-design approaches are detailed elsewhere (Kelter et al., 2021).

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