A Professional Development That Helps Teachers Integrate Computational Thinking Into Their Science Classrooms Through Codesign

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Abstract

Computational thinking (CT) is a key practice in the Next Generation Science Standards (NGSS Lead States, 2013) that high school inservice teachers struggle to teach alongside disciplinary content in their classrooms. They often require training on how computing intersects with traditional science content and how to use computational tools that foster CT and scientific practices. To this end, we developed a professional development (PD) program that positioned inservice teachers as (a) learners who engage in such practices and (b) codesigners of CT-integrated science curricula. In this paper, we describe the 4-week PD program as it was implemented in two settings: in person with seven teachers and online with 11 teachers. We share detailed descriptions of how we leveraged physical and digital spaces in PD activities and provide access to our resources so that other educators can adapt our PD program to help teachers integrate CT into their science classrooms. In both settings, teachers engaged in CT-integrated science activities designed for students to learn about CT in the context of disciplinary content. Furthermore, they worked with a team to develop curricular units that use computational tools to teach a specific topic in their classroom. In this process, teachers gained insights on CT, disciplinary content, and curriculum codesign through engaging in workshops and cocreating curricular materials with researchers and fellow teachers.

Introduction

Due to the inclusion of computational thinking (CT) in the *Next Generation Science Standards* (NGSS Lead States, 2013), there is a growing demand to integrate CT into K–12 curriculum (Grover & Pea, 2013). CT draws upon concepts from computer science (CS) to solve problems, design systems, and understand human behavior (Barr et al., 2011; Lu &

Fletcher, 2009; Wing, 2006), thereby promoting scientific computing practices. Such integration not only creates opportunities for students to engage in solving real-world problems but also has the potential to transform the classroom into a constructionist environment that positions students as programmers and designers of technology (Wilensky et al., 2014).

The integration of CT into science classrooms is particularly crucial in high school because computer science is typically taught as an elective. CT-integrated science courses would increase equity by introducing computing to all students in traditional high school classrooms, especially students belonging to populations underrepresented in computing and STEM fields (Code.org, 2021; Cuny, 2012; Wilensky et al., 2014). Further, CT-integrated science lessons that engage high school students in using, modifying, and constructing with computational tools have been shown to provide authentic learning experiences and deepen the learning of science content (e.g., Peel et al., 2019; Sengupta et al., 2013; Weintrop et al., 2016).

However, promoting CT learning for students requires a shift in professional development (PD) to support teachers as CT learners and designers (Gerard et al., 2011; Grover, 2021). Teachers must engage in CT practices in the context of their disciplinary content, gain skills with computational tools, and participate in constructionist design themselves (Kelter et al., 2021; Wilensky et al., 2014). Without such experiences, teachers may struggle to teach computational lessons that promote constructionist, authentic problem-solving practices afforded by CT. For instance, in two PDs with K–12 teachers using a constructionist CT tool, NetLogo (Wilensky, 1999), teachers struggled to customize curricula to their classrooms or teach without ready-to-use lessons (Borowczak & Burrows, 2019; Burrows & Borowczak, 2017).

To overcome these obstacles, our work has shifted towards *participatory codesign*, which positions teachers as partners in the development of CT-integrated curricula. Prior work has shown that engaging teachers in codesign can increase ownership, agency, and technological pedagogical content (Cober et al., 2015; Voogt et al., 2015). However, codesign requires substantial resources and time to adequately support teachers in learning new skills and technologies (Gerard et al., 2011; Huizinga et al., 2015). We address this gap through our work on the CT-STEM Summer Institute (CTSI), a 4-week PD program that positions teachers and researchers as learners and codesigners of CT-STEM curricula. In the following, we first describe in detail the structure and resources provided to teachers during CTSI. Then, we explore what teachers learned through engaging in CT during CTSI and integrating CT into their curricula and pedagogy. Finally, we provide practical recommendations on how to develop similar PD activities with concrete ideas that promote the integration of CT practices in science teachers' own classrooms.

CT-STEM Professional Development

CTSI was designed as a 4-week intensive summer PD program to help teachers develop their own CT-integrated curricula and implement them in their classrooms the following school year. We conducted CTSI in person in 2019 and translated it into an online format in 2020 because of the COVID-19 pandemic. First, we describe the general structure common across both PDs. Then, we describe each of the formats to highlight how we leveraged the affordances of the given physical and digital spaces to enhance communication and engagement with PD materials.

Overall CTSI Structure

In both formats, CTSI spanned 4 weeks of the summer with all content scheduled in 2-hour blocks between 10 a.m. and 3 p.m. with a 1-hour lunch break (Tables 1 and 2). The goal for teachers was to design CT-integrated curricula for content taught in their classrooms. Teachers received a stipend of $1,000 for each week of participation in CTSI and travel reimbursements for in-person meetings. They codesigned curricula with the support of researchers who were primarily graduate students in computer sciences or learning sciences who work on this CT-integration project year-round. All researchers have developed computational tools to investigate and teach disciplinary content for multiple years and contributed to the literature on student learning, teacher learning, and design of CT tools and practices for CT-integrated science classrooms (e.g., Aslan et al., 2021; Bain et al., 2020; Dabholkar et al., 2018; Kelter et al., 2021).

Table 1

Overview of PD Activities During CTSI 2019 Held in Person

Week	Monday	Tuesday	Wednesday	Thursday	Friday
1	• Presurvey Introductions • Demo: CT Lesson and Panel	• Introduction to Computational Models • Assessing CT-STEM Practices	• Computational Tools, Part 1 • Computational Tools, Part 2	• Introduction to Programming • Codesign: Unit planning • Weekly Reflection	Work from home
2–4	• Work from home • Review team's work	• Discuss feedback (~1 hour) • Codesign	• Codesign • CT-STEM Workshop (45–120 min)	• Codesign • Weekly Reflection (30 min)	Week 2–3: • Work from home Week 4 only: • Post-CTSI survey • Post-CTSI interview • Expo: Curriculum Showcase

Note. Grey squares indicate 6 days designated as work-from-home days on which teams did not meet in person and communicated via emails when needed.

Table 2

Overview of PD Activities During CTSI 2020 Held Online

Week	Monday	Tuesday	Wednesday	Thursday	Friday
1	• ***Introductions*** • Introduction to Project and Goal Setting • ***Discussion*** • ***Introduction to Computational Models***	• "Returner" CTSI Teacher Panel • ***Explore/Modify CT-STEM curriculum*** • Introduction to CT-STEM Practices • ***Discussion***	• Introduction to Programming[a] • ***Discussion*** • Computational Tools, Part 1[a] • ***Pair Programming and Discussion***	• Computational Tools, Part 2[a] • ***Discussion*** • ***CT Pedagogy***	• Intro to Codesign • ***Codesign team meeting*** • ***Weekly Reflection*** • Codesign
2–4	• Codesign • Review team's work	• Discuss feedback • Codesign	• ***CT-STEM Workshop (45–120 minutes)*** • Codesign	• ***Cross-Team Conference (CTC; 30 minutes)*** • Codesign	• ***Weekly Reflection (30 minutes)*** • Codesign Week 3 only: • ***Mini-Expo: STEM professional feedback*** Week 4 only: • ***Post-CTSI interview*** • ***Expo: Curriculum Showcase for public***

Note. Synchronous activities are shown in bold italics. Codesign formats differ by team and could be synchronous or asynchronous.

[a] These workshops were optional for returners, the three teachers who had participated in CTSI 2019.

The first 4 days of CTSI consisted of workshops to engage teachers as CT learners. The workshops introduced computational modeling, CT-STEM practices, programming, computational tools, and CT-STEM pedagogy. Each workshop was designed and led by researchers who sought to empower teachers with CT tools and practices in the context of disciplinary content. Workshops also focused on community building between teachers and researchers as well as reflecting on practices to help teachers assess their growth and challenges. See Appendices A and B for a detailed description of the workshops.

Most workshops engaged teachers in a CT-STEM lesson designed for students. For example, the first lesson, Introduction to Computational Modeling (https://ct-stem.northwestern.edu/curriculum/preview/495/pem_code/HE28N68HDQQSZE9XWSPM), involves using, modifying, and debugging computational models that simulate a forest fire (seehttp://tinyurl.com/netlogofire; Wilensky, 1999). Students answer questions about how each model works and how it can be used by scientists to engage with real-world phenomena. Students also collect data and analyze trends (e.g., "forest density vs. fire spread" tipping point) using the Common Online Data Analysis Platform (CODAP; The Concord Consortium, 2020). They then identify questions that can be tested with models, test their hypotheses, and reflect on the limitations of their simulated experiments. CTSI teachers completed all lesson activities as students, reflected on their experience as CT learners, and discussed takeaways for curriculum design and pedagogy to be applied in their own classrooms with partners and the whole group.

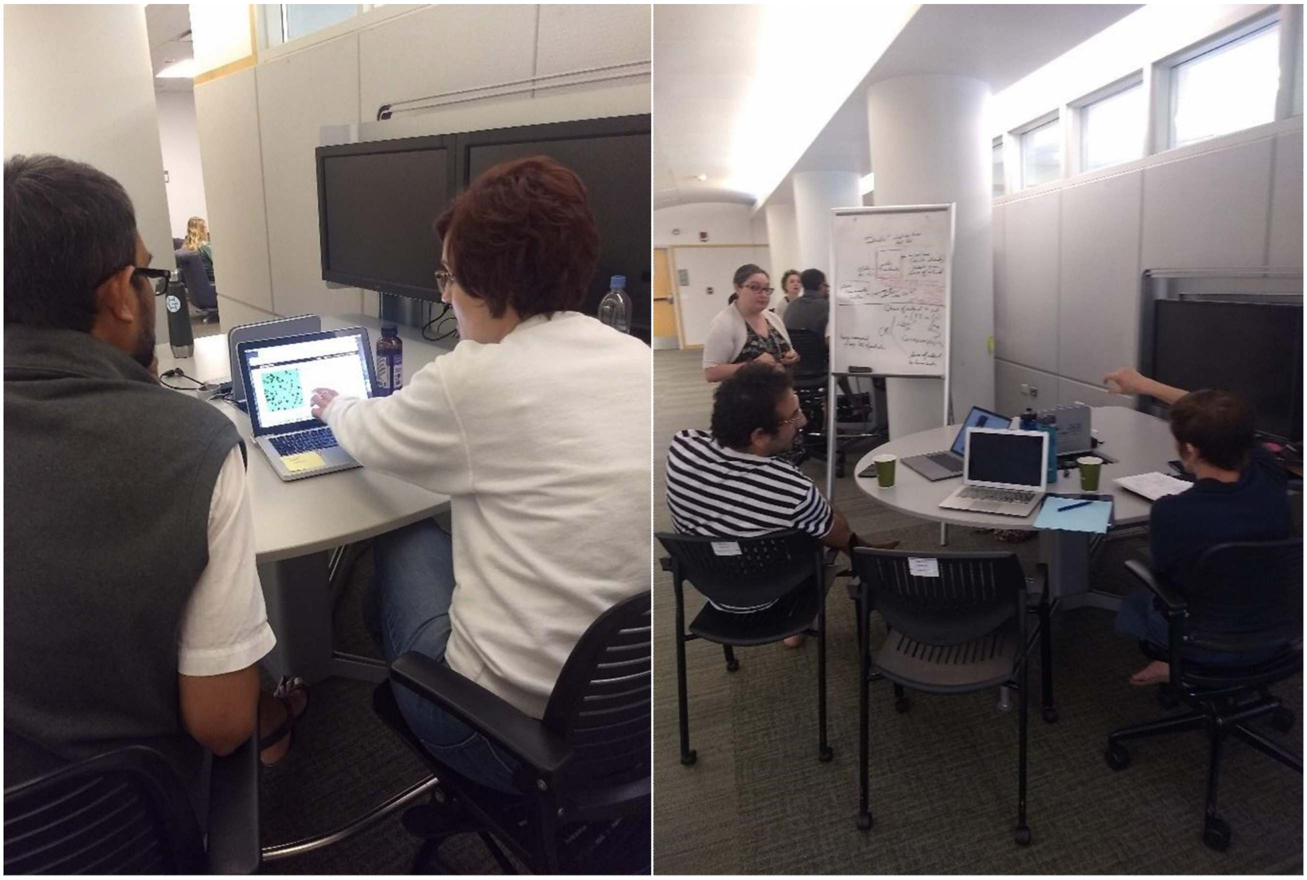
After the 4-day series of workshops, CTSI shifted to codesign of curricular units. Teachers were divided by subject area into codesign teams. Each team had two to five members (with at least one teacher and researcher). Codesign teams determined how they used their codesign time. In some codesign teams, teachers focused on designing curricular activities and questions while the researcher designed the computational tools, and in other teams, researchers designed computational tools and curriculum side by side with teachers (see Kelter et al., 2021). All teams communicated daily and met at least once a week to give feedback and discuss each other's curriculum drafts.

In addition to codesign meetings, Weeks 2–4 included a few whole-group sessions. Every Wednesday afternoon, participants engaged in supplemental CT-STEM workshops on CT tools or pedagogy. They also met for reflection sessions to discuss challenges and progress each week during the last scheduled hour of the week on Thursday afternoon (in person) or Friday morning (online). Finally, on the last day of CTSI, teachers and researchers showcased their codesigned CT-STEM curricula in an Expo open to the public.

In-Person CTSI (2019). For the in-person CTSI in 2019, teachers and researchers met in person for 14 days from 10 a.m. to 3 p.m. with a 1-hour lunch break. On six Fridays and Mondays, all participants worked from home and communicated via email as needed. Teams of teachers and researchers met in person to work on curricular materials for approximately 24 hours in total (see Figure 1). On Monday afternoons, each team reviewed each other's curricular materials asynchronously and discussed the feedback in person with their team on Tuesday mornings.

Figure 1

In-Person Codesign Time



Note. Teachers and researchers discuss curricular materials and computational tools during CTSI 2019.

Eight teachers (two men and five women) participated in CTSI 2019. Participants included three biology teachers, one chemistry teacher, three physics teachers, and one mathematics teacher from four metropolitan public schools (two urban and two suburban). The teachers worked in design teams divided by subject area with five researchers. In addition, a postdoctoral researcher and a curriculum director served as coordinators and floating designers. Codesign work continued into the remainder of summer and into the school year for teachers who did not complete their units during CTSI. Codesign partners supported CTSI teachers as they implemented their units with students during the 2019–2020 school year. Three CTSI 2019 teachers also participated in CTSI 2020 and are henceforth referred to as “returners.”

Online CTSI (2020). The online CTSI in 2020 had 11 participating teachers (six men and five women). Teachers designed curricula for high school biology (two teachers), chemistry (two teachers), environmental science (two teachers), physics (two teachers), and mathematics (three teachers) in four metropolitan public schools (three urban and one suburban). The teachers were placed into design teams by subject area with seven researchers and six undergraduate research assistants. The undergraduate assistants helped with administrative tasks such as recording meetings, managing online materials, and proofreading curricula. In addition, a curriculum director provided technology support and facilitated across teams.

CTSI 2020 activities were generally scheduled within the hours of 10 a.m. and 3 p.m., and Friday mornings were scheduled from 10 a.m. to 12 p.m. The first 4 days were again focused on workshops. However, all CTSI workshops from 2019 were converted to a hybrid format in which teachers first engaged with CT-STEM lessons, videos, or written materials asynchronously and then participated in a synchronous discussion on Zoom to address questions, identify takeaways, and build community. Google Classroom and Google Drive were used to organize materials, and Slack was used for announcements, discussions, and communication with others on the team (see Table 3). Several workshops were designated as optional for the three returners from CTSI 2019, who used the time to revise their units after they were implemented during the 2019–2020 school year.

Table 3

Tools and Resources Used During In-Person and Online CTSI

Type	Description
Curriculum development	All teachers used the project website (https://ct-stem.northwestern.edu/) to explore, create, edit, and implement curricula. In the first week, teachers created a student account to engage with the lessons. In the following weeks, teachers and researchers used teacher accounts to codesign student activities and review their team's units.
Meeting space	*In-person:* Most sessions were held in conference rooms. During codesign, teams spread out to individual tables designed for small group collaboration that had a monitor or screen for presentation purposes. *Online:* Synchronous sessions were held on Zoom. During Week 1, one "main room" Zoom link was used for all synchronous activities and was staffed as a help desk during asynchronous sessions. During Weeks 2–4, each codesign team used their own Zoom links and used the main room Zoom link for whole-group sessions or to reach the help desk. At the time of CTSI 2020, Zoom did not yet have the functionality of letting participants choose breakout rooms, so different Zoom links were used for codesign to reduce the need for a host to manage rooms throughout CTSI.
Learning management system: Schedule, materials, links, and general resources	The research team created a set of digital resources on Google Drive for teachers to use during workshops and curriculum codesign, as detailed in Table 2. The resources included a schedule, contact information, handouts from the workshops, lesson planning documents, and feedback forms. Each teacher also had an individual Google Drive folder for sharing curricular materials with their codesign team. *In-person:* CTSI resources were also provided physically in a folder for reference. *Online:* All resources were digital and were further organized within Google Classroom to help facilitate synchronous and asynchronous engagement during CTSI 2020 (as described in Appendix B). Activities were organized in modules by day (during Week 1) or category (e.g., General Resources or Codesign Materials). Synchronous sessions included the Zoom link for easy access.
Announcements/ communication	*In-person:* General updates and announcements were provided via email or during brief check-ins at the beginning and end of each day on campus. Teams generally used email to communicate with each other. *Online:* Participants primarily used Slack (https://slack.com/) for asynchronous discussions and general community building. Slack channels (indicated by hashtags) were used to make #general announcements, send reminders about upcoming events on our #schedule, share #random news, poll participants, provide #support on specific tools, talk within teams, and direct message each other. All participants were asked to share an intro in #general to make sure they were logged in and were familiar with how to send a message. The research team set up some channels before CTSI and added new channels as needed. CT-STEM researchers already used Slack, so they monitored it frequently. Teachers used it daily during CTSI to communicate with their teams, get support, or engage with the community. For instance, 3 days into CTSI, some teachers nominated songs to play as entrance or exit music each day. One teacher nominated another person in the CTSI community to pick the songs for the next day, leading to a series of YouTube music video links posted each day to set the tone. By the end of CTSI, 4,700+ Slack messages were sent. Some teachers continued to use Slack during the school year to communicate with their team or receive support during implementation. Others communicated primarily via email after CTSI.
Brainstorming/discussion	*In-person:* Flipchart paper or whiteboards were used to brainstorm, organize, and post ideas generated during discussions. *Online:* Google Docs, Google Slides, or Padlet (https://padlet.com/) were used to gather ideas and share with the group.
Presentation/showcase	*In-person:* Teachers created and printed research/symposia posters outlining their units to put on the wall next to their station at the Expo. Each station had a small screen for projection for each teacher to share their screen and showcase their curriculum. *Online:* Padlet was used as a digital poster board and launch page to showcase codesigned curricula to the public during the Expo. Teachers created videos and Zoom links that were posted on Padlet (https://padlet.com/sally_wu/CTSIExpo). In their Zoom room, they shared their screen to showcase their curriculum.

As in CTSI 2019, Weeks 2–4 focused on codesign. Each codesign team differed in how they collaborated and communicated. Some teams met every morning to check in or met on multiple days to cocreate curricular models and activities. Other teams primarily communicated asynchronously on Slack as they worked on materials and met on Zoom to discuss the materials or questions that arose. All teams reviewed each other's materials at least once a week on Monday afternoon, and most teams discussed materials multiple times a week.

In addition to the Wednesday workshops and end-of-the-week Friday reflections mentioned above, two additional sessions were added to provide teachers with more feedback on their units and build community. Every Thursday morning, teachers from different codesign teams gave feedback to each other during the Cross-Team Conference (CTC). Teacher pairs for each CTC session were announced the day before. Because CTC sessions were only 30 minutes long, each teacher was required to prepare a Google Slide with an overview of their curriculum and specific questions to ask the other teacher. A session was also added on Friday morning of Week 3 for teachers to meet with scientists and professionals who work in their subject area. This Mini-Expo served as a practice run for the Expo in Week 4 when teachers would showcase their units to the public. For the Mini-Expo, teachers created short videos about their units with help from their undergraduate assistants. All videos were posted publicly to Padlet (https://padlet.com/sally_wu/CTSIminiexpo) for professionals to review with a Zoom link for them to meet with teachers. This format was then used for the Expo in Week 4 to allow members of the public to view teachers' videos on Padlet (https://padlet.com/sally_wu/CTSIExpo), leave comments, and use Zoom links to meet with teachers to learn about the unit and share feedback.

Teacher Experiences

In this section, we briefly summarize research findings from CTSI 2019 and CTSI 2020, which have shown enhanced teacher and student outcomes. Then, we share post-CTSI interview responses from teachers on the key resources that helped them learn CT-STEM practices and integrate CT into their curriculum and pedagogy.

Summary of Teacher Learning Outcomes

Research on teacher outcomes from CTSI 2019 and CTSI 2020 shows general increases in teacher interest, confidence, skills, and knowledge of CT (Aslan et al., 2021; Wu, Anton, et al., 2020; Wu, Peel, et al., 2020) despite the differences in formats. A longitudinal investigation of one biology teacher over several years showed that codesigning with her researcher partner increased her comfort, confidence, and understanding of CT; facilitated the integration and centering of CT practices in her curriculum; and helped her create a classroom culture of comfort with debugging and asking questions alongside her students (Peel et al., 2020). Each curriculum codesigned by teachers integrated multiple CT-STEM practices using a diverse set of computational tools to teach science content (Wu, Anton, et al., 2020). Positioning teachers as curriculum codesigners promoted agency and ownership of the CT-integrated curricula by providing different pathways that allow teachers to pursue different interests and build their skills in model design, question design, or both in the codesign process (Kelter et al., 2021).

A conjecture mapping of CTSI 2019 activities to teacher learning showed that four processes (answering questions in the CT-STEM units, interacting with computational tools, discussions, and designing and creating computational tools) mediated three teacher outcomes: learning about and how to use CT tools, learning about pedagogy to support CT integration and scaffolding, and changes in values and attitudes regarding CT (Peel, Kelter, et al., 2021). Reflections also showed that teachers' knowledge grew over the 4-week period: They gained insight into how students can learn CT; deepened their understanding of content, pedagogy, and CT practices; and learned about computational thinking, how to use specific computational tools, how code works, and the value of collaboration (Wu, Anton, et al., 2020; Wu, Peel, et al., 2020).

Resources at CTSI

To identify specific PD activities that contributed to the research findings, we describe teachers' responses in their post-CTSI interview to the question: "What are the top three resources at CTSI?" A few teachers noted, "It was all useful. I don't know what was most useful" (Betsy, CTSI 2020) or "I don't know that there's any of [them] that, like, stand out specifically" (Emma, CTSI 2019). However, most teachers mentioned this ranking of resources: (1) their codesign team members, (2) people outside of their team, and (3) supplemental resources that helped them build curricular materials. For instance, Brooke (CTSI 2020) responded: "[Codesign researcher omitted] [. . .] Actually, the whole team for number two. Okay, everyone has been incredibly supportive and responsive. And I think number three was, would probably be, like, the NetLogo dictionary." We expand on each of these resources with example quotes from teachers below. See Appendix C for all responses by year and teacher pseudonyms.

Codesign Team. Most teachers mentioned collaborating with one or more members in their codesign team as the top resource at CTSI. For example, Paul (CTSI 2020) stated: "The people, you know, [undergraduate researcher omitted] and [codesign researcher omitted]. I couldn't have done it without them." Several teachers in CTSI 2019 specifically mentioned "having a researcher with us the whole time" "sitting right there" (Carrie, CTSI 2019) as crucial to getting "questions answered immediately" (Matt, CTSI 2019). Teachers, such as Penny (CTSI 2019), noted that this proximity and support helped them progress: "I think you, you people, having, like, everyone in the room and being able to say, like, 'Oh, I'm not, this isn't working. Can you help me with that?' [. . .] I didn't feel like working on coding over the weekends was productive because, like, I would get stuck right away and, like, not be able to go anywhere."

Other CTSI Teachers and Researchers. Many teachers mentioned other CTSI participants outside of their team, typically as a secondary key resource. These interactions could be spontaneous, such as one researcher Evan (CTSI 2020) contacted on Slack who "went out of her way to help" him. More often, it was through the sessions added in 2020 to facilitate cross-team discussion. For instance, Carrie (CTSI 2020) mentioned learning from peers at the cross-team conferences:

> The cross-curricular meeting things were, were really helpful. Um, okay, my, the one I had last week in particular was just like—I felt like I was able to contribute a lot to my partner, and he was able to contribute a lot to me, and just, you know, having somebody view your stuff with a fresh set of eyes. And even if it was minor little things [. . .] we came at it with, "I want you to look at this and help me with this," and we both had very specific questions that we were able to help each other [with].

Similarly, Emma (CTSI 2020) described how she got help on her computational model during the Mini-Expo when teachers presented their work to STEM professionals and other CTSI members:

> [Researcher omitted] popped in. And, so, I was explaining something to him. [. . .] And he was like, "Well, you could just color code it. [. . .]" It was, like, about social groups. So, it was like, you could color code the different organisms. So, like, they would know who their social group is because it would just be the other ones that have the same color as them. And I was like, "I hadn't thought about that." So, I think, really, the people are the biggest resource here.

Resource Materials. Various digital and physical materials were mentioned, typically as a second or third resource. For instance, after naming her codesign team, Briana (CTSI 2019) mentioned: "Then, just, like, the website, you guys provided the dictionary for NetLogo of, like, if I want to do this, like—so, like, just those basic things, those tools that you guys shared with us." The NetLogo dictionary (https://ccl.northwestern.edu/netlogo/docs/dictionary.html) helped Brooke (CTSI 2020) write a model on her own (https://ct-stem.northwestern.edu/curriculum/preview/1645/pem_code/4VTCC2EMQ27RUXFJGPQK). It also helped Matt (CTSI 2020) understand and write code alongside his researcher:

> I knew what I needed to do, but I didn't know exactly what that command was. And so, I could look it up in the dictionary, try it out, figure out if that was the right one or not. And then [codesign researcher 1 omitted], you know, would explain that, like: "We can do this, you know, multiple different ways, but this will be the fastest way that we can, you know, accomplish this task." So, that was really helpful as well, having the dictionary but also having [codesign researcher 1 omitted] there as a resource to say, you know, "Yes, that one will work."

Further, two teachers mentioned a table of CT-STEM practices based on a CT taxonomy (Peel, Dabholkar, et al., 2021) that was provided as a resource for teachers. For Martin (CTSI 2020), it served as a reference during workshops: "It lists the six practice categories of computational thinking, and, like, that, just that little snippet was a very useful thing for me throughout the workshops." This table also helped Peter (CTSI 2019) in curriculum design: "The table helped me think about, when I was designing questions or activities, um, what I was targeting for kids to work on, um, and what I wanted them to get out of the, uh, activities."

Parvez (CTSI 2020) mentioned getting ideas from Slack and, like Briana (CTSI 2019), also mentioned the project website as a resource:

> The Slack also is a good way where you can actually have—I never post anything on the Slack, but I was just looking at it. And then, you also have many examples of different lessons that you have on the CT-STEM site. And so, that gives you an idea. I mean, you can actually get ideas from those lessons and new ideas. (Parvez, CTSI 2020)

Workshops. Finally, several teachers mentioned that workshops were important introductions to CT: "The early on workshops and stuff were very useful. They helped me understand, like, what CT-STEM is, what we're doing over the course of this month. Like, I think that was very important" (Martin, CTSI 2020).Betty specifically recalled two workshops in 2019 in which she saw a model for her own curriculum on roly-polies written from scratch based on her feedback and engaged as a turtle in the human-size grids as described above:

> When [codesign researcher omitted] took us into that big room, and I thought he was just going to make the roly-poly model, but instead, he's like, "So, what do you want them to look like? How do you want them to move? How should we tell? How big do you want the chamber? Where do you want the chamber to be?" And I saw him doing it live with [researcher omitted]. In fact, [researcher omitted] was going to do a totally different one. And then [codesign researcher omitted]'s like, "Why don't we do the roly-polies one?" It's like, oh my God, we did it. So, that was really cool. So, the workshops, and that other one that I thought was, like, really cool was the, um, unplugged one where we actually made the little grids and moved. I had no idea that's how the turtles were moving.

Some teachers in 2020 mention specific online workshops that introduced computational tools in which they received a "walkthrough" (Chelsea, CTSI 2020) and were able to ask questions during parallel programming on Zoom, as Evan (CTSI 2020) described: "So, it was you in one window and me in this window and just doing side-by-side, parallel coding. [. . .] 'I'm just going to follow along, and—Oh no, I get this error. What does this error mean?'"

Implications for Professional Development Design

Our prior investigations suggest that a 4-week summer PD program that positions teachers as learners and codesigners can help them learn about CT and integrate it into their classroom through codesigning their own CT-integrated curriculum. We did not observe drastic differences in teachers' learning outcomes and experiences between the online and in-person format, which may be due to the consistency of several PD design elements. In our two iterations of the PD program for teachers, we found these aspects crucial in helping teachers learn about computational thinking and design CT-STEM curricular materials for their students.

Our PD program focused on curriculum development, providing 3 weeks in small codesign teams by content area composed of both teachers and researchers. These small teams allowed teachers to discuss ideas, receive feedback, and get support in using CT tools from the teacher and researchers on their team. Teachers reported that their partnership with the codesign researchers was crucial to helping them integrate CT. In most teams, researchers did not have in-depth content knowledge of their subject area but instead served as consultants on ways to code phenomena in models, design computational data tools, or write more readable, efficient code. As a result, teachers led the codesign process in which they decided the topic, computational tools, and scaffolding questions for their units (Kelter et al., 2021; Wu, Anton, et al., 2020). This participatory codesign work empowered teachers as designers, building skills that can support not only their students but also their peers and research partners through close collaboration.

In the codesign process, teachers also reported benefiting from collaboration and discussions with teachers and researchers outside of their team. These interactions allowed teachers to learn from each other and get new perspectives on their curricular materials. In the in-person PD format (CTSI 2019), we provided multiple opportunities for the group to build relationships through formal discussions and informal chats. In the online PD format (CTSI 2020), we deliberately scheduled sessions, such as the Cross-Team Conference, to ensure that each teacher could connect with those outside of their teams. In line with prior research on participatory design (Cober et al., 2015), "the collaborative nature of the design process, in which teachers influence each other or are supported by experts, can lead to an improved quality of teachers' knowledge and skills and consequently advances the quality of the outcomes of the curriculum design process" (Voogt et al., 2016, p. 136).

Because CT is new to teachers, we designed introductory CT workshops using lessons situated in disciplinary content for the first 4 days to help teachers learn about CT practices and tools. These workshops positioned teachers as learners to help them understand difficulties students may face and what types of support are required to simultaneously manage the classroom and encourage student agency. These experiences not only gave teachers ideas about how to integrate CT into their classrooms but also set a foundation of common knowledge for all participants to know what they are doing over the course of the PD. This step is particularly important for teachers with no background in coding to ensure that they look at underlying code and are gradually exposed to things they can do with code (Wu, Peel, et al., 2020). This could help teachers understand what CT might look like in their classroom and envision pedagogical supports that they could design and enact for their own students.

Teachers particularly benefited from design workshops in which they built computational models from scratch. These workshops helped teachers see how adding a few lines of code at a time results in specific model behaviors and develop an understanding of how programming works. Teachers valued parallel programming in which they had the opportunity to write code alongside a researcher doing so on a shared screen and ask questions. This included 1-hour sessions during which teachers wrote a simple model relevant to their discipline and codesign meetings with their team that engaged teachers in designing or codesigning a computational tool for their students. Given that each teacher had divergent interests and needs, this approach provided an adaptive, personalized, and evolving experience for each teacher's goals, particularly in the online setting where activities can be tailored to teachers in breakout rooms.

Finally, our PD approach supports teachers longitudinally in integrating CT because our summer PD program is only the beginning. Researchers also serve as teaching partners or support staff when implementing CT-STEM curriculum in the classroom. After implementation, teachers can return to our PD program to revise their curricula. Our longitudinal studies have shown that teachers' CT knowledge, practices, and attitudes develop over several years (Wu, Peel et al., 2020). Teachers' shifts in CT practices take time because the practices are challenging for teachers and require a radical shift in teacher roles from users to designers. Teachers expressed feeling overwhelmed in the beginning because they are learning a lot of new information about CT, and it can be daunting to design an entire unit with novel tools that require computational skills (Wu, Peel, et al., 2020). However, through our structure of workshops over 1 week, codesign over 3 weeks, and continued support throughout the school year, teachers gain critical skills with computational tools and deepen their understanding of not only technology but also content and pedagogy for their classroom (Wu, Anton, et al., 2020; Peel, Kelter, et al., 2021; Levy et al., 2021).

Conclusion

This work contributes to work in participatory codesign and provides a detailed account of PD activities that researchers and teacher educators can adapt in future work. Our work identified PD approaches that benefit teachers when designing for CT integration and outcomes that show the value of participatory design for teachers. We also detailed how we leveraged the affordances of the physical and digital spaces to engage teachers in PD using in-person and online formats. As a result, teachers were able to engage with content as learners, lead the design of computational tools for their classroom, work closely with their codesign teams, and build on their experiences as learners and educators to design CT-STEM curricula for their students in both online and in-person formats. Although the small sample size limits the generalization of findings in this study, we will continue to work toward the sustainability and scalability of our PD program to a broader audience (Coburn, 2003). We hope that others join this effort.

Supplemental Files

Appendices-Wu-et-al.-2022.docx

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