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Building a Virtual Community of Practice: Teacher Learning for Computational Thinking Infusion

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Abstract

The COVID-19 pandemic led to an urgent need for professional development (PD) experiences to support teacher learning across hybrid and digital contexts. This study investigates teachers' experiences in a Virtual Pivot, a PD workshop designed to support computational thinking integration into disciplinary teaching. Participants were 151 middle and high school content area teachers, including 49 teachers who participated in previous face-to-face workshops. Virtual Pivot employed research-based design principles for virtual teacher PD, including asynchronous and synchronous engagement, explicit instruction in technological tools and scaffolds for teacher collaboration. Data sources included pre-PD surveys (n = 151), post-PD surveys (n = 119), interviews (n = 57) and six-month follow-up surveys (n = 105). Findings describe elements of Virtual Pivot which supported teacher learning and engagement (virtual community of practice, PD structure, during-PD support, pre-PD support and badges). We conclude by discussing this study's theoretical, methodological and practical contributions for designing and investigating virtual computational thinking PD experiences.

Keywords Communities of practice · Computational thinking · Computer science · Cooperative/collaborative learning · Distance education and online learning · Teacher professional development · Teaching/learning strategies

Introduction

The COVID-19 pandemic created a seismic shift in education (Lopez, 2020) and with this great change came new opportunities to reimagine the role of professional development (PD) in supporting teacher learning. Even prior to the pandemic, researchers questioned the efficacy of existing PD models, specifically in regard to sustaining meaningful pedagogical change (Appova & Arbaugh, 2018; King, 2014). Recent research points to the need for more

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rigorous studies to investigate effective models, formats and goals for teacher PD (Coenders & Verhoef, 2019; Fairman et al., 2020), particularly as a mechanism for pedagogical innovations that involve technology (Barr & Stevenson, 2011; Gamrat et al., 2014). However, and perhaps even more importantly, questions remain about how to design PD experiences that force teachers to think deeply, connect across school communities and disciplinary boundaries and engage meaningfully with big questions about teaching and learning.

This paper draws on data collected from the Infusing Computing project, a four-year study (2017-2021) of teacher PD that supports the integration of computational thinking into disciplinary teaching. From 2017-2019, more than 250 middle and high school content area teachers participated in week-long, face-to-face Infusing Computing workshops in the summers, as well as monthly webinars and follow-up sessions to support CT-infused lesson implementation (Jocius et al., 2020). In April 2020, as a result of the COVID-19 pandemic, our research team shifted the Summer 2020 PD to a virtual format. In this paper, we describe the process our team undertook to create a virtual community of practice, as well as the resulting experiences that fostered critical learning moments for our participating teachers.

Specifically, this study examines the experiences of 151 middle and high school teachers who participated in Infusing Computing: Virtual Pivot workshops in Summer 2020. We draw on several sources of data, including pre-PD surveys (n = 151), post-PD surveys (n = 119), teacher interviews (n = 57) and follow-up surveys (n = 105) to address the following research questions:

- What was the impact of Virtual Pivot on teachers' self-efficacy and implementation of CT-infused lessons?
- Which elements of Virtual Pivot supported teacher learning and engagement?

Communities of Practice: Integrating Computational Thinking

This study is grounded in theories of communities of practice (CoP) (Lave & Wenger, 1991), which we define as a community in which "social learning occurs between people with a common interest in a subject or problem who collaborate over longer periods of time to share and exchange ideas, find solutions and build knowledge" (Kirschner & Lai, 2007, p. 128). The concept of a CoP draws upon sociocultural theories (e.g., Schon, 1983; Vygotsky, 1978) that assume that learning is social and situated. In a CoP, members engage in a variety of activities, including problem-solving, seeking experience, reusing assets, coordination, mapping knowledge and identifying gaps (Wenger, 2010). A CoP is not static (Roberts, 2006), but is continuously reconstituted.

Reconstitution of a CoP occurs as long-standing members of the community share knowledge, practices, ideas and identities; newcomers become embedded within the social world of the community through the process of legitimate peripheral participation (Lave & Wenger, 1991). This theoretical framing offers an important lens for understanding teacher PD experiences. Over the past decades, researchers have pushed back against individual PD models in favor of learning experiences that prioritize sharing expertise, knowledge and practical experience (Hadar & Brody, 2010; Patton & Parker, 2017). Within a CoP, participants simultaneously develop new skills and new identities as leaders in a field (Barab & Duffy, 2000; Guldberg & Mackness, 2009). This is particularly important in relation to computational thinking instruction, which is unfamiliar to many teachers.

Studies of virtual CoPs have shown that fully online or hybrid models can be effective in supporting teachers' critical reflective practice (El-Hani & Greca, 2013) and facilitating the development of close ties with colleagues (Tseng & Kuo, 2014). However, researchers (Trust & Horrocks, 2019; Yurkofsky et al., 2019) caution that while virtual CoPs can be an effective means for building and sustaining professional communities, careful attention needs to be paid to organizational structures and supports for facilitating and sustaining interactions. Much of the power in virtual learning comes from modification or manipulation of time and place. While synchronous videoconferencing serves as a powerful means for developing a CoP (McConnell et al., 2013; Morreale et al., 2012), other studies (Hawkes & Romiszowski, 2001) indicate that asynchronous components can facilitate teacher reflection and connections to classroom practice. Asynchronous and synchronous tools can be used to encourage interaction among participants and support the formation of virtual CoPs (Sotillo, 2000).

Research also suggests facilitators need to consider and rethink the goals of the virtual PD experience and shared experiences (Carpenter & Krutka, 2015; Trust et al., 2016). For example, Yurkofsky and colleagues (2019) argue that teachers' goals for virtual PD often differ from their goals for face-to-face PD, with virtual PD goals often focusing on shifts in professional identity and building relationships within online communities. Specific tools for community-building, such as digital badge leaderboards where participants can set learning goals and track their performance with respect to others, can encourage more active engagement with content (Facey-Shaw et al., 2017; Gamrat et al., 2014). As an added benefit, research suggests that when teachers experience digital badging as learners, they are more likely to use similar systems in their own classrooms (Jones et al., 2018).

In reconstituting the Infusing Computing community in a virtual space, both newcomers to the PD and teachers who had participated in face-to-face workshops had opportunities to engage in critical reflection and practice using a variety of digital tools. In this CoP, members were tasked with sharing practices found not only within their schools but also their disciplinary teaching communities. Next, in order to illustrate the specific complexity of teacher PD for integrating computational thinking, we unpack the existing literature around CT and teacher learning.

Infusing CT into Disciplinary Teaching

As schools search for opportunities to better prepare a twenty-first century workforce, there has been growing interest in integrating computational thinking into K-12 classrooms. We use the term *computer science* (CS) to describe the study of computers, their uses and their impact on society (Tucker et al., 2003); *computing* as a general term to describe computer science-related fields and processes implemented by computers (Barr & Stephenson, 2011); and *computational thinking* (CT) as the concepts and processes commonly used in computer science but that are generalizable to other situations (Dong et al., 2019; Israel et al., 2015; Wing, 2006). There is a growing body of research that documents the impact of CT integration on STEM pedagogies (Hambrusch et al., 2009; Lin et al., 2009; Weintrop et al., 2016) and the benefits of developing critical thinking and problem-solving skills that transfer across disciplinary boundaries.

Integrating CT into disciplinary teaching presents a new and challenging context for teacher PD. Specifically, teachers need explicit support in order to understand the goals of CT infusion, connections to content learning and how to enact these pedagogies using virtual and hybrid tools (Rich & Hodges, 2017, Yadav et al., 2018). Teachers bring existing perspectives on computational thinking to any CT PD, including the common notion that CT is just the use of computers (Yadav et al., 2014). To help teachers reconceptualize CT, PD should foreground definitions of key terms (including CT itself) and how it applies to students and content (Ketelhut et al., 2020), and offer ongoing training and support (Barr & Stephenson, 2011; Hestness et al., 2018). While existing research has focused on changes to teacher beliefs and self-efficacy (Rich et al., 2021), more work is needed to identify practical supports for teachers to integrate CT into existing disciplinary curricula (Hestness et al., 2018). Further, there is a paucity of literature on virtual PD to help teachers integrate CT (Haines et al., 2019; Mason & Rich, 2019).

The COVID-19 pandemic has accelerated the need to document elements of effective virtual teacher communities across time and space. To address gaps in the research literature related to virtual CoPs, especially in regard to CT integration, this paper highlights teachers' experiences during Virtual Pivot and details specific PD elements that supported the reconstitution of a CoP in a virtual space. In the next section, we describe the context and methods for our study.
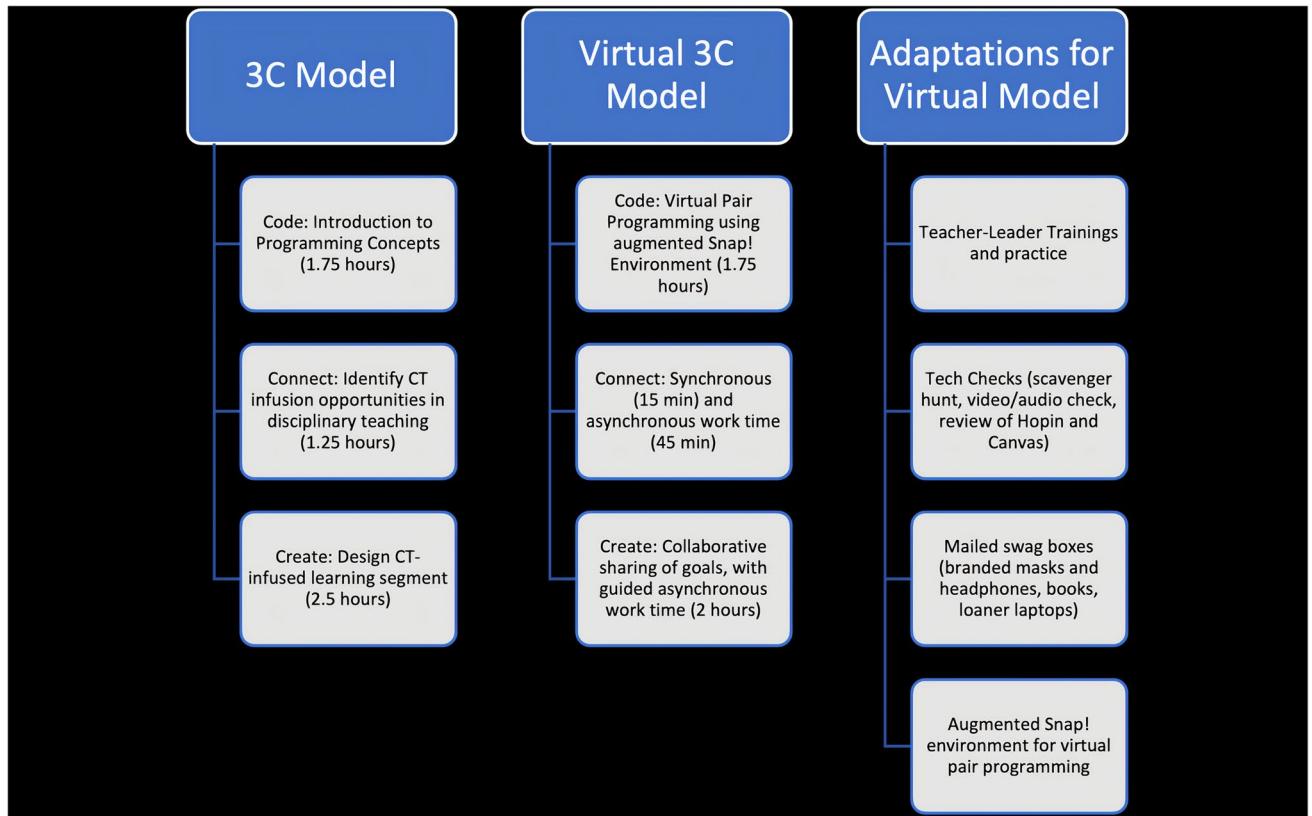
Setting & Participants

Infusing Computing is a four-year, NSF-funded project designed to support content area teachers in infusing CT into their disciplinary teaching (Jocius et al., 2020, 2021). In 2017-2018, members of the project team, including experts in computer science, science education, math education, literacy education and teacher education, collaborated with teachers to design and test PD materials for the project. Week-long, face-to-face summer PD workshops held in 2018 (Y1) and 2019 (Y2) were designed according to the 3C (*Code, Connect, Create*) model (Jocius et al., 2020) (see Fig. 1). Throughout each 3C session, we drew upon a conceptualization of CT that refined elements of Google's (2018) CT definition: (1) Pattern Recognition: observing and identifying patterns; (2) Abstraction: identifying ideas that are important by naming concepts and hiding details; (3) Decomposition: breaking down problems into meaningful smaller parts; and (4) Algorithms: providing instructions for solving a problem and similar problems (Dong et al., 2019).

Code sessions, which were led by research team members and teacher facilitators with computer science expertise , helped participants develop Snap*!* coding skills (Harvey & Mönig, 2010). Snap*!* is a block-based programming language similar to Scratch (Maloney et al., 2010). *Connect* sessions supported participants in developing knowledge of CT vocabulary, structures and connections to disciplinary concepts. *Create* sessions tasked teachers with creating a lesson that included the following components: (1) a Snap*!* prototype; (2) a detailed lesson plan; and (3) supplemental pedagogical materials, such as slides, links, or handouts. After each summer PD, participants remained engaged with the Infusing Computing community through monthly webinars, a podcast series, virtual networking, attendance at subsequent summer PDs and opportunities to serve as teacher-leaders.

Virtual Pivot

In March 2020, as institutions across the US closed for what was originally a "two-week pause," our Infusing Computing team was preparing for Summer 2020 teacher leader training, where we would support Y1 and Y2 participants in learning how to lead *Code* and *Connect* sessions. During the first week of April, it became apparent

Fig. 1 3C model and adaptations for Virtual Pivot

that COVID-19 restrictions would be extended indefinitely and major changes were needed to salvage Infusing Computing for Summer 2020 (Y3). In the next sections, we unpack our decision-making processes to illustrate how the shift to a virtual PD was grounded in research and participant feedback.

Gauging interest First, we surveyed accepted participants to gauge interest in a fully virtual version of Infusing Computing. Over 90% of respondents said that they were still interested in attending, so by mid-April, we made the decision to change formats. This gave us three months to reconsider PD outcomes, experiment with virtual platforms, train facilitators and create structures to support approximately 150 teachers. Most members of the project team had been teaching online courses for undergraduate and graduate students, including in-service teachers, for several years. While these experiences laid the groundwork for Virtual Pivot, none of us had designed a virtual workshop on the scale of Infusing Computing. We had the additional challenge--and privilege--of attempting to create a positive, collaborative and meaningful experience for teachers in the midst of crisis. Our goal was to reconstitute the CoP in a virtual space, provide teachers with clear expectations and create multiple layers of technical support.

Scaling up support Because substantive interactions with facilitators has been shown to increase virtual participant engagement (Park et al., 2013), we decided to substantially increase the number of facilitators from 35 in Y1 and Y2 to 79 for Virtual Pivot. Virtual Pivot facilitators included research team members, past participants, graduate students, K-12 CS teachers and 30 high school interns. Past participants were selected as *Connect* facilitators based on successful classroom CT integration; they also acted as participants during *Code* and *Create* sessions and designed their own CT-infused lessons. 30 high school students (interns) served as *Create* session helpers as part of a summer internship program, where we prepared them to work with teachers on the coding elements of their CT-infused lessons (Jocius et al., 2021).

Filling the virtual toolbox Probably the most crucial part of the design process was selecting the right tools for the job. A common complaint that participants shared was frustration with navigating numerous platforms while teaching during the initial phases of the pandemic. Research on virtual teacher PD also suggests that organizational structure and convenient access to materials is essential for success (Mumford et al., 2017). To address these elements, we decided to use only two platforms for the PD: Canvas (https://www.

instructure.com/canvas/) as an asynchronous learning management system (LMS) and Hopin (https://hopin.to/) as a synchronous virtual venue. We chose Canvas to house all PD materials and tasks since several participants indicated their schools would be using Canvas starting in 2020-2021. Canvas also hosted the digital badging system, Badgr (www. badgr.io), which allowed participants to earn badges and track their progress on a leaderboard.

The choice of a synchronous conferencing venue posed a more difficult dilemma. While we considered stand-alone tools (e.g., Zoom and Microsoft Teams), we sought a tool with different affordances to meet our goal of reconstituting a virtual CoP. Hopin, a platform that became publicly available in 2020, offered many features to facilitate community-building, including an all-in-one navigation and registration system, a Stage for whole-group sessions, Sessions for breakout sessions, multiple screen-sharing features, built-in networking and an Expo Center for open-all-day Help Desks (see Fig. 2 for a screenshot of the Hopin platform as used during Virtual Pivot).

We used teacher-leader workshops held in June 2020 as a field test for Hopin and Canvas. *Connect* facilitators practiced Hopin screen sharing, led mock discussions about CT infusion and reviewed Canvas materials, while *Code* facilitators and HS interns practiced pair programming roles and learned about inclusive pedagogies. Overall, facilitators reported positive experiences with both tools, but difficulties in navigating Hopin meant that we needed to design additional scaffolds.

In accordance with the research literature (Jones et al., 2018), we created "Tech Checks" to give participants practice with the s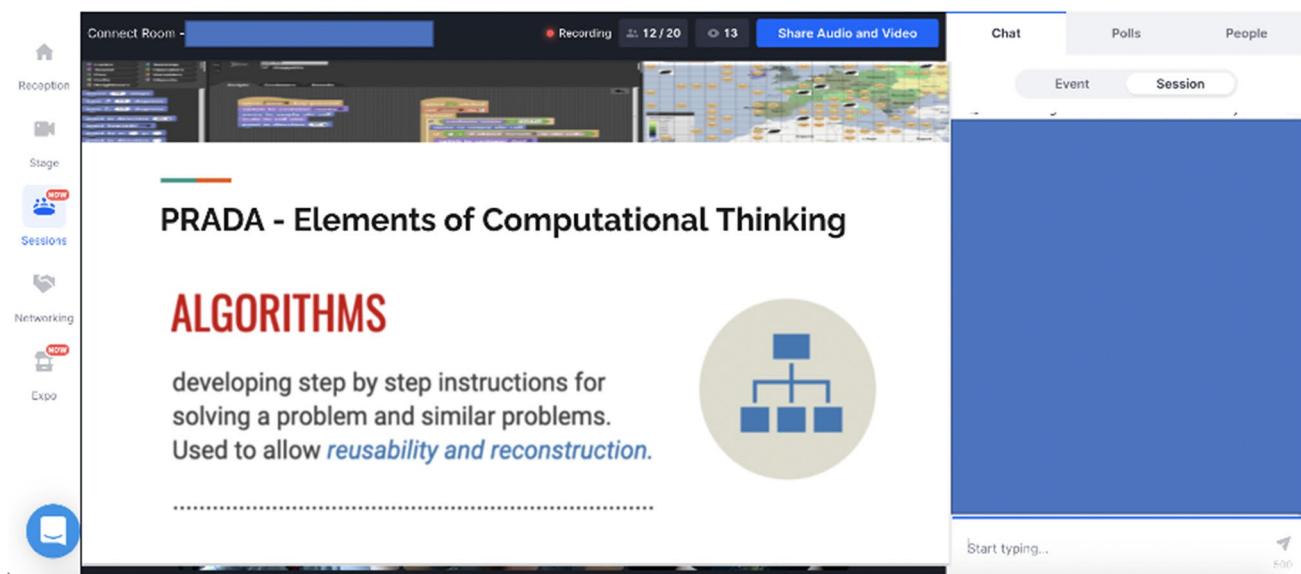elected tools prior to the PD. During 10 Tech Check sessions held in July 2020, participants tested video and audio connections and practiced using Hopin and Canvas through a virtual scavenger hunt. We also designed optional pre-PD homework to give participants practice with Snap! functions.

Virtual Pivot Session Formats

Each morning, introductory whole-group sessions served to orient participants to the Virtual Pivot CoP, address daily participant survey feedback, highlight key CT concepts and celebrate participant accomplishments. Then, synchronous *Code* sessions allowed participant pairs to collaborate on self-paced, pair-programming Snap! activities. Multimodal coding guides contained objectives, step-by-step instructions and solution code. We assigned one *Code* facilitator and two high school interns for every 3-4 pairs of participants.
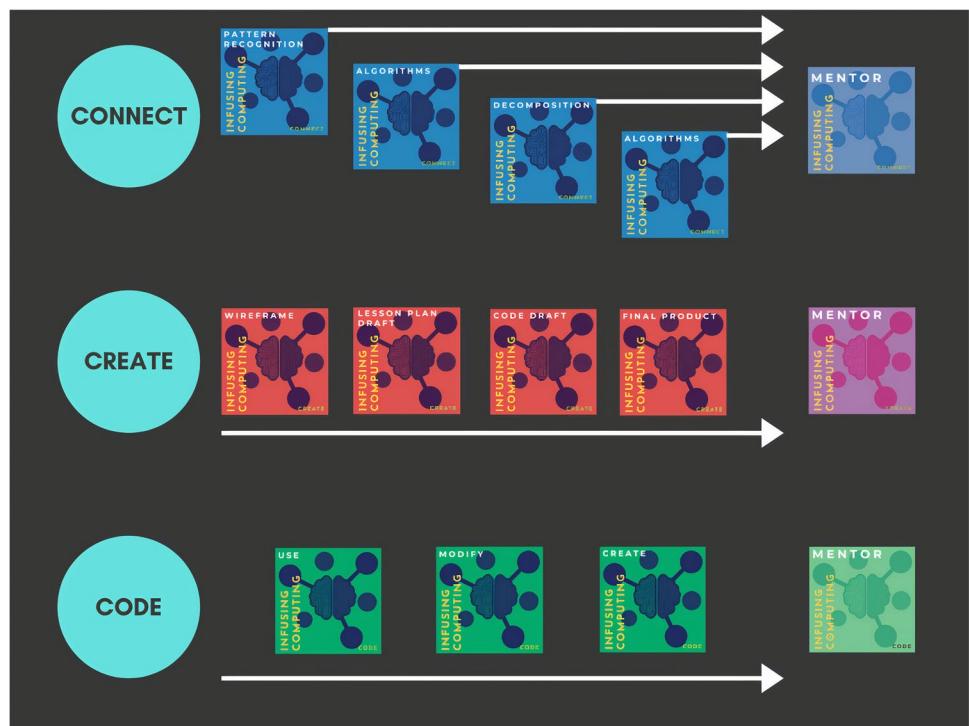
Connect sessions offered both synchronous and asynchronous learning experiences. Sessions were kept to no more than 14 participants and were organized by content area and school level (middle or high). Each room had two facilitators--a teacher-leader (Y1 and Y2 Infusing Computing participants) and a room facilitator. At the start of each session, teacher-leaders introduced CT concepts. Participants then engaged in asynchronous standards mapping activities that connected disciplinary standards to CT concepts and applied for badges (see Fig. 3 for badging infrastructure).

Create sessions also offered both synchronous and asynchronous engagement. *Create* "homerooms" of 6 participants provided a space for participants to collaborate, reflect and ask questions. During each *Create* session, participants

Fig. 2 Screenshot of Hopin as used during Virtual Pivot

Fig. 3 Infusing Computing: Virtual Pivot badging infrastructure

discussed lesson goals and shared resources. Then, they worked asynchronously on their lessons. A high school intern was assigned to each *Create* homeroom to offer targeted coding assistance.

Participants

Of the 151 teachers in this study, 26% identified as math teachers, 24% identified as science teachers, 19% identified as English teachers, 7% identified as social studies teachers, 3% identified as special education teachers and 21% identified as other (i.e., PE, business, Spanish, French, instructional coach, forensic science, media specialist, band and technology). Teachers had an average of 12.8 years of teaching experience; 9 teachers had fewer than 3 years and 33 teachers had more than 20 years. 58.2% (n = 88) were new participants, while 41.8% (n = 63) were returning teachers. The returning teacher group also included *Connect* teacherleaders who were in participant roles during *Code* and *Create* sessions.

Data Collection and Analysis

Data sources included pre-PD survey responses (n = 151), post-PD survey responses (n = 119), post-PD interviews (n = 57) and follow-up surveys (n = 105) administered six months after the summer PD. Pre-PD survey items focused on beliefs and self-efficacy related to CT infusion,

professional learning goals and teaching experiences with CT. The post-PD survey included additional items related to participants' experiences with Virtual Pivot. A paired sample t-test with 104 matched pairs was used to analyze changes in participant perceptions about CT and self-efficacy in infusing CT from the pre-PD to post-PD surveys. We also compared survey data from all three years to analyze participants' perceptions of the virtual and face-to-face PDs.

The next phase of analysis focused on post-PD teacher interviews (n = 57). After the PD, we asked volunteers to participate in 30-min, semi-structured interviews. To ensure that a wide variety of perspectives were represented, we recruited groups of new participants (n = 32), returning participants (n = 8) and teacher leaders/returning participants (n = 17). Interview questions focused on participants' teaching contexts, past experiences with virtual PD and their Virtual Pivot experiences. Returning participants were also asked to compare the face-to-face and virtual Infusing Computing experiences and describe lesson implementation. After transcribing each interview, qualitative interview responses were broken into meaning units (Gee, 2011), so that each unit contained one unique idea. In total, we identified 1177 meaning units across 57 interviews. We analyzed the data in recursive cycles of open and axial coding. Open coding was used to identify emergent themes, while axial coding was used to organize information into themes and sub-themes (Patton, 2014). During each phase of analysis, two researchers met to discuss emergent themes and to come to agreement on the coding scheme (see Table 1). As the

Table 1 Themes and Sub-themes from Analysis of Teacher Interviews (n = 57)

Theme	Definition	Subthemes	Percentage of Responses (n = 1177)
Virtual Infusing Computing Elements	Elements of Virtual Pivot that served as affordances or constraints for teacher learning	Community of Practice Structure of Virtual Pivot Sessions Pre-PD Support During-PD Support Badges	34.7% (n = 408)
Past Virtual PD Experiences	Responses related to teachers' previous experiences with virtual PD	Asynchronous Sessions Synchronous Lecture Technical Issues No Experiences Unclear Goals	5.9% (n = 69)
Goals for Infusing Computing	Teachers' goals for participating in Infusing Computing: Virtual Pivot	Expanding Access to CT and CS Infusing CT into Disciplinary Content Student Engagement Personal Growth	4.3% (n = 51)
Impact of Infusing Computing	Impact of Infusing Computing program on personal growth, knowledge of CT, or classroom teaching	Infusion into Disciplinary Teaching Personal Growth CT Ambassador Returning Teachers: Shifts in Practice Teaching Impact: Badges Teaching Impact: Canvas Teaching Impact: Asynchronous and Synchronous Structure Teaching Impact: Student Experience Teaching Impact: Tools	28.5% (n = 335)
Lesson Implementation	Responses related to past or anticipated future lesson implementation	Teacher Collaboration Enrichment Infusion into Disciplinary Content Lack of Self-Efficacy Scaffolding Student Leadership Project Team Support Technical Issues Uncertainty	23.2% (n = 273)
Facilitator	Responses from participant-facilitators related to their role in facilitating their peers' learning	Collaboration Personal Growth	3.5% (n = 41)

goals of this study are to investigate participants' experiences with the reconstitution of a virtual CoP, we specifically focus on participant responses in relation to elements of Virtual Pivot (n = 408 responses) that served as affordances or constraints for teacher learning.

The final phase of analysis focused on analyzing quantitative and qualitative responses to the six-month follow up survey (n = 105). Survey items focused on teachers' implementation of CT-infused lessons, barriers to lesson implementation, experiences with lesson implementation and professional learning goals. Descriptive statistics were compiled for quantitative measures related to lesson implementation and qualitative responses were coded using open and axial coding cycles (Patton, 2014). Themes included shifts in teacher learning about CT, student leadership in CT infused-lessons, embedding CT into disciplinary content, the use of unplugged CT lessons, project team support, CT-infused lesson implementation, technical challenges and difficulties in navigating CT infusion during COVID-related shifts in teaching modalities. The analysis of these responses, in addition to a review of teacher-created lesson plans and lesson implementation journals, were used to triangulate findings.

Findings

Teachers' Experiences with Virtual Pivot

Analysis of teachers' post-PD survey responses indicates that Virtual Pivot successfully increased participants' self-efficacy in infusing CT into disciplinary teaching. Participants reported stronger beliefs about CT as a competence

all students should develop, more interest in incorporating CT into disciplinary teaching and higher self-efficacy in their abilities to integrate CT. These changes were statistically significant at the p < .001, p < .01 and p < .001 levels, respectively (see Table 2).

Interestingly, when we compared participant responses across all three years of Infusing Computing, Virtual Pivot participants' scores were the highest in all categories, including overall PD rating (see Table 3). Returning participants, in particular, described the "top-notch virtual approach" and the "intense," "inspiring" and "incredibly personalized" virtual experience. As Katie said, "The best aspects were the *Create* sessions, the *Create* help desks that were available, how time was managed, shout outs and how the sense of community was still developed despite being in an online setting."

Post-PD survey responses also indicate a high level of satisfaction with the PD tools. On a five-point Likert scale item asking teachers to rate the effectiveness of the synchronous and asynchronous tools, 63.41% of teachers strongly agreed that Hopin was an appropriate synchronous tool and 66.67% strongly agreed that Canvas was an appropriate asynchronous tool. The mean was 4.58 for Hopin and 4.63 for Canvas.

Analysis of the survey administered six months following the PD (n = 105 responses) indicates that many participants were able to successfully infuse CT into their disciplinary teaching. Despite pandemic-related changes to teaching formats and schedules, 44.3% (n = 47) implemented a CT-infused lesson during the Fall 2020 semester and 33.9% (n = 39) planned to infuse CT into a lesson during Spring 2021. The remaining participants (21.8%) stated students lacked access to technological tools or that their lessons no longer fit within their curriculum due to COVID-19. These implementation rates represented an increase from 2018-2019, when 20.8% of teachers implemented lessons after the Y1 summer PD and from 2019-2020, when 11.3% of teachers implemented lessons after the Y2 summer PD. There were many factors that may have contributed to the increase in implementation rates for Virtual Pivot, including the fact that many teachers were returning participants with previous experience in infusing CT and that Y2 lesson implementation was interrupted due to COVID-19. However, teachers did report that the structure of Virtual Pivot, which allowed for more access to asynchronous materials and more flexibility in terms of lesson creation, supported their abilities to use lessons in their classrooms.

Follow-up survey results suggested Virtual Pivot supported shifts in participants' approaches to disciplinary

Table 2 Pre-PD and Post-PD comparison of teachers' beliefs about CT

	Mean	Paired Samples t-test[1]	Strongly Disagree (1)	Disagree (2)	Neither Agree or Disagree (3)	Agree (4)	Strongly Agree (5)
Survey Item: CT is a competence that all students should develop.							
Pre-PD	4.49	p < .001**	0%	0%	4%	45%	56%
Post-PD	4.72		0%	0%	2%	24%	74%
Survey Item: I am interested in integrating CT into my teaching.							
Pre-PD	4.54	p < .05*	0%	0%	3%	42%	59%
Post-PD	4.69		0%	0%	3%	26%	71%
Survey Item: I can integrate CT into my teaching.							
Pre-PD	4.23	p < .001**	0%	4%	10%	50%	40%
Post-PD	4.48		0%	2%	3%	41%	55%

[1]Paired samples t-tests assess significant changes from pre to post; *p < .05; **p < .01, ***p < .001

Table 3 Comparison of participant self-efficacy and PD rating over 3 years

Questions	2018: Y1 (n = 111)	2019: Y2 (n = 115)	2020: Virtual Pivot (n = 119)
I am more likely to incorporate CT activities in my classroom. (1 = Strongly disagree to 5 = Strongly agree)	4.56	4.57	4.65
I can more effectively design CT activities. (1 = Strongly disagree to 5 = Strongly agree)	4.42	4.47	4.52
I can better engage students in making sense of CT and designing solutions to problems. (1 = Strongly disagree to 5 = Strongly agree)	4.43	4.50	4.58
Overall PD Rating (1 = Poor to 5 = Excellent)	4.71	4.74	4.78

teaching. As Connie, a high school English teacher, said, "I try to take into account the computational thinking skills when planning lessons, even with creative writing." Similarly, Aveus, a returning middle school business teacher, reported using CT in daily instruction: "I have made sure to point out that much of our everyday lives aligns with computational thinking. We break down problems systematically."

Other teachers referenced using CT elements in unplugged formats to guide students' thinking. As Mike, a high school math teacher, said,

> I taught [it] like its own set of process standards. So, it was all unplugged. We just started using the verbiage: 'This is how you approach this problem and the data, we're looking for a pattern. What type of model would likely be shown?' And then the abstraction piece was, "Let's ignore all those individual points.'

Vanessa, a high school English teacher, said that while she was initially skeptical about CT infusion, she did a "complete 180" and discovered authentic connections to her content: "I was like, 'Oh, this is all that we do.' We literally just break things into parts and compare how those parts work together and come up with this formula...all of it actually does connect to what I do."

Supports for Teacher Learning and Engagement within Virtual PD

In the following sections, we describe elements of Virtual Pivot that participants identified as supporting their learning and/or engagement during the PD, including the community of practice, Virtual Pivot session structure, during-PD supports, pre-PD supports and badges.

Community of practice Of the 408 coded interview responses related to Virtual Pivot elements, 37.3% (n = 152) focused on teachers' experiences participating in a virtual CoP. Participants highlighted several tools and participation structures that helped to build and sustain the CoP, including pair programming, interactions with colleagues and networking.

Pair programming offered an important context for participants to interact with facilitators and other participants to reconstitute the CoP in the virtual space. As one participant said:

> I wasn't sure what to expect. Meeting someone who is in another state online and coding with them, initially it was kind of odd, but then we became, you know, we started talking to each other, why we're coding and learning about each other's schools and experiences and stuff like that.

Keith, a high school technology teacher, said that the Hopin platform enabled him to build a connection with his partner:

> That Hopin software really helped out a lot with the cooperative coding stuff. That was really my favorite part--just getting to work with somebody, because my partner luckily had strengths that I didn't have and I had strengths that she didn't have so that work together was great.

The *Connect* sessions provided an important venue for participants to collaborate with disciplinary colleagues. Teachers pointed to several *Connect* elements, including small group engagement, Hopin use and standards mapping, as being important for their learning. As Ashleigh, a middle school math teacher, said,

> My Connect group started with people jumping in and talking and we felt we all had a lot to say. And we started utilizing the chat and that was fun, too, because you could like see people's ahas as they're frantically typing. Yeah, that was fun."

Returning participants also referenced the idea that some forms of collaborative talk were easier within a virtual CoP; as one returning teacher said: "In the *Connect* session before, I do feel like it was a lot easier to hide in the background and kind of take that session off. And I felt like participants got more out of that session this time around."

Hopin's networking feature, which allows participants to easily connect with one another in a virtual setting at random, was one of the primary reasons that our team selected that particular tool. Networking allowed participants to interact across different content areas, school districts and states. Lee, a returning participant, referenced the ease of using Hopin networking:

> It was almost like just going from a physical classroom to another physical classroom. I really enjoy meeting all the different people from different areas with networking. So, that's also a great benefit of virtual versus being in the classroom.

While some returning participants said that they missed "hallway conversations" that had occurred in previous years, others said that moving among virtual rooms allowed for more varied interactions.

Structure of Virtual Pivot sessions In interviews, participants repeatedly mentioned the importance of the virtual PD structure in relation to three key sub-themes: balance of asynchronous and synchronous work, consistent schedules and material organization. Overall, 32.1% of the interview responses (n = 131) focused on the Virtual Pivot experience (n = 408) related specifically to structure.

First, participants said they appreciated having a balance of synchronous and asynchronous work time. As LaKeisha, a returning high school technology teacher said,

> I really thought the balance of time was appropriate and it was effective for people to learn and also have that time where they can kind of work on their own and then come back with enough time to be able to process information, to have questions and to really get feedback.

Other participants appreciated that synchronous introductions were limited to less than 10 min and were followed by group discussion or independent work. Dee, a returning participant, said the balance between work time, breaks and synchronous sessions allowed her to "get through the whole day" while still "feeling refreshed." Other teachers praised the purposeful balance between practice and discussion, stating that new information was shared in "short chunks and then you can practice it and that's how my mind works."

Participants also referenced the organization of Canvas and Hopin materials as being supportive of their learning. Diane, a returning participant and science teacher, referred to the PD as "a fine-tuned machine" and said, "Canvas was great. Everything was there, everything you needed to know. I never was like, where do I go and what do I do?" Returning participants also noted that the layout of materials, particularly the guided explanations of CT concepts, allowed for deeper connections to disciplinary teaching.

During-PD supports 10% of interview responses (n = 41) related to PD elements focused on during-PD supports, including the open-all-day Help Desks and high school interns. Diane noted that "the Help and Support was there the entire time when I had questions that were technology-based and when I had questions that were content-based. I mean, no matter what it was." Other teachers praised the ease of "just hopping in" to the help desks to ask "anything, anytime" and said that "it was awesome just to know it was there."

Another during-PD support was the assistance of the high school interns. Allie, a middle school social studies teacher, said:

> He really took the time to show me exactly what I needed to do and why the code would need to read the way that it did. He did probably give me the low-end tasks that needed to be doing, and I was okay with that. But overall, I felt like it was a labor of love on both of our parts. He knew my end vision and he helped me make that a reality for myself.

Teachers mentioned that while they were initially nervous about working with high school students, it was "empowering" to watch each intern "becoming a teacher of teachers."

Pre-PD supports Pre-PD supports (i.e., Tech Checks and Snap*!* homework) were referenced as a key element in 6.6% (n = 27) of interview responses. Teachers said Tech Checks gave them "an idea of what to expect." Others said that they provided a PD roadmap: "I learned that it would be very beneficial to have two Canvas tabs open and a Hopin tab...I just kept all those tabs open every day and it just helped me navigate tremendously."

A majority of participants also noted that pre-PD Snap*!* activities created familiarity with PD tools: "Even that pre-PD stuff where they were teaching us how to use Snap*!*, I think that was a great and in-depth explanation." However, some reported that the homework was too difficult, with one stating that it "made my head explode," and another suggesting a more "differentiated" approach for pre-PD activities.

Badges Throughout Virtual Pivot, participants applied for badges as they completed PD tasks and reflected on new CT understandings. Badges were displayed within Canvas and could be exported for sharing on social media. Overall, 14.0% of interview responses (n = 57) referenced badging as a supportive element of Virtual Pivot.

Participants noted that badges served as virtual checklists to independently monitor daily progress towards PD goals. Teachers used the badges to "keep track of deliverables" and said that they were "motivating." Other teachers said that the badges allowed them to see their "progression" and that they "encouraged participants to record their learning as opposed to just attending the sessions."

The badges also served as a tool for motivation and engagement. As Ava, a new participant and middle school ELA teacher, said, "I wanted all the badges. And I was super proud when I got that final badge, that teacher leader badge... because I wanted people to know I had learned a lot." Others referenced the competitive aspects of the leaderboard; for example, one middle school media specialist, Rachel, mentioned sharing her badges with a colleague:

> You're gonna laugh. I'm a competitive person by nature. I didn't want to tell people, but that was really motivating for me. I literally texted my friend who did it with me for my grade level. And I was like, 'You're gonna think I'm a total nerd, but I'm so excited. I got all my badges.' And she's like, 'Yep, you're a nerd.'

While a few participants mentioned that the badges served as a "distraction," overall, participants felt that the badges encouraged them to set learning goals, monitor their progress and engage with the Virtual Pivot CoP.

Discussion and Implications

The need for meaningful and practical professional learning experiences has never been more urgent. As the COVID-19 pandemic has caused veteran teachers to leave the profession in droves (Kraft et al., 2020), teachers need more opportunities to become part of communities driven by interest and necessity across time and place. We fundamentally believe that PD can enable generative interactions with colleagues in a profession that is often demoralizing. However, PD experiences, particularly in virtual and hybrid formats, often have the opposite effect.

Despite many mistakes made over the years, our participants told us time and again the prospect of bringing CT into their classrooms made them excited to be teachers again. During Infusing Computing's first two years, our favorite moments were those where teachers shared their excitement about conversations, connections, or new ideas they discovered during the PD. We weren't sure that Virtual Pivot would produce those moments, but to our delight, we found that the virtual space offered new opportunities to reconstitute and reimagine the Infusing Computing community of practice.

At first, we were surprised by findings indicating that teachers felt that Virtual Pivot was more effective than the face-to-face version of Infusing Computing. Teachers had reported high levels of engagement with the two prior summer PDs; we worried that switching to an entirely virtual experience might limit opportunities for community-building. Through an intensive design process guided by both research and participant feedback, we hoped to replicate PD elements that had been successful and utilize the affordances of Hopin and Canvas to create new virtual spaces for teachers to learn and interact. Our analysis indicated that Virtual Pivot was more successful than we had hoped. Teachers found that participating in a virtual community of practice, engaging in asynchronous and synchronous formats and using digital means for collaboration (help desks, badges and discussion boards) offered new ways of connecting across space, time and disciplinary boundaries.

Virtual Pivot afforded teachers a qualitatively different experience than years past. First, within the context of a pandemic and professional isolation, the Virtual CoP allowed teachers the experience of "just getting to work with somebody." In fact, several felt that due to specific affordances of the online space (cg. virtual networking), they interacted with more participants in the Virtual CoP than they would have face-to-face. Moreover, our teacher-participants were able to experience the student perspective of online learning when it was crucially needed for their teaching practice. It can be hard for teachers to understand, let alone empathize with, the difficulties that can arise for online students. In the Virtual CoP, our teachers came to appreciate the integrated systems of learning supports that they could immediately incorporate into their own teaching. With all of this in mind, it is not surprising that teacher self-efficacy and implementation numbers were higher during Virtual Pivot than in previous years of the project.

Many of the Virtual Pivot changes (e.g., providing asynchronous access to materials both before and during the workshop, offering multiple means of engaging with session content and other participants, moving among synchronous and asynchronous sessions, and virtual networking) could be implemented in a variety of face-to-face, hybrid and virtual contexts to support teacher learning. However, other shifts, including significantly increasing the number of support personnel for virtual professional development, present challenges for replication and sustainability. While our findings suggest that increasing the number of facilitators to provide more personalized support in a virtual space can help to build a more responsive community of practice, we also recognize that this may not be feasible in many cases. Future work that identifies alternative solutions to this issue, including leveraging participant expertise and leadership, would make a valuable contribution to the literature.

Conclusion

Despite a growing interest in virtual teacher PD, information on the best models, structures and tools is often lacking. This is particularly important not only for our area of PD, but also identifies the need to re-examine tools, spaces, interactions and affordances across all interactions within a CoP. Our findings suggest that when PDs are designed to support teachers through scaffolded digital learning engagements, virtual environments can afford opportunities to build and sustain communities of practice. The Virtual Pivot CoP successfully supported teacher learning around CT, as evidenced by high rates of CT-infused lesson implementation in their classrooms and continued growth as a community of practice.

This work helps inform the design of PD that fosters the development of professional communities for CT integration. This work also provides guidance and urges some points for reflection as designers of virtual PD in other areas develop and implement community interactions. It can be a challenge to balance synchronous and asynchronous sessions, plan pre-PD and during-PD supports and integrate alternative assessment tools (i.e., digital badging systems). Despite these challenges, we believe that this study shows that virtual PD has the ability to transcend, and not just

transform, teachers' professional interactions and learning opportunities.

Declarations

References

Appova, A., & Arbaugh, F. (2018). Teachers' motivation to learn: Implications for supporting professional growth. *Professional Development in Education, 44*(1), 5–21.

Barab, S. A., & Duffy, T. M. (2000). From practice fields to communities of practice. In D. Jonassen & S. Land (Eds.), *Theoretical foundation of learning environments* (pp. 25–56). Erlbaum.

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: what is Involved and what is the role of the computer science education community? *ACM Inroads, 2*(1), 48–54.

Carpenter, J. P., & Krutka, D. G. (2015). Engagement through micro-blogging: Educator professional development via Twitter. *Professional Development in Education, 41*(4), 707–728.

Coenders, F., & Verhoef, N. (2019). Lesson study: professional development (PD) for beginning and experienced teachers. *Professional Development in Education, 45*(2), 217–230.

Czerkawski, B. (2015). Computational thinking in virtual learning environments. In *Proceedings of E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2015* (pp. 993–997). Association for the Advancement of Computing in Education (AACE).

Darling-Hammond, L., Hyler, M.E., & Gardner, M. (with Espinoza, D.). (2017). *Effective teacher professional development*. Learning Policy Institute. Retrieved from https://learningpolicyinstitute.org/sites/default/files/product-files/Effective_Teacher_Professional_Development_REPORT.pdf

Dong, Y., Cateté, V., Jocius, R., Lytle, N., Barnes, T. Albert, J., Joshi, D., Robinson, R., & Andrews, A. (2019). PRADA: A practical

model for integrating computational thinking in K-12 education. In *Proceedings of the 50th ACM Technical Symposium on Computer Science Education (SIGCSE '19)* (pp. 906–912). ACM.

El-Hani, C. N., & Greca, I. M. (2013). ComPratica: A virtual community of practice for promoting biology teachers' professional development in Brazil. *Research in Science Education, 43*(4), 1327–1359.

Facey-Shaw, L., Specht, M., Van Rosmalen, P., Brner, D., & Bartley-Bryan, J. (2017). Educational functions and design of badge systems: A conceptual literature review. *IEEE Transactions on Learning Technologies, 11*(4), 536–544.

Fairman, J. C., Smith, D. J., Pullen, P. C., & Lebel, S. J. (2020). The challenge of keeping teacher professional development relevant. *Professional Development in Education*, 1-13.

Ferdig, R. E., Baumgartner, E., Hartshorne, R., Kaplan-Rakowski, R., & Mouza, C. (Eds.). (2020). Teaching, technology, and teacher education during the COVID-19 pandemic: Stories from the field. Association for the Advancement of Computing in Education (AACE).

Jocius, R., Joshi, D., Dong, Y., Catete, V., Robinson, R., Barnes, T., Albert, J. & Lytle, N. (2020). Code, connect, create: The 3C model for integrating computational thinking into content area classrooms. In *Proceedings of the 50th ACM Technical Symposium on Computer Science Education (SIGCSE '20)* (pp. 971–977). ACM.

Jocius, R., Albert, J., Joshi, D., Dong, Y., Catete, V., Robinson, R., Barnes, T., Albert, J. & Lytle, N. (2021). The virtual pivot: Transitioning computational thinking PD for middle and high school content area teachers. In *Proceedings of the 51st ACM Technical Symposium on Computer Science Education (SIGCSE '21)* (pp. 1198–1204). ACM.

Gamrat, C., Zimmerman, H. T., Dudek, J., & Peck, K. (2014). Personalized workplace learning: An exploratory study on digital badging within a teacher professional development program. *British Journal of Educational Technology, 45*(6), 1136–1148.

Gee, J. (2011). *How to do discourse analysis: A toolkit*. Routledge.

Google, Inc. (2018). What is computational thinking? Computational thinking for educators. Retrieved from https://computationalthinkingcourse.withgoogle.com/unit?lesson=8%5C&unit=1

Guldberg, K., & Mackness, J. (2009). Foundations of communities of practice: Enablers and barriers to participation. *Journal of Computer Assisted Learning, 25*(6), 528–538.

Hadar, L., & Brody, D. (2010). From isolation to symphonic harmony: Building a professional development community among teacher educators. *Teaching and Teacher Education, 26*(8), 1641–1651.

Haines, S., Krach, M., Pustaka, A., Li, Q., & Richman, L. (2019). The effects of computational thinking professional development on STEM teachers' perceptions and pedagogical practices. *Athens Journal of Sciences, 6*(2), 97–122.

Hambrusch, S., Hoffmann, C., Korb, J. T., Haugan, M., & Hosking, A. L. (2009). A multidisciplinary approach towards computational thinking for science majors. *ACM SIGCSE Bulletin, 41*(1), 183–187.

Harvey, B., & Mönig, J. (2010). Bringing "no ceiling" to scratch: Can one language serve kids and computer scientists. *Proc. Constructionism*, 1–10.

Hawkes, M., & Romiszowski, A. (2001). Examining the reflective outcomes of asynchronous computer-mediated communication on inservice teacher development. *Journal of Technology and Teacher Education, 9*(2), 285–308.

Hestness, E., Ketelhut, D. J., McGinnis, J. R., Plane, J., Razler, B., Mills, K., ... & Gonzalez, E. (2018). Computational thinking professional development for elementary science educators: Examining the design process. In *Proceedings of the SITE Conference* (pp. 1904-1912). Association for the Advancement of Computing in Education (AACE).

Israel, M., Pearson, J. N., Tapia, T., Wherfel, Q. M., & Reese, G. (2015). Supporting all learners in school-wide computational thinking: A cross-case qualitative analysis. *Computers & Education, 82*, 263–279.

Jones, W. M., Hope, S., & Adams, B. (2018). Teachers' perceptions of digital badges as recognition of professional development. *British Journal of Educational Technology, 49*(3), 427–438.

Ketelhut, D. J., Mills, K., Hestness, E., Cabrera, L., Plane, J., & McGinnis, J. R. (2020). Teacher change following a professional development experience in integrating computational thinking into elementary science. *Journal of Science Education and Technology, 29*(1), 174–188.

King, F. (2014). Evaluating the impact of teacher professional development: An evidence-based framework. *Professional Development in Education, 40*(1), 89–111.

Kirschner, P. A., & Lai, K. W. (2007). Online communities of practice in education. *Technology, Pedagogy and Education, 16*(2), 127–131.

Kraft, M. A., Simon, N. S., & Lyon, M. A. (2020). Sustaining a sense of success: The importance of teacher working conditions during the COVID-19 pandemic. EdWorkingPaper No. 20-279. *Annenberg Institute for School Reform at Brown University.*

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge University Press.

Lawless, K. A., & Pellegrino, J. W. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. *Review of Educational Research, 77*(4), 575–614.

Lin, C. C., Zhang, M., Beck, B., & Olsen, G. (2009). Embedding computer science concepts in K-12 science curricula. In *Proceedings of the 40th ACM technical symposium on computer science education* (pp. 539-543). ACM.

Lopez, A. E. (2020). Reflection: Harnessing energy of social movements for lasting change. *Multicultural Perspectives, 22*(3), 115–117.

Maloney, J., Resnick, M., Rusk, N., Silverman, B., & Eastmond, E. (2010). The Scratch programming language and environment. *ACM Transactions on Computing Education (TOCE), 10*(4), 1–15.

Mason, S. L., & Rich, P. J. (2019). Preparing elementary school teachers to teach computing, coding, and computational thinking. *Contemporary Issues in Technology and Teacher Education, 19*(4), 790–824.

McConnell, T. J., Parker, J. M., Eberhardt, J., Koehler, M. J., & Lundeberg, M. A. (2013). Virtual professional learning communities: Teachers' perceptions of virtual versus face-to-face professional development. *Journal of Science Education and Technology, 22*(3), 267–277.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation.* Jossey-Bass.

Morreale, P., Goski, C., Jimenez, L., & Stewart-Gardiner, C. (2012). Measuring the impact of computational thinking workshops on high school teachers. *Journal of Computing Sciences in Colleges, 27*(6), 151–157.

Mumford, J. M., Fiala, L., & Daulton, M. (2017). An agile K-12 approach: Teacher PD for new learning ecosystems. In *Handbook of research on teacher education and professional development* (pp. 367-384). IGI Global.

National Research Council. (2012). *A framework for K-12 science education.* National Academies Press.

Park, G., Johnson, H., Vath, R., Kubitskey, B., & Fishman, B. (2013). Examining the roles of the facilitator in online and face-to-face professional development contexts. *Journal of Technology and Teacher Education, 21*(2), 225–245.

Patton, K., & Parker, M. (2017). Teacher education communities of practice: More than a culture of collaboration. *Teaching and Teacher Education, 67*, 351–360.

Patton, M. (2014). *Qualitative research and evaluation methods: Integrating theory and practice* (4th ed.). Sage.

Rich, P. J., & Hodges, C. B. (Eds.). (2017). *Emerging research, practice, and policy on computational thinking.* Springer.

Rich, P. J., Mason, S. L., & O'Leary, J. (2021). Measuring the effect of continuous professional development on elementary teachers' self-efficacy to teach coding and computational thinking. *Computers & Education, 104196.*

Roberts, J. (2006). Limits to communities of practice. *Journal of Management Studies, 43*(3), 623–639.

Schon, D. (1983). *The reflective practitioner.* Temple Smith.

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational Research Review, 22*, 142–158.

Sotillo, S. M. (2000). Discourse functions and syntactic complexity in synchronous and asynchronous communication. *Language Learning & Technology, 4*(1), 77–110.

Trust, T., & Horrocks, B. (2019). Six key elements identified in an active and thriving blended community of practice. *TechTrends, 63*(2), 108–115.

Trust, T., Krutka, D. G., & Carpenter, J. P. (2016). "Together we are better": Professional learning networks for teachers. *Computers & Education, 102*, 15–34.

Tseng, F. C., & Kuo, F. Y. (2014). A study of social participation and knowledge sharing in the teachers' online professional community of practice. *Computers & Education, 72*, 37–47.

Tucker, A., McCowan D., Deek F., Stephenson C., Jones J. and Verno A. (2003). *A model curriculum for K-12 computer science: Report of the ACM K-12 Task Force Computer Science Curriculum Committee.* ACM.

Vygotsky, L. (1978). *Mind in society.* Harvard University Press.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology, 25*(1), 127–147.

Wenger, E. (1998). Communities of practice: Learning as a social system. *Systems Thinker, 9*(5), 2–3.

Wenger, E. (2010). Conceptual tools for communities of practice as social learning systems: Boundaries, identity, trajectories and participation. In Wenger (Ed.), *Social learning systems and communities of practice* (pp. 125-143). Springer.

Wing, J. M. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–35.

Yadav, A., Krist, C., Good, J., & Caeli, E. N. (2018). Computational thinking in elementary classrooms: Measuring teacher understanding of computational ideas for teaching science. *Computer Science Education, 28*(4), 371–400.

Yadav, A., Mayfield, C., Zhou, N., Hambrusch, S., & Korb, J. T. (2014). Computational thinking in elementary and secondary teacher education. *ACM Transactions on Computing Education (TOCE), 14*(1), 1–16.

Yurkofsky, M. M., Blum-Smith, S., & Brennan, K. (2019). Expanding outcomes: Exploring varied conceptions of teacher learning in an online professional development experience. *Teaching and Teacher Education, 82*, 1–13.