Reimagining Computational Thinking Professional Development: Benefits of a Community of Practice Model

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Abstract: Cultivating teacher understanding of embedded computational thinking (CT) in elementary STEM instruction can be challenging. In this paper, we investigate the success of a science teacher computational thinking inquiry group (STIG^{CT}) as a professional development (PD) model. By observing participants as they collaboratively produced multiple CT-infused elementary science lessons we determined our STIG^{CT} structure, specifically the diversity of the participants, the collaborative structure of activities, and the time for iteration and experimentation, leveraged, and exceeded, the benefits of a community of practice (CoP) model. Our STIG^{CT} represents the first research effort to develop a CoP to educate teachers about CT, addressing a gap in understanding which will be of interest to those in CT education. The success of our STIG^{CT} model, especially as driven by the design choice of including pre- and in-service teachers in the community, also contributes to the PD field.

Keywords: Elementary science, Teacher Professional Development, Community of Practice, Computational Thinking

Introduction

Teacher PD is being continuously refined, emphasizing the importance of reflection, collaboration and activity grounded in classroom practice that takes place over a series of engagements (e.g., Borko, 2004; Fishman, Davis, & Chan, 2014; Nelson, Slavit, Perkins, & Hathorn, 2008). Communities of Practice (CoPs) are one of the PD models being explored. First described by Lave and Wegner (1991) with regard to novice and expert learning dynamics, CoPs have been increasingly adopted in education (Vangrieken, Meridith, Packer & Kyndt, 2017). In this paper, we present our novel version of a CoP, called a Science Teacher Computational Thinking Inquiry Group or STIG^{CT}. Uniquely designed to include both pre-service and in-service teachers along with facilitator researchers, our STIG^{CT} was a longitudinal experience that provided information, mentorship and proximate value in the form of resources and lesson ideas that participant teachers could immediately bring back to the classroom to experiment and iterate upon. Our STIG^{CT} was focused around the shared enterprise of building elementary science lessons that integrated computational thinking (CT) practices. Previously, we found evidence that the STIG^{CT} was successful at supporting this goal (Ketelhut, Mills, et al., 2019). In this paper, we investigate the STIG^{CT} factors that supported the ability of participants to successfully create a lesson that integrated CT by answering the following research question: What are the benefits of our STIG^{CT} model of professional development to support in-service and pre-service teachers when integrating computational thinking into inquiry science lessons?

To answer this question, we analyzed the interactions of STIG^{CT} participants (pre-service teachers, in-service teachers, and facilitator researchers) during multiple sessions of CT infused science lesson ideation. We focus on three key structural elements of the STIG^{CT} design: diversity of the participants, collaborative structure of activities, and a longitudinal timeline (Figure 1). Data analysis revealed four key benefits of these structural elements that contributed to the success of this PD: seeking and sharing experience, mapping knowledge and identifying and remedying knowledge gaps, expanded mentorship, and ease of classroom integration (Figure 1).

In this paper, we first ground our work in the literature of both CT integration in elementary classrooms and PD through CoPs. We then present the structure of our STIG^{CT} and explain how we collected and analyzed our video data. Next, we frame the three structures of the STIG^{CT}. Finally, using analysis of the video data, we present our four benefits. We focus our discussion on the first of those benefits: seeking and sharing knowledge. We conclude by recommending our STIG^{CT} design as a version of a CoP that is well-suited to presenting CT practices to elementary teachers. Those that are planning PD around other topics that are unfamiliar to most participants, topics such as culturally sustaining pedagogy, digital literacy or data fluency, will find particular utility in our work.

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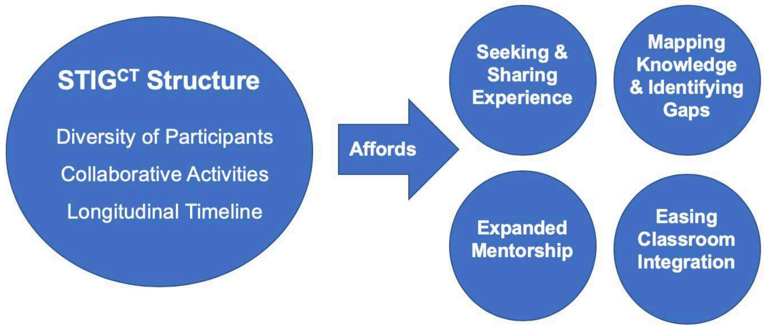

Figure 1. STIG^{CT} Structures and Benefits.

A community of practice to support computational thinking

We will now situate our work both in the literature of teaching communities in general and teacher communities based on a CoP model in particular, as well as in the literature around CT and teaching CT practices.

Building communities in professional development

Previous work that developed teacher communities in PD can be found in specific disciplines such as math and literacy, or across disciplines (Brouwer, Brekelmans, Nieuwenhuis, & Simons, 2012; Butler & Schnellert, 2012; Palincsar, Magnusson, Marano, & Brown, 1998). Within science education, learning communities have been used to successfully strengthen general pedagogy (Jones, Gardner, Robertson, & Robert, 2013) and to introduce new ideas, such as science literacy and the nature of science (Akerson, Cullen, & Hanson, 2009), and new technologies (Hammond et al., 2019) to teachers.

CoPs have been widely adopted in education as a model to build a cooperative community that values reflection and sharing (Vangrieken, Meredith, Packer & Kyndt, 2017). Wagner and colleagues describe a CoP as "a group of people who share a concern, a set of principles, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis" (Wegner, McDermott, & Snyder, 2002, p. 4). To contribute to understanding how best to educate teachers in CT, our research team implemented a CT PD experience for teachers designed as a CoP. In building our CoP we were mindful of Lave and Wegner's (1991) de-emphasis of the mentor-novice dyad in favor of a group of colleagues with varying skill levels, a dynamic our prior research had supported (Ketelhut, Hestness, et. al., 2019). We were also aware of research that indicated preservice teachers are better able to translate new curricular innovations when their mentor teachers are supportive (Sadaf et al., 2016). This led us to include both pre-service and in-service teachers as well as researches in our community of practice.

Computational thinking in professional development

CT, defined by Cuny, Snyder, and Wing (2010) as a way of defining problems so that they can be solved by a computational agent, is considered a critical skill for learners that should be integrated into formal settings and applied in contexts beyond computer science (Wing, 2006; Guzdial, 2008). Researchers believe that teacher preparation is essential to implement this integration into K-12 schools (Barr & Stephenson, 2011).

Much of the work around PD for CT has taken a traditional approach: content experts—usually with a background in computer science—create opportunities for teachers to learn the definitions of CT and then integrate them into their own teaching (e.g., Bower et al., 2017; Curzon, McOwan, Plant, & Meagher, 2014). While these approaches have shown success in increasing teachers' understanding of the components of CT, the links between teachers' CT knowledge and their ability to integrate CT into their classrooms remains less explored (for an exception, see Israel et al., 2015). Although these models may lead to teachers implementing some CT activities in their classroom, PD experiences are more likely to be sustainable and successful when they are designed in a collaborative environment where teachers can contribute their curricular and pedagogical expertise (Darling-Hammond, Hyler & Gardner, 2017). Additionally, pre- and in-service teachers may face different challenges when attempting to integrate CT into their classrooms, and the opportunity to learn *with* peers of varied experience is rare in CT PD literature. To our knowledge, there have been no previous efforts to design PD for CT using a CoP model.

With the goal of understanding how to productively leverage different types of teacher and researcher expertise to integrate CT into elementary science instruction, we created a PD experience based on a CoP framework. In this paper, we highlight the benefits that our CoP PD design created and how different aspects of our PD created specific benefits to develop expertise around CT.

Having grounded our work in prior literature on CoPs and CT professional development, we now move to a discussion of our methods and findings. We start with a description of the design of our STIG^{CT} and focus on the unique structural elements that differentiated our CoP-based STIG^{CT} from traditional professional development. We then present the first identified benefit of our STIG^{CT}: Seeking and Sharing Experience. We end with implications for the teacher education field and recommendations for using CoP to enhance PD, especially when presenting topics that are novel to most teachers, such as CT.

Method

Science Teacher Computational Thinking Inquiry Group (STIG^{CT})

This NSF-funded work through the STEM+C initiative is part of a multi-year study investigating how CT can be integrated into elementary science teacher education through two pathways: a methods course and the STIG^{CT}. The data reported in this paper was collected from the STIG^{CT} during the spring of 2019. This STIG^{CT} met for four monthly sessions, each lasting three hours.

Participants

The CoP design of the PD brought together 19 in-service and 21 pre-service teachers with 7 university researchers that acted as facilitators. As facilitators we came from a broad diversity of academic backgrounds. There were four categories of participants in the STIG^{CT}, as detailed in Table 1. Pre-service teachers were in their final year of undergraduate work and were working in their student teaching placements during the STIG^{CT}. While all pre-service teachers had classroom mentors in their placements, not all mentors participated in the STIG^{CT} with them.

In-service teachers included both experienced teachers and those that were in their first year of teaching. The first-year teachers had been student participants in our first iteration of the STIG^{CT} the previous year. The four participants who first participated as pre-service teachers are referred to as returning first-year teachers. The seven returning participants who first participated as experienced, established teachers, are referred to as retuning experienced teachers. The final 8 participants were experienced teachers, most of whom were actively mentoring a pre-service teacher at the time. Therefore, the STIG^{CT} was comprised of teachers with three different levels of teaching experience and two different levels of STIG^{CT} experience. All of the teachers had some exposure to CT prior to the STIG^{CT}, either through their university science teacher education course, during the first iteration of the STIG^{CT}, in a traditionally structured PD course required of all in-service participants, or through a combination of these (Table 1). The STIG^{CT} facilitations brought a diverse set of experiences: two were teacher educators, one was a computer science educator, two were science educators, and two were CT specialists.

Table 1: Diversity of STIG^{CT} Participant Background and Experience

Participants	Number	Previous STIG^{CT} Experience	Teaching Experience (years)	CT Instruction
Pre-service teachers	21	No	<1	Science methods class
In-service teachers				
Returning first-year teachers	4	Yes – as pre-service teachers	1	In their science methods class and in a single traditional one-day, 6-hour PD experience
Returning experienced teachers	7	Yes – as mentors	5 - 37	Two, 4-hour traditionally structured PD experiences
Experienced Teachers	8	No	5 - 37	One traditionally structured 4-hour PD experience

Context and content

Our STIG^{CT} was developed through design-based research (Barab & Squire, 2004) over a two-year period. Each session was focused on one set of CT practices (Data, Programming, Computational Simulations, Systems Thinking from a CT Perspective; Ketelhut, Cabrera, et al., 2019). The three-hour sessions each involved three activities (see Figure 2). First, researchers introduced one set of CT practices and gave examples in a whole group presentation. Teachers were then given the opportunity to work with themed examples of how to integrate that set of CT practices within the classroom. For example, when discussing Data Practices, teachers worked with sorting data using Excel to find patterns and relationships, represented data in a simulation using Scratch, and experimented with technology tools to collect data. Finally, groups of teachers and a researcher worked collaboratively in teams to create a proto-lesson, referred to as a lesson seed, that utilizing CT practices. These lesson seed groups were constructed of grade similar in-service and pre-service teachers paired with a facilitator researcher. Each lesson seed was posted to a group site online so they could be shared. Towards the end of the experience, each teacher (or mentor/mentee pair) selected one lesson seed to expand into a full lesson plan that they taught in their classroom during the third or fourth month of the PD. Teachers then reflected on and shared their lesson plans with the STIG^{CT} during the final meeting. Participants received a monetary remittance based upon full attendance with the option to make-up one missed session on-line.

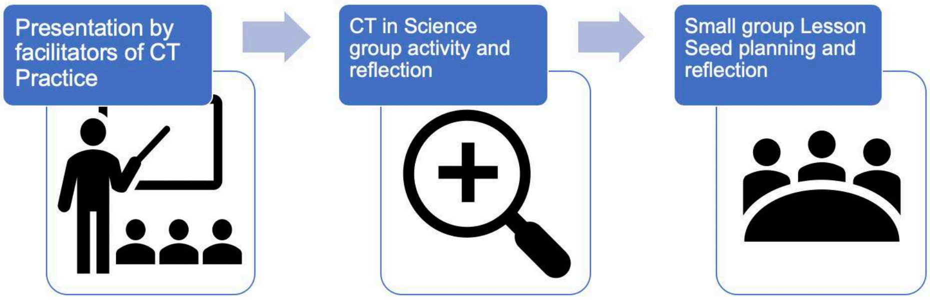

Figure 2. Structure of the STIG^{CT}.

Three key structures of the STIG^{CT}

Diversity of participants

Broadly, we had three participant groups within the STIG^{CT}: pre-service teachers, in-service teachers, and facilitators, which created a very diverse CoP that integrated multiple perspectives and backgrounds. The STIG^{CT} had teachers representing twelve schools in two school districts. Most participants had at least one other STIG^{CT} member in their school. The STIG^{CT} was also led by a diverse research team. Facilitators came from backgrounds in science, computer science, and teacher education.

Collaborative structure of activities

Collaborative working relationships, rather than a top-down structure where facilitators impart knowledge, is a hallmark of CoPs (Pyrko, Dörfler, & Eden, 2017) that we, as STIG^{CT} designers, were committed to leveraging. Every STIG^{CT} session had structured time for collaboration and experimentation that fore fronted practice. For this paper, we focus on the collaborative building of lesson seeds by the pre-service teachers, the in-service teachers, and the facilitators. During this collaborative time, facilitators 'stepped-down' into direct working relationships with the pre-service and in-service teachers. This structure allowed groups to ask questions of facilitators during lesson seed development, gaining just-in-time CT knowledge. Additionally, unlike traditional expert-to-novice PD models, the STIG^{CT} design positioned teachers as knowledgeable collaborators with the agency to share their expertise in classrooms and children and contribute to the learning of others.

Longitudinal timeline

The STIG^{CT} was purposefully designed to take place over a series of sessions rather than in a single afternoon. This promoted both increased time working together as a community and a longitudinal nature that allowed participants to take what they had collaboratively developed and bring it back to their classrooms to implement, allowing participants to apply what they learned that week in the STIG^{CT} immediately to their practice. We also designed time for teachers to share reflections on how their application experience in the classroom went at the next STIG^{CT} meeting.

Data and analysis

This study draws on approximately nine hours of video recordings of groups collaboratively producing lesson seeds. All videos were professionally transcribed. Transcripts of the video underwent two cycles of coding by the research team. Researchers used the videos throughout transcript coding to confirm transcription accuracy and determine context when needed (through observing body language, for example). Transcripts were thematically coded using structural, process, and emotion codes (Corbin, Strauss, & Strauss, 2015; Saldana, 2015). To compare across researchers, all researchers applied these codes to a single transcript.

Second cycle coding involved axial coding to look across the different STIG^{CT} sessions and groupings and determine dominant connecting themes (Saldana, 2015). Themes were identified and the properties and dimensions of these themes were examined (Strauss & Corbin, 1998). From this deep analysis we realized our initial conceptualization of the structure of the STIG^{CT} as one of a variety of affordances we were identifying from the PD was incomplete. This deep analysis informed our understanding that the benefits that we were identifying that were leading to teacher growth were emerging directly from the structure of the STIG^{CT}.

We now present the first of four benefits we identified that this unique structure supported: seeking and sharing experiences. Within this benefit, we identify multiple ways our unique CoP design resulted in additional value for in-service teachers, pre-service teachers, and facilitators. We conclude with a discussion of what these findings mean for the field and how they can be used to support teachers during PD.

Findings

Three key aspects of STIG^{CT} structure, the diversity of the participants, the collaborative structure of the activities, and a longitudinal timeline, afforded four unique benefits: (1) the ability to seek and share experience, (2) the ability to map knowledge and identify and remedy knowledge gaps, (3) expanded mentorship, and (4) increased ease of classroom implementation. In this paper we present a deep discussion of the first benefit: seeking and sharing experience.

Seeking and sharing experience

One of the hallmarks of CoPs in education is that the community learns productively from each other by working collaboratively (Borko, Jacobs, & Koellner, 2010; Putnam & Borko, 2000). We found ample evidence of this in the STIG^{CT}. We observed that the community often relied on the experience of the in-service teachers at the beginning of the lesson seed building process as they decided on a science topic for their lesson. The following exchange below between Sam, an in-service teacher with 31 years of experience and Mary, an in-service teacher in her first year of teaching, exemplifies this benefit:

Sam: Okay, so are we going through every procedure starting with definitions of everything, like all the vocabulary, backgrounds?

Mary: I feel like we should just identify what prior knowledge they would need before this lesson.

Sam: Okay.

Mary: Like, what you would pre-teach?

Sam: Right. That's what I mean. Are we going to put everything in here, or are we just going to start with building the circuit?

Mary: This is just a seed, so we don't have to flush out everything, but I think just identify what they would need to know coming into this. I feel like for this lesson, like they would have all that background knowledge already, so like …

Sam: They would have already built simple circuits.

Mary: Yeah, so you would just have to introduce the current, the measure. Then explain what they're going to be testing with and keeping track of. Yeah, because they should know about everything else already.

Mary and Sam are collaborating on building this lesson as peers as they consider what the students have already been taught and what, in a very practical way, they will need to teach to set the activity up for success. Mary asks Sam for her opinion on what to pre-teach, a pedagogical question that leverages Sam's experience when deciding how much of a constructivist attitude the lesson should adopt.

In the next excerpt, the group, comprised of the facilitator, Deborah, two pre-service teachers, Alice and Rhonda, and two experienced in-service teachers, Susan and Becky, leverage Susan and Becky's proficiency to build a lesson that cuts across standards:

Deborah: Yeah, you guys could absolutely use the micro:bits to collect data about energy.

Alice: And record your classroom data.

Susan: Temperature. I would love to know what my classroom temperatures were though, and for real time, like set them on there.

Deborah: To create an argument for ... action

Susan: Yeah, action . . . Persuasive writing.

Becky: So, it could be cross curricular, and then it also has real life application for the students which will make it more meaningful and engaging.

While working together to build lesson seeds that would be developed later into lesson plans, members of the STIG^{CT}, especially the pre-service teachers, benefited from the resources of more experienced teachers. Susan is able to expand a science lesson to include a cross-cutting language element, which Becky identifies as useful for student interest. Becky emphasizes and clarifies a major strength of the lesson seed they are building – rooting the lesson in a real-world experience of the students – and highlights how this will make the lesson much more engaging.

Within the lesson seed building we also observed that pre-service teachers were often able to contribute to discussions involving the integration of CT through tech tools. In the excerpt above it is Alice, a pre-service teacher, that first recommends using the Micro:bit,

Alice: We could use the Micro:bit to code energy. You could use them to take temperature.

Susan: Alright, so something with heat transfer might be interesting with the Micro:bit. They're interesting to me. I think we could do that.

In a later exchange, Susan makes it clear that she relies on her mentee, Alice, to take the lead on tech tool integration in their classroom. In the exchange above, Susan is expressing some hesitation about including a tech tool that will have to be programmed as a central part of the lesson seed they are building. Alice expresses her agency as a knowledgeable contributor to the group by recommending that they use a tool that she is familiar and comfortable with. Unlike in traditional top-down PD models, in our STIG^{CT} pre-service teachers are given the space and agency to share their knowledge and ideas with more experienced teachers and facilitators.

Not only the diverse experience levels of teachers, but the diverse schools and classrooms they came from allowed for the sharing of experience in rich ways the researchers had not anticipated. In the excerpt below Susan and Alice, the pair from above, are in a lesson seed building group with Jen, another pre-service teacher, and a facilitator with no classroom teaching experience. They are discussing how they might use a computer simulation involving fish ecosystems to infuse CT into a lesson on adaptation and evolution. Susan, the experienced teacher, expands the lesson scope to accommodate the students she has learned are in Jen's classroom.

Jen: I feel like that's easily tied into adaptations as well, because you have to learn to work with different things to survive.

Susan: I think that's an extension for your TAG [Talented and Gifted] kids.

Jen: Yeah, right.

Susan: I think really what you put up is an extension for those students who are talented and gifted. Like at the end of charting, that graph is asking them, what adaptations would you have made in round four when there was no shelter and seven of our fish population died? What adaptation could have been made? I think that's more of a higher-level thinking question on that theme, but it links very well.

Jen: I'm also thinking kind of more generally too. Like, can we just kind of throw the idea out there that you cannot just ask them to survive. Like, you need to give them change.

Susan has expanded the lesson beyond what her class needs and is demonstrating for Jen, Alice, and the facilitator how a basic lesson can be adapted to different student profiles within the same grade level -a complicated task requiring experience and familiarity with the intersection of student ability and science content.

Discussion and implications

In our STIG^{CT} design, we have leveraged the best practice of the PD field, including an extended duration, paying attention to content knowledge in relation to standards and other measures teachers attend to, opportunities for reflection and collaboration, and the fore fronting of practice (Fishman, Davis, & Chan, 2014). This resulted in a very successful PD, as assessed by over 80% of participants demonstrating an ability to embed CT in their final inquiry-based elementary lessons (Ketelhut, Cabrera, et al., 2019). The diversity of the participants, the collaborative structure of the activities within the sessions, and the longitudinal timeline maximized opportunities for teachers to learn from each other and over time. The structure also gave teachers the opportunity to integrate information in their classrooms as they were learning it and bring back questions and ideas for the full community.

In our effort to design an effective CoP-based PD, we developed a $STIG^{CT}$ that resulted in four affordances, the ability for participants to seek and share experience, the ability of participants to map knowledge and recognize and remediate knowledge gaps, the opportunity for extended mentorship, and an increased ease of integration of new ideas into the classroom. We presented the first of these benefits, seeking and sharing experience in this paper. Examining how $STIG^{CT}$ participants sought and shared experiences during the collaborative process of developing lesson seeds, we observed that all participants realized opportunities to share experience, including the pre-service teachers. Research indicates that the least experienced members of PD benefit most (Jones, Gardner, Robertson, & Robert, 2013). This may have been true for $STIG^{CT}$ participants as well, however we identified opportunities for all members of the $STIG^{CT}$, including facilitators and experienced in-service teachers, to realize value from the experience, indicating that, as long as the structural benefits we identified are in place, a group with extremely diverse participant experience is not an impediment and can, in fact, be a rich resource when designed PD.

Through careful $STIG^{CT}$ design we realized extended opportunities for experience sharing between participants. We do recognize that this work is grounded in a PD experience that sought to educate teachers in CT, and may, as a consequence, have produced benefits that arose from that specific context. We think, however, that many of the choices we made when designing the $STIG^{CT}$ will produce benefits regardless of the discipline. We therefore recommend educators think about structuring their PD in a similar way, especially when educating around a concept that is unfamiliar to most participants.

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