International Society of the Learning Sciences

Teacher Learning of Novel Computer Science Concepts and Practices: A Collaborative and Expansive Approach

Courtney Stephens, Utah State University, stephens.cmh@gmail.com
Victor R. Lee, Stanford University, vrlee@stanford.edu
Jody Clarke-Midura, Utah State University, jody.clarke@usu.edu
Mimi Recker, Utah State University, mimi.recker@usu.edu

Abstract: This paper presents findings from a study of elementary teachers participating in professional development (PD) developed to accompany a novel computer science instructional unit. This 7-lesson unit introduces students to programming concepts by having students first play an "unplugged" tabletop board game and then create game levels in Scratch. The PD sessions were structured as a set of participatory routines where the previous week's lesson was reviewed, the upcoming lesson was modeled, and then adaptations to it were discussed. Teacher discourse analyses during PD revealed three kinds of sense-making episodes (reflections, connections, suggestions). Analyses also showed that connection and suggestion episodes were frequently grounded in the board game, matching the intent of the instructional approach for supporting teacher learning. Finally, a majority of the suggestions made by teachers during PD were used during subsequent classroom enactments, indicating teachers' reliance on each other despite their collective lack of experience teaching this content.

Introduction

Elementary level teachers are increasingly being asked to teach computer science (CS) in their classrooms (Blikstein & Moghadam, 2019). However, these teachers often have limited prior knowledge related to CS content, practices, and pedagogy. Teacher professional development (PD) is the typical means for addressing such gaps. Yet evidence on the effectiveness of PD in supporting teacher learning and creating sustainable change in classroom practice is decidedly mixed (Lefstein et al., 2020). This could be because many PD experiences are often in the form of presentations of curriculum and content to teachers rather than opportunities for teachers to reflect and more actively participate in the PD experiences.

In response, new approaches, called collaborative PD, have been developed that invite teachers to be active participants in the process. Examples of activities in such PD approaches for CS include engaging teachers in collaboratively designing (Biddy et al., 2021), modeling (Goode et al., 2014), and reflecting (Yadav et al., 2018) on CS curricula and curricular activities. While these approaches are promising, there is a need to better understand how teachers engage in collaborative PD and the interactions that take place during these kinds of experiences (Walkoe & Luna, 2019). This is especially true for elementary level CS, where little is known about how teachers learn about and teach unfamiliar CS content and curricular activities. Given that the demand for elementary teachers to integrate CS into their instruction is only going to grow, it is important for learning scientists interested in teacher learning to more closely examine teacher PD in this area.

This study attempts to do some of that work. This study is part of a larger design-based implementation research (DBIR) project (Penuel et al., 2011), centered on designing and supporting a CS unit for fifth-grade students. During our second iteration of this design (and the focus of this paper), we were especially interested in the teacher experience of learning, adapting, and enacting this new unit. Our analyses thus focused on teacher discourse during PD experiences to gain insights into how teachers participated, what they learned, and how this influenced their subsequent classroom enactments. Our study was guided by the following research questions: What was the nature of teachers' discursive participation in collaborative PD for this new CS unit? How did collaboration within the PD influence teachers' learning of CS content and pedagogy in ways that influenced their classroom enactments?

Curricular and professional development approaches

The curriculum followed a model for designing CS instruction that we call "Expansively-framed Unplugged" or "EfU" (Lee & Vincent, 2019). The underlying intent of the EfU model is to engage learners with relevant CS content and practices through activities that are personally familiar or accessible and typically do not involve digital technology. These approaches are typically referred to as "unplugged" (Bell et al., 2009). One motivation for using an "unplugged" approach at first is to shift learner's expectations about what one needs to know and understand in order to engage with computing.

EfU is based on the theory of expansive framing (Engle et al., 2012). This theory of transfer posits that making frequent connections back and forth between the context of learning and the context of transfer can help learners create an encompassing context that aids in knowledge transfer. That is, the framing of what kind of activity is being completed is broadened to encompass both the unplugged experience and the digital instantiations (usually in the form of a written computer program).

To enable expansive framing to happen, Engle et al. (2012) identified several specific ways in which connections can be made to help create and strengthen that encompassing context. These include supporting learners in *connecting* settings in order to cue relevant prior knowledge, *understanding* how skills and practice in one setting are useful in a future setting, and *authoring* and *creating* in the new contexts. This model has been used to design more broadly appealing instruction (e.g., Hickey et al., 2020), as well as computational thinking curriculum and assessments (e.g., Grover et al., 2014). In our work, it has been the basis for a design framework for sequences of unplugged-to-plugged CS learning activities (Lee et al., 2020).

Collaborative and participatory professional development

CS represents new territory for elementary teachers to include in their teaching. And while PD has long been used to support teacher learning of new content and curricular approaches, more recent collaborative PD approaches have emerged. These aim to scaffold teachers in engaging in peer discussions, reflecting on the intentions and enactments of new curricula (Borko, 2004; van Es & Sherin, 2008), and developing a shared process for designing and planning adaptations to the lessons to support classroom enactments (e.g., Biddy et al., 2021; Severance et al., 2016; Voogt et al., 2015). These activities offer opportunities for teacher learning as they are closely linked to their everyday experiences and challenges (Putnam & Borko, 2000). Within these collaborative PD approaches, what has been less studied is the *process* of teacher learning during the course of PD engagement; for example, how teachers make connections to their prior knowledge, and how they take ownership of these new ideas in ways that influence their classroom enactments (Walkoe & Luna, 2019).

Although EfU was intended as a situated approach to support student learning and transfer, we posit that it also applies to teachers with little CS and programming background by helping them, like their students, make connections from their prior knowledge to new CS content. Unlike the other topics they may teach, elementary teachers are often also learners in the CS content area, and the EfU model designed for students may benefit teachers as well. Thus, we posit that designing a CS curriculum informed by unplugged ideas and expansive framing will lead to activities with low threshold for *both* teachers and learners. Further, when the accompanying PD is supportive and collaborative, it will help teachers with little computer science background successfully engage with, adapt, lead, and support such activities. We next describe a study to examine these conjectures.

Methods

Setting and participants

The project was oriented as design-based implementation research (Penuel et al., 2011). Specifically, we worked with a local school district to address a problem of practice (offering CS education at the elementary level), to commit to iterative design (implementing in different schools), to contribute to theory (examining design implications of EfU for students and teachers), and to design for sustainable change (involving teachers in collaborative PD).

To address this problem of practice, we designed a new instructional unit that could accommodate the time constraints faced by teachers. We also deliberately involved school library time and school librarians as per the partnering district's request. As discussed elsewhere, librarians, and school librarians in particular are beginning to take on some of the role of providing CS learning opportunities for their library patrons (Lee et al., 2020). We worked closely with two rural elementary schools, one each year over two years. For the current study, we focus on the second iteration, involving three fifth-grade teachers (Maria, Teresa, and Debbie; all names are pseudonyms), one teacher librarian (Julia). The fifth-grade classes enrolled 74 students.

Expansively-framed unplugged CS curriculum

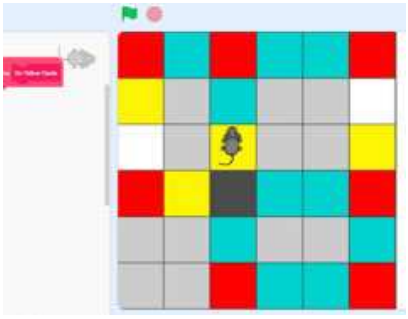
Following the EfU model, we designed a seven-lesson CS curricular unit to fit within teacher and librarian allotted time for this unit. The initial draft of the scope and sequence of the unit was sketched at a high level by the researchers with the intention of using the collaborative PD sessions (described below) as a space for teachers and the librarian to propose adaptations for their specific school context.

In this unit, students first play an unplugged tabletop board game, *//Code: On the Brink* (see Figure 1) which, as a game, may be more broadly appealing while also serving as a rich space to explore several computing concepts. Students then play a digital version of the same board game programmed in the block-based

programming language, Scratch (see Figure 2). Finally, students create and program their own game levels and challenge other students to play them.

The lessons were designed to span both the classroom (preparatory lessons introducing CS concepts) and school library (playing the board game and programming the digital version of the game). Game playing was situated in the school library because it aligned with the partnering district goals, and, as found in prior research, board games were a common library activity for students in the district (Lee et al., 2020). Classroom and library enactments for a lesson each lasted approximately 20 to 30 minutes.

Table 1 shows an overview of how the unit unfolded across lessons and classroom and library settings, and the specific CS concepts addressed. Specific lessons also highlighted EfU phases, including connecting to prior knowledge (lessons 1-3), connecting between settings (lessons 3-6), and authoring (lessons 6-7).

Figures 1 & 2: Sample Levels from *//Code: On the Brink* tabletop board game and Scratch version

Collaborative professional development: structure and routines

The three classroom teachers, teacher librarian, and two researchers participated in weekly 45-minute collaborative PD sessions that preceded each of the seven lesson's enactment. Each PD session was structured to follow a set of participatory routines: 1) reviewing the previous lesson's enactment, with a focus on noticing equitable student participation and engagement, 2) modeling the current lesson, 3) discussing the lesson and related CS concepts, 4) discussing adaptions to the lesson plan, and 4) revising the lesson plan based on that day's discussions. All lessons plans were developed using Google Docs to support easy modifications and commenting by researchers and teachers alike.

In the first three PD sessions, a researcher modeled the lesson while the teachers acted as classroom learners, thereby using a "teacher-as-learner" modeling approach where teachers engage in the unit as students (Goode et al., 2014). In the final four PD sessions, each teacher took a turn leading the lesson while the others acted as students. Note that not all teachers were able to attend all PD sessions.

Table 1: Focus of each PD session and accompanying classroom and library lessons

	Lessons 1-3	**Lessons 4-6**	**Lessons 6-7**
Classroom	Learn about conditionals and step-by-step programming	Learn about conditionals, procedures & how to program in Scratch	Review CS concepts in the game
School Library	Play board game and Scratch versions of game	Design and program own game levels	Play each other's games
CS concepts	Conditionals, algorithms, procedures	Conditionals, debugging, simulation, abstraction	Review
EfU phases	Connect board game play and prior knowledge	Understand how board game play informs game design and programming	Author (program) new game levels

Data sources and analyses

Audio recordings of the seven PD sessions and classroom enactments for all three teachers were transcribed and then inductively coded, categorizing utterances by their conversational purpose (e.g., reflection) as well as content (e.g., pedagogy). Talk unrelated to the curricular unit was not coded (e.g., "I have bus duty so we need to shift the meeting time"). Among the conversational purposes coded were *suggestion*, *reflection*, and making a *connection*.

Once utterances were coded for purpose and content, we noted that the discourse typically consisted of extended collaborative discussions. These were coded into episodes called *suggestion*, *connection*, and *reflection*, or collectively, *sense-making* episodes. These episodes framed much of the meaningful conversation that occurred during the PD, and, in what follows, we describe these episodes to provide context for the findings that they frame.

The sense-making episodes consisted of at least one of the three types of utterances, as well as a *triggering event* that caused the utterance to be made. This would often take the form of the first part of an adjacency pair (Schegloff & Sacks, 1973), such as a peer's question. The focal utterance (i.e., suggestion, connection, or reflection) would be the second half of the adjacency pair. Then we examined the "trailing" conversation that occurred after the utterance was made. This tended to contain concurrences or clarifications from other participants. The episodes were bounded by the presence of the adjacency pair or statement of a new topic. All utterances coded as suggestion, reflection, and connection were included in episodes, although some were grouped into the same episode if they focused on the same conversational topic and occurred close to one another. This would happen, for example, when two teachers would make suggestions in response to the same question.

After identifying these sense-making episodes, they were coded to determine their topic and the type of triggering event for each. We also analyzed them for various other features, such as length, placement within the PD, and the type of utterances that occurred in the trailing conversation. Finally, after identifying all episodes, we looked for evidence of the use of a suggestion or connection made during the episodes that translated to the classroom by reviewing the classroom enactment transcripts.

Findings

Overall, we found increasing teacher participation in the PD over the course of the 45-minute PD sessions. Figure 3 shows how the number of sense-making episodes grew over the seven sessions, with a 60% increase in the number of episodes in the final three sessions as compared to the first four. In those final three sessions, the teachers, rather than the researchers, were modeling the lessons.

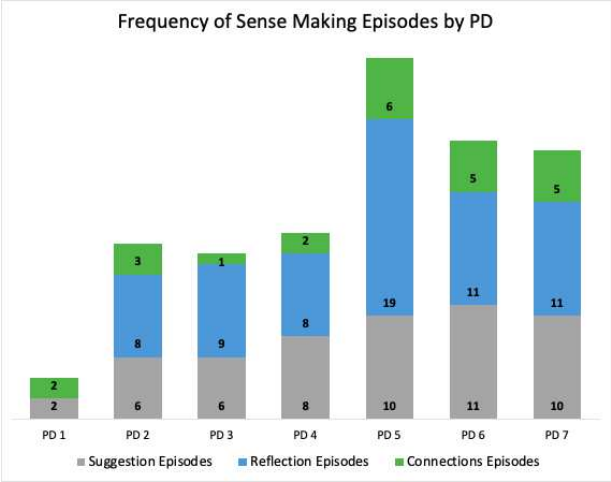


Figure 3: Frequency of sense-making episodes over PD sessions

We found that conversations during suggestion and connection episodes in particular were important in affecting the ways that teachers made sense of CS ideas. We next describe these two types of episodes in more detail and illustrate how they affected teachers' pedagogical choices during classroom enactments.

Suggestion episodes

Suggestion episodes occurred when teachers recommended changes to the lesson plans for the CS unit. While some of the episodes contained only one suggestion made by a single teacher, many contained multiple suggestions made by multiple teachers as they engaged in conversation about a particular topic, such as how to teach the concept of a procedure to students.

In the following example suggestion episode, Maria, a teacher, is modeling the upcoming lesson where game cards specify moves (e.g., hop forward) made by the game piece (a sprite) and acting as if she were talking to her students (Macey and Jacob):

Maria: So, if you made your own card, like 'I know, Macey [a student], you did a hop forward', 'I don't know what hop forward means'. 'I'm the sprite, so you're gonna have to tell me'. So, we're gonna have to make our own procedures right here for what it means to hop forward.

Julia (Librarian): Well, it means 'just hop forward', is what they [the students] said to me.

Maria: 'Okay, Macey, what does the hop, hop forward mean to you, think it in your head'. 'Jacob, what does it mean?' 'Ok, what does it mean, Macey', she tells me, 'Jacob [a student] tell me.' 'Oh, so like this, or like this?' (*Maria hops twice)*. 'Which one? Who's right? How do I know?'

Debbie: Okay, that works.

Here we see Julia, the librarian, make a comment about what students have said to her in the past and therefore how they would likely respond. Taking this into account, Maria then incorporates the suggestion seamlessly into her modeling of the lesson, showing how the teacher can have students demonstrate their personal definitions of a procedure to show the importance of procedural precision.

Over the seven PD sessions, teachers generated a total of 53 suggestion episodes (see Figure 3). Further, teachers made 41% more suggestion episodes during the final three PD sessions, when the format of the PD was more teacher-led. Suggestion episodes covered a variety of topics—the use of Scratch, general pedagogy, and CS-specific pedagogy. In particular, 41 (77%) of these suggestions were pedagogical in nature, with half of those being specifically related to CS pedagogy.

Finally, we note that peer questions and peer reflections triggered a majority of the suggestion episodes, accounting for 36 of the 53 (70%). This is indicative of the value of teacher-led conversations and peer collaboration in helping teachers develop agency in recommending adaptations to the lessons. This claim is further supported by the fact that 10 additional suggestions were made when teachers were modeling upcoming lessons—a component of the PD that was teacher-centered and teacher-led.

Connection episodes

Connection episodes illustrate how teachers make connections between the CS content and other content. The connections focused on their growing understanding of programming and the Scratch interface, and often drew on past experiences, prior understandings, and the board game used to frame the unit. In the following example, teachers are discussing the concept of programming abstraction and are beginning to differentiate between procedures and abstraction:

Maria: I mean, I don't think I knew the word abstraction.

Teresa: The kind of all, I mean, is like, well, the procedure isn't a small abstraction.

Maria: Yeah, maybe I was actually like, so procedure was like all the steps, right? And abstraction is like the act of doing it. Maybe I wasn't, I don't know if I taught that completely correctly.

Teresa: You could have really big abstractions—

Maria: Well, cuz like I said, like I gave a similar example about the sharpened pencil like, when I say get out your Elevate [district curriculum] stuff, we know that means get out this, this, this, start your language sheets, like you don't have to say all those steps.

Teresa: Right.

Maria: So, I kind of said that, but—

Teresa: Yeah, and the algorithms are all the instruction—

Maria: And those are the procedures, the abstraction is like the act of making it smaller?

Researcher: Yeah.

Here, the teachers connect the concepts to their classroom teaching and use "Elevate", the district-authored writing curriculum, as an analogy to explain their thinking.

Many of the connection episodes consisted of analogies meant to help relate the content to every-day occurrences, like the weather or classroom routines. Furthermore, half of the connection episodes involved comparing CS content to the board game, suggesting the value of the expansive framing instructional approach. One example of such an episode occurred during the second PD session, when teachers were trying to make sense of the definition of CS events and turned to the board game's rules to define the meaning of the term:

Researcher: So, level 15 would be right here. Okay. Right. And so, looking at level 15, we would say what are some of the events that you see? And there's two ways to answer this, right? One of this we could say, actually, we'll just have you guys, what are the events that are on here?

Maria: I think as a kid, I would be like, 'wait what do you mean, like what—'

Julia: Yeah, I wouldn't understand what the word events means either. […]

Debbie: Well, if it's, like what you're saying with the games, are you meaning like when I land here, I need to turn left, is that what you're wanting as an event? […]

Teresa: Or this guy has to turn right or left before he—

Maria: Yeah, they're gonna start telling you what to do, I think. […]

Debbie: And is that considered an event?

Researcher: Yeah, I mean, that would be an event, and probably what I would consider is that if you're on red, do the red cards.

Maria: So, landing on red is, or being on red is the event.

Researcher: Yeah. So being on red is the event.

As seen in this episode, teachers used the board game mechanics of determining movements based on the color that the sprite is touching ("being on red") to understand the meaning of a computational event. Across all PD sessions, teachers generated a total of 24 connection episodes (see Figure 3). While the number of connection episodes was lower than other sense-making episodes, they almost doubled during the final three PD sessions—again, sessions which were more teacher-led.

Classroom enactments

We examined the three types of episodes to see how the collaboration within the PD influenced teachers' classroom enactments. First, connection episodes impacted the way that teachers described CS content to their students. An example of this was the enactment of the previous excerpt, where all three teachers explained events or conditionals using the game mechanic of how touching different colors caused the sprite to perform different moves.

Second, we also found that suggestion episodes influenced teachers' CS pedagogical enactments. Of the 53 suggestion episodes that occurred during the PD sessions, 33 had the potential to be used by teachers in future lesson enactments. Of those suggestions, 23 (about 70%) were enacted by at least one teacher, 14 (42%) were enacted by two of the three teachers, and 10 (30%) were enacted by all three teachers.

For example, a suggestion that was enacted by all three teachers was to have students physically stand up and move their bodies to demonstrate new game procedures during lesson 3. This was used by each teacher but enacted in slightly different ways. Maria had one student stand and demonstrate the new procedure, Teresa had all the students do it simultaneously, and Debbie had students individually demonstrate procedures before having the whole class do it together. The use of an idea that was not in the lesson plan and the varying ways in which teachers took ownership of the pedagogical choice shows their agency in classroom practices as well as their engagement in the PD.

Figure 4 shows the flow of suggestions between teachers, with the arrow pointing from the teacher who made the suggestion to the teacher who used it. A circular arrow represents a teacher enacting her own suggestion. As can be seen, each teacher relied on suggestions made by peers, as well as a smaller number of suggestions made by the librarian.

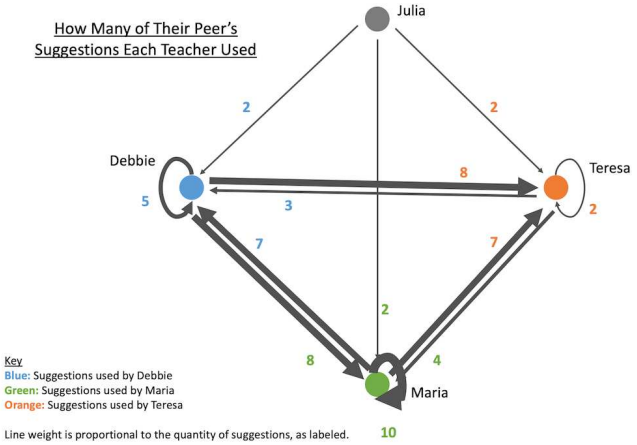


Figure 4: How teachers enacted peer suggestions (circular arrows represent a teacher taking her own suggestion)

Figure 5 shows the percent of topics of suggestions enacted by teachers in their classrooms. Suggestions regarding CS-specific pedagogy were taken up the most by all three teachers, as would be expected given the unfamiliarity of the CS content. In particular, 12 out of 16 (75%), of all CS pedagogical suggestions were used by at least one teacher. Thus, teachers appeared to rely on each other to find enactment advice, despite their collective lack of experience in the subject matter.

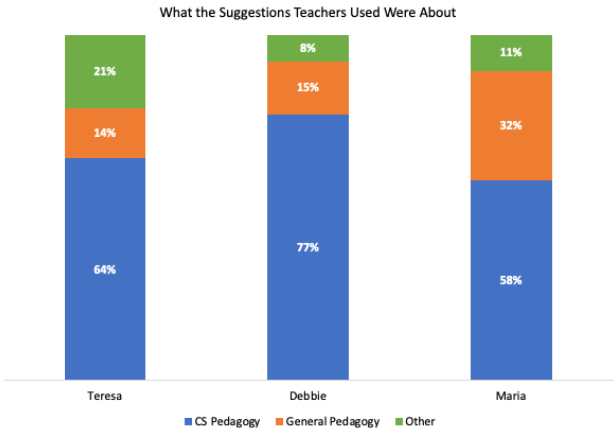


Figure 5: Topics of suggestions enacted by each teacher

Finally, teachers also used a large proportion of suggestions that occurred during lesson modeling. In particular, 91% came from the modeling portion of the PD or the conversation immediately following their modeling, where teachers were still discussing their plans for the upcoming lesson. While modeling activities did take up more time and therefore were more likely to generate suggestions, the highest percentage of the suggestions made during the modeling portion —which was more teacher-centered and directed—were enacted than from any other PD activities.

Discussion

This paper investigated how elementary teachers participated in a collaborative PD for a 7-lesson unit that was new to them both in content (CS) and pedagogy (EfU). The PD sessions were structured as a set of participatory routines where teachers reflected on the previous week's lesson, modeled the upcoming lesson, and discussed adaptations to it. While these kinds of routines have been incorporated in other PD designs, our study closely examined teachers' utterances to characterize the kinds of sense-making episodes they engaged in during the PD sessions. We identified three episode types and found that episode frequency increased over the course of the PD sessions as teachers gained agency in the PD process.

By closely analyzing the specific episode types, we unpacked how teachers participated in the PD, what they learned, and how these interactions influenced their classroom enactments. The connection episodes showed how teachers made connections between their teaching and the content as well as between the board game and the content. While the EfU approach is intended to support student sense-making, the findings suggest it also supported teachers' sense-making. Further, the vast majority of suggestion episodes, where teachers recommended adaptations to the lessons, were pedagogical in nature, with half of those being related to the specific CS pedagogy. Our findings thus show how the teachers developed a repertoire for teaching CS despite its relative unfamiliarity and, like previous work, show how teacher agency during PD can lead to curricular changes (Severance et al., 2016; Voogt et al., 2015).

Conclusion

Elementary teachers with little CS background are increasingly being asked to include CS in their instruction. To help prepare teachers for this, learning scientists need to better understand the process of teacher learning in order to design impactful PD. In this paper, we examined how teachers in our study actively made connections and took ownership in suggesting adaptations to the curriculum in ways that influenced their classroom enactments.

DBIR approaches can be powerful ways to address local and meaningful problems. Nonetheless, questions remain about their scalability and sustainability. The study highlighted several routines, tools, and strategies to structure collaborative PD that appeared to result in fruitful teacher engagement and agency in lesson enactments. Future work should examine to what extent these can be productively employed in other PD settings

without researcher support. Further, the content in the current study only addressed introductory CS ideas—engaging teachers around advanced CS concepts might be harder to realize in this setting.

References

Bell, T., Alexander, J., Freeman, I., & Grimley, M. (2009). Computer Science Unplugged: School students doing real computing without computers. *Journal of Applied Computing and Information Technology, 13*(1), 20-29.

Biddy, Q., Gendreau, A., Bush, J., Hennessy Elliott, C., Jacobs, J., Recker, M., Sumner, T., & Penuel W. (2021). A professional development model to integrate computational thinking into middle school science through codesigned storylines. *Contemporary Issues in Technology and Teacher Education, 21*(1).

Blikstein, P., & Moghadam, S. (2019). Computing education: Literature review and voices from the field. In S. Fincher & A. Robins (Eds.), *The Cambridge Handbook of Computing Education Research* (pp. 56–78). Cambridge: Cambridge University Press.

Borko, H. (2004). Professional Development and Teacher Learning: Mapping the Terrain. *Educational Researcher*, *33*(8), 3–15.

Engle, R. A., Lam, D. P., Meyer, X. S., & Nix, S. E. (2012). How does expansive framing promote transfer? Several proposed explanations and a research agenda for investigating them. *Educational Psychologist, 47*(3), 215-23.

Goode, J., Margolis, J., & Chapman, G. (2014). Curriculum is not enough: The educational theory and research foundation of the exploring computer science professional development model. *Proceedings of the 45th ACM Technical Symposium on Computer Science Education - SIGCSE '14*, 493–498.

Grover, S., Pea, R. D., & Cooper, S. (2014). Expansive framing and preparation for future learning in middle-school computer science. *Proceedings of 11th International Conference of the Learning Sciences (pp. 992-996).* ISLS.

Hickey, D. T., Chartrand, G. T., & Andrews, C. D. (2020). Expansive framing as pragmatic theory for online and hybrid instructional design. *Educational Technology Research and Development*, *68*:751–782.

Lee, V. R., & Vincent, H. (2019). An Expansively-framed Unplugged Weaving Sequence Intended to Bear Computational Fruit of the Loom. *In P. Blikstein & N. Holbert (Eds.), Proceedings of FabLearn 2019* (pp. 124-127). New York, NY: ACM.

Lee, V. R., Poole, F., Clarke-Midura, J., Recker, M., & Rasmussen, M. (2020). Introducing coding through tabletop board games and their digital instantiations across elementary classrooms and school libraries. In *Proceedings of ACM Technical Symposium on Computer Science Education (pp.* 787–793). New York: ACM.

Lefstein, A., Vedder-Weiss, D., & Segal, A. (2020). Relocating Research on Teacher Learning: Toward Pedagogically Productive Talk. *Educational Researcher*, *49*(5), 360–368.

Penuel, W. R., Fishman, B. J., Haugan Cheng, B., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational researcher*, *40*(7), 331-337.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning?. *Educational researcher*, *29*(1), 4-15.

Schegloff, E., & Sacks, H. (1973). *Opening up closings.* Semiotica, 8, 289-327.

Severance, S., Penuel, W. R., Sumner, T., & Leary, H. (2016). Organizing for teacher agency in curricular co-design. *Journal of the Learning Sciences*, *25*(4), 531-564.

van Es, E. A., & Sherin, M. G. (2008). *Mathematics teachers "learning to notice" in the context of a video club.* Teaching and Teacher Education, 24, 244-275.

Voogt, J., Laferrière, T., Breuleux, A., Itow, R., Hickey, D. T., & McKenney, S. (2015). Collaborative design as a form of professional development. *Instructional Science, 43*, 259–282.

Walkoe, J. D., & Luna, M. J. (2019). What We are Missing in Studies of Teacher Learning: A Call for Microgenetic, Interactional Analyses to Examine Teacher Learning Processes. *Journal of the Learning Sciences, 29*(2), 285-307.

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.

Acknowledgements

This work was supported by the National Science Foundation (#1837224). The opinions expressed are those of the authors and do not necessarily reflect those of the NSF. We thank our partner educators and their students.