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Transformative learning for computer science teachers: Examining how educators learn e-textiles in professional development

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HIGHLIGHTS

- Experienced CS educators seek PDs to address specific *problems of practice* from their classroom teaching.
- Hands-on making inspires teachers to try new pedagogical strategies with their students.
- Educators learn through problem-posing, critical assessment, exploring new options, and acquiring knowledge/skills in PD.

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ABSTRACT

Recent international efforts have focused on broadening opportunities for students to learn computer science (CS) in schools, prompting expansion of professional development (PD) programs for educators. But there is little research supporting the ongoing professional needs of computing teachers. This qualitative study examined how in-service CS teachers approached, learned, and anticipated teaching a hands-on electronic-textiles unit. Our findings illustrate that "problems of practice" from the classroom served as a compass to guide CS educators' learning in PD. We also share implications for key features of PD programs that can transform the pedagogical knowledge and classroom practices of experienced teachers.

In recent years, there has been a global educational movement to strengthen and expand computer science (CS) learning opportunities in schools. England introduced new computing lessons as part of their National Curriculum, and New Zealand recently infused CS as a core school subject. Other regions worldwide are expressing enthusiasm for broadening computing education to a wider group of students. In the United States, a nationwide effort to empower all schoolchildren with valuable computational skills to thrive in our digital economy and society is underway (Margolis, Goode, & Chapman, 2015). This presents a formidable challenge, as few teacher education programs in the US offer computing content and many states lack formal credentialing pathways toward a CS teaching authorization (Goode, 2007; Franke et al., 2013). While the National Science Foundation (NSF) and other entities make significant investments in programs that introduce CS content to educators and prepare them to teach computing (Astrachan & Briggs, 2012; Cuny, 2012; Goode, Margolis, & Chapman, 2014; Menekse, 2015), the US Department of Education (2016) continues to report large shortages in CS educators across the country. This scarcity is perceived as a barrier to providing equitable access to CS learning opportunities at all US schools (Google, 2015).

These initiatives have created an immediate demand for more computing teachers in the field, but in the US, emphases on recruitment and preparation can overshadow the need to provide ongoing support and growth opportunities for CS educators who are beyond their initial years of teaching computing (Ericson, Guzdial, & McKlin, 2014). In education, the leaky bucket syndrome of turnover results when induction efforts are prioritized over teacher retention (Ingersoll & Smith, 2003). We suspect this is happening in CS education, too. The Computer Science Teachers Association (CSTA), an international organization, described the need to provide professional development opportunities for

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"veteran teachers with computer science teaching experience" as a "crisis" (Ericson, Armoni, Gal-Ezer, Seehorn, Stephenson, & Trees, 2008, p. 14). But adjacent efforts to democratize computing classes also require a "radical transformation" and significant investment in CS teacher preparation, so that educators acquire content knowledge along with a profound awareness of how systemic inequities privilege economically-advantaged White and Asian men in computing fields (Goode, Chapman, & Margolis, 2012, p. 49). These two initiatives are likely further impacted by the leaky bucket of teacher turnover, which occurs more often in under-resourced, urban school districts (Ingersoll & Smith, 2003). Cuny, program director for the NSF's Computing Education division, has called for "a sustainable ecosystem" that prioritizes both the "unprecedented effort" to expand credentialing programs that help educators learn how to showcase the relevance of computing for all students, and provides ongoing support for in-service CS teachers (2015, p. 57; p. 56).

We know from broader teacher education research that regular participation in professional growth and collaborative learning communities strengthens teacher retention (Cochran-Smith, 2004; Smith & Ingersoll, 2004; Wenger, McDermott, & Snyder, 2002), and that professional development (PD) is the most common vehicle for these experiences (Borko, 2004). To gain a better understanding of how to design enriching learning opportunities for CS teachers' ongoing professional growth and to explore how computing educators experience PDs, this inquiry is framed by *transformation theory*, a constructivist and critical model of adult learning (Mezirow, 1981; 1994). According to this framework, learning is the process of revising one's own interpretations of experiences, which then guides future actions (Mezirow, 1990, p. 141). Building on what Habermas (1973) called *communicative action* and Freire (2000) called *conscientization*, Mezirow theorized that learning can be transformative for an individual when critical awareness of social realities awakens new ways to make meaning and alters the person's deeply held perspectives (Mezirow, 1981; 1994). The result is a profound, structural shift in the basic premises of the person's thinking, feelings, and actions.

Our qualitative study examined a small sample of experienced CS teachers who participated in a series of Saturday PD workshops designed to prepare them to teach electronic-textiles (e-textiles) in their high school computing classes. We solicited their responses around their expectations and learning experiences through multiple interviews and surveys, and analyzed our findings through this transformation theory lens, asking:

RQ1: What attracts CS teachers to continued professional learning through PDs?
RQ2: What do experienced CS teachers learn in PDs?

1. Literature review

To frame the need for this study and given the limited availability of prior work on CS educators' needs for professional growth, we begin with a review of the literature from general education research on teacher retention and the desired outcomes of PDs. We then review studies on PDs for computing teachers and from related subject areas to speculate on essential features of transformative PDs for CS teachers: that PDs should be content-specific for computing teachers; address problems of practice from CS classrooms; and build community and a sense of solidarity among computing teachers. While our review describes emerging research about PDs designed and delivered to initially induct in-service educators to teach computing, we also highlight the scarcity of research on experienced CS teachers, why they engage in PDs, how they learn, and how professional learning impacts their work as educators.

1.1. The importance of PDs for teachers

From prior work on teacher education and retention, we know that ongoing professional learning is crucial to educators' survival and persistence in the field. Ingersoll (2002, p. 21) noted that through PD, teacher education initiatives must address the "revolving door" of frequent teacher turnover, particularly to retain educators in the first few years of teaching. But nationwide employment data from schools clarified that job turnover is nearly as common among more experienced educators as it is for novice teachers (Donaldson, 2005; Goldring, Taie, & Riddles, 2014; Hancock, 2008). This may be because, as Huberman (1989) theorized, beginning in the four to six-year stage and into the mid-career phase, there is a division among educators. Some teachers strengthen their commitment toward teaching, while others grow increasingly disillusioned about their chosen profession (Fig. 1).

PDs offer opportunities for teachers to learn beyond their classroom walls and experience rich professional growth (Cochran-Smith, 2004; Fiarman, 2007). Effective PDs expand teachers' pedagogical content knowledge of the subjects they teach, and hone their ability to foster student learning in their classes (Van Driel & Berry, 2012). Such experiences inspire in-service teachers to experiment and transform how they engage with their students (Huberman, 1989), ultimately deepening teachers' commitment to their work (Donaldson, 2005).

In computer science, PD offerings generally focus on introductory computing content (Cuny, 2015; Ericson, Guzdial, & Biggers, 2007; Goode et al., 2014) because of the aforementioned push to recruit CS educators, especially among those who earned their first credential in other subjects (Goode, 2007). Armoni (2011, p. 9), in reviewing the literature, warned that many CS PDs introduce only enough content to begin teaching computing, and that additional subject-specific pedagogy must be acquired by in-service CS educators through "future professional development." Yadav and Korb (2012) pointed out the pressing need to provide in-service CS teachers with opportunities for in-depth and continual training so

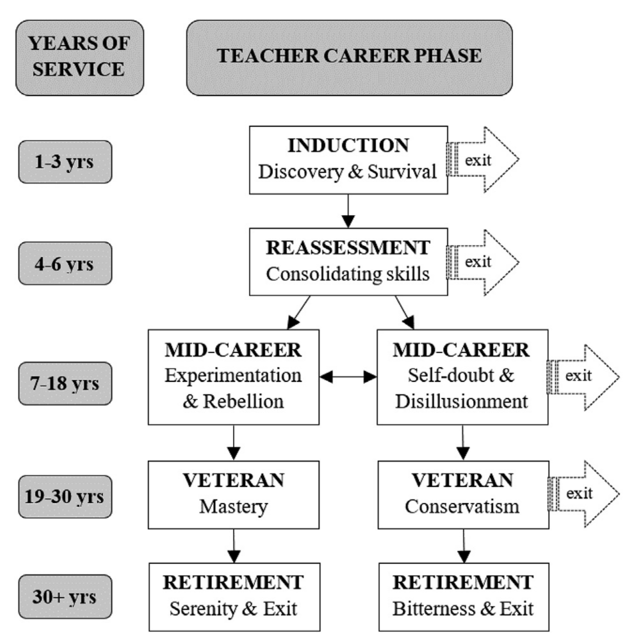

Fig. 1. Phases of a teacher's career, adapted from Huberman (1989).

that they can continue to teach rigorous and rich computing classes infused with advanced concepts. While PDs that specifically address the needs of experienced computing teachers are sporadically offered, face-to-face meetings are few and often require long travel times, making them particularly prohibitive for in-service CS educators working full-time (Ni, 2011). Such limitations in access compelled us to examine how CS educators approach and learn in PDs specifically aimed at supporting their ongoing professional growth.

1.2. Key features of PDs for experienced CS educators

1.2.1. Professional learning should be subject-specific

In addition to the need for CS PDs, we highlight three features of these learning opportunities that might be important for educators. Computing teachers must remain abreast of a unique field that constantly reshapes itself with technological trends and breakthroughs (Cuny, 2015; Ericson et al., 2008; Ni, 2011). While researchers found that most educators prefer PDs with subject matter focus (Fishman, Marx, Best, & Tal, 2003; Kennedy, 1998), presumably to learn of advances in their fields (Opfer & Pedder, 2011), this preference is likely compounded for CS teachers to broaden knowledge of new computing concepts not taught in any other school subject (Armoni, 2011; Brown, Sentence, Crick, & Humphreys, 2014; Ravitz, Stephenson, Parker, & Blazevski, 2017). Interdisciplinary PDs reportedly cannot meet “the scholarly needs of CS educators” as well as computing-specific workshops could (Tenenberg & Fincher, 2007, p. 517).

CS education researchers also suggest that PDs engage computing teachers in content-specific activities (Armoni, 2011; Stephenson, Gal-Ezer, Haberman, & Verno, 2006; Yadav & Korb, 2012), to situate participants in the fundamental thinking and learning practices of the discipline (Borko et al., 2005; Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2009). Doing so helps educators gain confidence as “doers” of the subject, confront gaps in their own content knowledge, and improve their strategies for engaging students (Borko et al., 2005, p. 49). One fruitful method of blending pedagogy and concepts in CS PD is the Teacher-Learner-Observer model, in which educators take turns playing the role of different stakeholders in the classroom (Goode et al., 2014). One group prepares and teaches selected lessons as instructors while their colleagues participate in the lesson as “learners” or objective “observers,” then the three groups dialogue together to debrief and reflect on the effectiveness of the instructional strategies of the lesson from different perspectives. The roles shift for each lesson. Given that scholarly literature on CS-specific PDs is still emerging, there is a need for further examination of how PDs extend CS educators' computing-specific pedagogical knowledge, increase teacher empathy for the perspectives of their students, and enhance instructional practices to support student learning.

1.2.2. PDs should address problems of practice

Scholars of professional learning also report that adults seek PDs to solve problems that relate directly to their lives (Hunzicker, 2011). Freire described how the need to resolve problems often catalyzes people to develop a more critical awareness of the world, and that the process of transforming one's perspective and personal paradigm begins with problem-posing (1973). For schoolteachers, the opportunity to examine specific *problems of practice* from their classroom experience has been found to be the primary motivator for PD attendance (Archibald, Coggshall, Croft, & Goe, 2011; Darling-Hammond & McLaughlin, 2011). Additionally, discussions with peers around problems can be key to improving teaching (Elmore, 1996; Elmore & Burney, 1999), by helping educators adopt new perspectives, conceptualize, grow (Horn & Little, 2010), and ultimately develop instructional interventions to alleviate those problems (Elmore, 1996; Elmore & Burney, 1999). However, there is little scholarship on the problems experienced in computing classes and limited evidence of the transformative value of PDs that focus on problem-solving for CS educators, despite CS being described by some as the process of designing problem-solving systems based on observations of human behavior (e.g., Wing, 2006). In one study of CS PDs, researchers examined college faculty “actively engaging in issues of mutual concern” from their computing classes through sharing and evaluating one another's teaching portfolios (Tenenberg & Fincher, 2007, p. 517). In their post-PD evaluation, participants responded that discussing “teaching issues” was “most valuable” (p. 517). While this research is informative, it took place in a higher education setting. More investigation on how K-12 computing teachers might benefit from opportunities to examine and learn from problems is necessary.

1.2.3. PDs should build professional learning communities

The most transformative PDs also situate subject-specific teacher learning within communal contexts (Borko, Koellner, & Jacobs, 2010; Frykholm, 1998; Lomos, Hofman, & Bosker, 2011; Shulman & Sherin, 2004; Smylie, Allensworth, Greenberg, Harris, & Luppescu, 2001; Wineburg & Grossman, 1998). This need for community is tremendous for CS educators, as many report feeling isolated without professional colleagues in the same subject area at their schools (Ericson et al., 2014; Goode, 2007; Guzdial, 2014; Ni, 2011; Ni, Guzdial, Tew, Morrison, & Galanos, 2011; Ravitz et al., 2017; Schlager & Fusco, 2003; Stephenson et al., 2006). Many CS teachers commune in virtual learning communities online because so few colleagues work in proximity (Tenenberg & Fincher, 2007). However, studies indicate that educators typically prefer the social and community interactions of face-to-face environments to workshops conducted exclusively online (McConnell, Parker, Eberhardt, Koehler, & Lundeberg, 2013; Ravitz et al., 2017).

Across a variety of programs, the literature indicates that CS teachers highly value community-centered approaches to PD. In the multinational Disciplinary Commons Model, groups of CS educators from diverse institutions collaborated in PDs that emphasized a strong professional network and group identity (Fincher & Tenenberg, 2011). In their post-PD evaluations, communal activities - namely small group discussion, peer observation, and the giving and receiving of feedback - were the most valued by computing teachers in PDs because these activities helped them connect with and support one other. Above all, the identity-building and sense of belonging as same-subject educators achieved within the Disciplinary Commons CS PD setting is something that computing teachers rarely experience (Ni, 2011; Ni et al., 2011). A recent study of the Exploring Computer Science PD program found that educators valued the teacher learning community more than any other aspect of their PD series, even more than content knowledge and pedagogical preparation (Margolis, Ryoo, & Goode, 2017). A fourth-year computing educator remarked that the collegial cohort experience “had a great impact on my professional development” (p. 1). Similarly, in an examination of the efficacy of a week-long PD program for in-service Advanced Placement CS teachers, the bringing together of the participants to learn and work with like-minded teachers in “class meetings” - when participants discussed curricular material and practiced applying new concepts hands-on — was found to be the keystone of the program (Leyzberg & Moretti, 2017, p. 370). This body of evidence suggests that PDs in communal settings that meet in-person might be key to transformative learning for computing teachers in PDs.

This review suggests that experienced CS educators seek professional opportunities to immerse themselves in subject-specific content, to address problems of practice from the classroom, and participate in-person as part of a collaborative learning community. When mid-career educators engage in these activities through PDs, the professional growth and collegial solidarity they experience can increase job satisfaction and mitigate teacher turnover (Huberman, 1989). The dramatic influx of CS teachers and classes brings a new urgency for providers of PDs to better understand how transformative learning can be experienced by computing educators when these conditions for professional growth are met.

2. Methods

Our inquiry was situated within a larger project to provide professional learning to in-service Exploring Computer Science (ECS) educators in Los Angeles County. ECS is an introductory computer science course taught at high schools around the country, a year-long elective class designed for students with no preparatory background in CS (Goode, Margolis & Chapman, 2014). In the initial PDs to learn how to teach the curriculum, ECS educators undergo two summers of all-day workshops that emphasize pedagogical practices that build student interest and knowledge of CS, such as teaching through inquiry and establishing an inclusive and culturally-responsive classroom culture (Goode et al., 2014; Margolis, Goode, Chapman, & Ryoo, 2014). They also examine the lack of diversity in computing professions, how certain racial, gender, and socio-economic demographic groups are over-represented in CS education, and discuss how instructional activities can help create spaces for students to shift those structural inequities and stereotypes (Goode et al., 2012).

In 2015, our research team authored an electronic-textiles (e-textiles) unit for ECS. E-textiles involves crafting circuits in fabric, paper, and other soft surfaces to connect electronic components (Buechley, Eisenberg, & Elumeze, 2007), which encourages students to design, tinker, and build artifacts using a variety of computational tools (Honey & Kanter, 2013; Peppler, Halverson, & Kafai, 2016). A key device developed for e-textiles is a sewable, washable Arduino micro-computer[1] that can be adhered to different surfaces like sweatshirts and stuffed animals, then programmed by the maker to customize output of LED lights, sensors, even audio speakers (Buechley et al., 2007). As maker education takes root in schools nationwide, e-textiles has been heralded as a medium for transforming teaching and learning in STEM courses (Halverson & Sheridan, 2014). In particular, researchers report that creators of e-textiles artifacts are disrupting the racial and gender dynamics of the current maker movement, a field which remains dominated by White, college-educated, middle-aged men (Kafai, Fields, & Searle, 2014). Thus, e-textiles mirrors the ethos and objectives of the ECS course - to broaden the participation of learner groups historically under-represented in computing - and incorporating it effectively as a curricular unit to teach computing was the foremost objective of our greater research team.

2.1. Teacher participants

In this NSF-funded pilot project, a small group of ECS teachers attended PDs to receive the new e-textiles curriculum and supplies, and go through the lessons themselves in preparation for implementing the unit in their own ECS classes. Sample selection was not influenced by the research team, rather, the school district-ECS liaison sent out an initial e-mail call for participation to the Los Angeles-area mailing list for experienced ECS teachers, educators who had completed the two-year PD program and taught the course for multiple years. The pilot study was limited in resources (supplies, teacher stipends, research staff, etc.), so the liaison selected five among the twelve seasoned educators that expressed interest, to maximize the variety of feedback on the curriculum and based on his knowledge of their diverse teaching styles, range of teaching experience, and different school settings (see Table 1).

In the research consent process, all five agreed to participate in the project at-will, with the understanding that their responses to our requests for data would not affect their inclusion in the e-textiles pilot study. They attended three, all-day Saturday PD sessions that immersed them in hands-on making with cutting-edge e-textiles materials, tools, and advanced computing content. In addition to the new curriculum, these five received a modest stipend for PD attendance, and a class set of e-textiles materials and tools a year for the duration of the three-year project. The project also budgeted for all teacher and student participants to keep their own completed artifacts.

While the small sample size of the first year is a limitation to this paper, these five educators experienced our first PDs in an intimate setting and the resulting in-depth data collection and analyses of their perceptions, experiences, and reflections informed the rest of the longitudinal study. They pioneered the integration of making, circuitry, and text-based programming into the existing ECS course at their public schools. Two of these teachers implemented the lessons with their students later in Year 1, the other three planned to do so in Year 2. The third year of the project scaled to 17 teachers.

2.2. Data collection

We adopted a narrative inquiry approach (Clandinin, 2006) to examine what motivated these in-service educators to seek out PDs and what they learned. We solicited their lived experiences around CS instruction and professional learning through surveys and interviews. Specifically, the five were interviewed individually a month before the PD workshops launched with open-ended questions in a semi-structured approach (Pre-PD Interview). Before the PDs commenced and after each workshop, we also conducted a survey with open-ended questions that probed for teachers' narrations and reflections on their own learning in PD (Pre-PD Survey; Post-PD Survey 1; 2; 3). When the PD series concluded, all five were interviewed again to capture their thoughts on the experience as a whole and after the fact, how they reflected on their own engagement, participation, if and how they were transformed through these workshops.

The interview protocols were drafted jointly by the larger research team and the interviews were conducted by a researcher not authoring this paper. Each interview lasted about an hour, they were audio-recorded then transcribed. The surveys were adapted from the post-PD questionnaires utilized by the ECS program to solicit feedback on their PD workshops. Our surveys were conducted online, took less than ten minutes to complete, and participants were given time to do so at the end of each PD. With this format, we encouraged the teachers to respond from their own frame of reference and share their thoughts freely at different time points and through various mediums (Bogdan & Biklen, 2007). We acknowledge that instrumentation and investigator bias is inescapable in qualitative data collection; therefore, we worked as a team to construct study-specific, discovery-oriented inquiries that welcomed our pilot teachers' perspectives with open-ended questions designed to impose little or no limitations on their contributions to the study (Chenail, 2011).

[1] The stitch-able micro-controller originally prototyped by Buechley (2006) underwent several major iterations and spawned competitor models. Our research team explored them throughout the longitudinal study, and ultimately transitioned to another developer and distributor when the project scaled (Kafai et al., 2019).

Table 1
Study participants.

Self-Identified Teacher Characteristics				School/Student Demographics									
Teacher	Ethnicity (Race) Gender	Yrs of Teaching	Yrs of Teaching ECS	Total # of Students	English Learners	Low SES	Student Race						
							Afr. Am. /Black	Native Am.	Asian/Pac. Isl.	White	Hisp./ Latino	2 + Races	Decline to State
Angela	Vietnamese (Asian) Woman	11	3	1570	2.6%	89.4%	42.3%	0.2%	0.6%	0.6%	55.7%	0.1%	0.5%
Ben	Jewish (White) Man	6	2	4480	3.2%	53.7%	3.7%	0.2%	28.6%	26.1%	38.7%	1.4%	1.3%
Gail	Cambodian (Asian) Woman	5	2	532	22.90%	91.70%	13.7%	0.4%	–	0.4%	85.3%	–	0.2%
Mahmud	Persian (Middle-Eastern) Man	17	4	2377	6.4%	59.1%	1.6%	0.5%	29.0%	10.8%	57.0%	1.2%	–
Sergio	Mexican (Hispanic) Man	18	5	2001	22.5%	94.7%	9.3%	0.2%	–	1.0%	89.2%	0.2%	–

Notes: All names are pseudonyms.

2.3. Data analysis

We used a general inductive approach for data analysis (Thomas, 2006), and this process was guided by our research questions. The first author initially immersed herself in the interview transcripts and survey responses (Borkan, 1999) to develop a spreadsheet of excerpts that answered both RQ1 and RQ2. RQ1 (What attracts CS teachers to PDs?) was answered with selected quotations from pre-PD data, and a coding frame was developed to organize the excerpts into the broad themes that emerged (Jain & Ogden, 1999). For RQ2 (What is learned in CS PDs?), findings were further informed a priori by our theoretical lens, that transformative learning involves certain elements like critical assessment of assumptions and traditions, self-examination, exploration of new options, acquisition of knowledge and skills, and reflection (Mezirow, 1981; 1994). Learning is a process, so answering RQ2 required matched readings of individual participant's data from different timepoints. Both authors read the excerpts again and the quotes were applied to the phases of transformation. This rigorous, systematic, and iterative activity of reading and coding enabled us to analyze data excerpts along several themes identified by our participants (Thomas, 2006), to bring forth only themes that were common across all data collection points (Gibson & Brown, 2009, pp. 128–129), and to interpret relationships found between the themes through our theoretical frame (Thomas, 2006).

3. Results

This exploratory study sampled a small group of experienced ECS teachers that attended a specialized PD series, so we make no attempt to generalize to the greater population. Though the educators represented very different perspectives, life experiences, and diverse pedagogical approaches, we identified themes consistent among all of the participants, which are organized here into two parts to answer our research questions. We use double quotation marks (") to denote direct quotes from our data, and a single quotation mark (') to denote teacher voice that was denaturalized[2] and condensed to highlight evidence for these main points. Through this inquiry, we gained a better understanding of who our sample are, their motivations for attending these PDs, what aspects of PDs were helpful to them, what challenged them, and what they learned.

3.1. RQ1: CS teachers problems of practice

Though our seasoned educators had accumulated years of teaching experience in CS classrooms, they sought more opportunities for professional learning. When asked directly about this in the Pre-PD interviews, all five stated that they were motivated to attend PDs to address problems they had encountered in their practice, and that their decision to explore e-textiles was deeply influenced by the need to develop solutions for the classroom. Our findings for RQ1 were organized around four *problems* common among our sample: 1) How to authentically engage more students in CS and programming; 2) How to address social inequalities through CS education; 3) How to develop students' problem-solving skills; and 4) How to incorporate more hands-on, tangible learning in CS classes.

3.1.1. Problems of practice drive teachers to professional learning

Our teachers reported that the need to address problems from their classroom experience was the primary reason they sought to expand their own knowledge of CS through PD. In the educational context, "problems" are not presented as unendurable or intolerable aspects of teaching, nor are they questions that have precise or correct solutions. *Problems of practice* are complex and open-ended topics from the classroom that can generate discussion and multiple perspectives, as one study defined, within a "web of shared expectations" (Elmore & Burney, 1997, p. 13). Similarly, we noted that our teachers did not describe difficulties that could not be overcome, nor were they searching for a panacea; rather, they pondered what they could do to shift conditions in their classes.

3.1.2. Problem 1. How to authentically engage more students in CS and programming

All of the teachers volunteered for the e-textiles PD primarily to learn new ways to welcome all youth to ECS, especially those

[2] In the denaturalization process, we removed involuntary vocalizations and corrected grammatical errors. This was most frequently performed on excerpts from the two participants who were not native speakers of English.

students without prior knowledge, skills, or interest in CS or programming. As Angela explained, the main challenge for computing educators is to “get kids in the door, whet their palates, and build interest that they can take further” by designing fun learning activities in ECS class. This was echoed by her colleagues, who all used the word “fun” in describing how they hoped the resulting joy and interest would motivate students to want to learn more. Angela described herself as “very intimidated, afraid” of programming when she was a student: ‘I remember how I felt taking CS classes in college, and my students have that already, that computer science is really hard and you have to be really smart. I've been trying all year to get those kids excited about things.’

3.1.3. Problem 2: How to address social inequalities through CS education

The teachers told us that many students enter their CS classes not feeling confident or successful in computing because of broader inequalities of race, gender, and ability that are institutionalized in American schools and society. These educators attend PDs because they seek innovative techniques for managing equity issues that play out in their classrooms. For example, Gail sought to learn more about CS because support from community organizations and industry partners has not been enough for African American boys in her class: ‘They are such deficit thinkers about themselves because of the many traumas African American students have experienced in their history, their family life, the neighborhood, and their middle school experience with a super high rate of teacher and administration turnover.’ Gail wanted ECS to ‘address these inequities and contribute to the community's growth mindset in CS education.’ Gender dynamics were also discussed by our educators. Ben observed that boys tended to dominate over girls in his classes, even when Ben mindfully set up group projects so that historically underrepresented students' voices could be better heard: ‘But it's an uphill battle of trying to take away that dominance from the boys, especially in the programming units of ECS.’ The teachers expressed hope that a curricular unit on e-textiles would shift these racial and gender inequities in their classes.

3.1.4. Problem 3. How to encourage students to problem solve

Our teachers sought PD to explore different ways to encourage students to solve problems creatively in ECS. Gail realized that the ‘ECS class represents new content, new structure, a new way of learning for students,’ different from the direct instruction teaching format common in schools. In direct contrast with how she admitted teaching her math classes, Angela explained that computer science ‘is not about getting the correct answer.’ But as a result of these differences, the teachers noted that ECS students hesitated, appeared to lack initiative, or behaved apathetically, unable to proceed with computing tasks at hand without validation from the instructor. Sergio described this as an attitude of ‘Tell me what you want me to do, give me my points’ that students exhibited when faced with ambiguous, open-ended, complex problems in ECS. The teachers wondered how e-textiles could shift classroom focus from a binary paradigm of right vs. wrong, and motivate students to let their unique individuality and creativity guide how they solve the problems posed in their computational assignments.

3.1.5. Problem 4: How to incorporate hands-on learning into CS class

All of our teachers emphasized that CS should be taught through inquiry-based approaches, one of the three pedagogical principles of ECS. Gail wanted students ‘to learn computing content through *doing* something, rather than with textbooks and worksheets.’ Ben explained:

> Everything that we do in ECS really is on a computer and it stays on the computer, it's behind that screen. I want it to come out of the screen. I'm waiting for the next movement in computers to venture into more of an interactivity with the world around us, rather than having to go to our desk and turn away from the world and enter a screen.

Mahmud agreed that it’s ‘a lot better for them when students build things, draw things, do things by hand. They enjoy it more than doing repetitious busy work.’ This idea of incorporating more handcrafted maker-based projects in class was exciting to all of these ECS teachers and prompted them to attend the e-textiles PD series.

3.2. RQ2: What experienced teachers learn in PD

3.2.1. Teacher learning in CS PDs addressed problems of practice

Our collection of interview and survey data demonstrated that the professional growth that took place in the PDs aligned with the teachers' earlier-stated problems of practice, that what educators said they learned afterwards matched up with what they had set out to learn. In addition, our RQ2 findings (what teachers learned) could be framed as transformative experiences as well (Fig. 4). For example, when the teachers remarked on some of the new skills acquired through PD, these pertained to strategies for incorporating more hands-on activities in their computing class (Problem 4). The critical self-examination phase of transformative learning was linked to awareness of the educators’ own assumptions about CS, and how those might be similar or different from what their students bring to the course. Our detailed RQ2 findings and further discussion of their implications follow.

3.2.2. CS teachers narrated their learning in PD

The PD workshops were dedicated to teachers experiencing the curriculum as learners, i.e., the educators completed all of the assignments and created the required artifacts for themselves. Throughout this learning process, we encouraged them to narrate their experiences, perceptions, and observations for us, and describe how the experiences impacted their roles as educators in CS classrooms.

Making is engaging. According to the teachers, the highlight of the e-textiles PDs was the making - the experience of designing, crafting, programming then troubleshooting their own handcrafted projects. Each participant commented that making was fully engaging, and motivated them to learn more CS content through these Saturday workshops. In her post-PD interview, Angela told us ‘these hands-on sessions made the PDs enjoyable the whole time.’ Sergio agreed: ‘hands-on workshops are the most rewarding and most engaging of the PDs I have attended.’ Once he had a design idea, Sergio said he had to ‘focus a hundred percent to make the project come alive. There was no time to be disengaged.’ Ben wrote after the third workshop that it blew his mind that “everything was hands-on. We spent the day on one project!”

The artifacts represented hours of crafting time in the PDs (and between PDs, as the teachers had homework), and evidence of the satisfaction garnered from persisting in intellectually challenging activities (Fig. 2). All of the teachers said they were most proud of making something that worked, i.e., their electronic components were programmed and functioned according to their designs. As Ben noted: ‘I am most proud that I made a stuffed animal. When you touch its hands, it lights two different patterns based upon the pressure that you apply. I'm ecstatic, I'm showing everyone: Oh my god, look at this! and everyone's like: Shut up! (laugh) Congratulations, you made a toy.’ Aside from celebrating his creation (“It's so

Fig. 2. CS teachers interacting with the touch sensors on their e-textiles artifacts.

cool!!"), Ben reflected that he also 'learned to sew, that's a big deal, that's huge! I'm still at the stage where I wouldn't be able to creatively figure out how to do that without a manual, a reference. But now that I know how you stuff things - you do one side and then go across - I can figure out other stuffed animals from there.'

3.2.3. *Making inspires persistence*

The hands-on artifacts also made challenges visible in the PDs, and it was obvious when projects did not have spectacular outcomes. Gail was distraught after the first PD: "I made a monster and it ended up looking like Donald Trump, I was really upset about it. I wanted to make something cute!" Sergio had sewn an LED upside-down on his final project: 'That showed the rush I was in to try to finish. It was so hard! I turned it around by accident.' But the teachers overcame their disappointments because they were motivated to bring their design visions to fruition. Gail made another project at home, brought it alongside her Trump monster, which she called her "practice run." Sergio bounced back from his crafting error, saying: 'I'm going to cut up the stitching there, then go back the same way.' These teachers persisted because they felt ownership of their handcrafted creations and wanted to see projects to completion.

Angela narrated her own sense of persistence throughout the PD series, explaining: 'In most PDs, we don't do what we ask the kids to do. But here, we learned all that, we saw what other people created and their problems, and how they fixed their problems. This kept us working on things that we wanted to work on, talking about things that we wanted to talk about.' Grappling with her own problems and observing how peers trouble-shot their projects helped foreshadow some of the issues that Angela's students would later encounter, a mental exercise that she considered necessary for every teacher before implementing curriculum in their classroom. The making of errors and correcting them was an anticipated but not always scheduled part of the PDs. But the practice of crafting together and sharing materials around a table created many informal opportunities for teachers to chat about their projects, express frustration, and encourage one another. For Angela, this experience of problem-solving real-time made the workshops 'engaging and useful and enjoyable, which can't be said for all PDs.'

3.2.4. *Making teaches CS concepts in a unique way*

While the crafting activities were physically and intellectually engaging, the human-computer interaction was equally enthralling for these CS educators, i.e., building a relationship with their artifacts while they were making them. After completing his final project, Mahmud was intrigued:

> The fact that you can interact with your product is very important to me, that you can actually touch something and it does something for you. That's the meaning of programming to me, to actually see the result of your programming. Many times in Java, you may program for two-three pages and nothing happens. It's not as rewarding [and] you can't get immediate feedback. [It] really helps you [keep] going when one light turns on, at least something happens that is tangible. E-textiles is all tangible.

Ben also talked about interacting with his e-textiles artifacts. In determining audience ranges for the touch sensors on his stuffed animal final project, Ben realized: 'Every person who tries it has a different range; my wife, for example, cannot get to the final program. I don't understand that because, barely touching it, I get to the final.' But this making and interacting with the projects hit home a very important CS concept for Ben, a cognitive connection between three different curricular units of ECS: data collection, problem-solving, and programming. 'When we engineer or we create, we want to collect data first and then figure out what to do based upon the data. We have to test things out first and see what happens before we can actually do the coding. The data is used to bring out the coding, to influence the coding.' He was excited that e-textiles would thus be a wonderful culmination to his year-long course.

3.2.5. *Students were on teachers' minds during the PDs*

Teachers' design ideas were inspired by students. Our participants maintained their primary teacher identities even as they engaged as learners in the PD setting. The teachers told us that they incorporated their students in different ways, even in the earliest design phases of their projects when brainstorming about what to make. Gail told us that she wanted to make a stuffed Pikachu doll for a student leaving for college in the Fall: "I wanted to make her something to take with her, to let her know that she's got support back home while she's transitioning." Sergio created a Mexican Day of the Dead *calavera* (skull) out of fabric, and when asked how he came up with the design, Sergio said he attempted to "replicate" a student's drawing in his e-textiles project: "My students' drawings from prior years are still on my desk. I thought to myself: I could put lights on them!" Fig. 3 displays a sample of teachers' projects.

PD artifacts were designed to be used as instructional tools. Teachers also centered students in the crafting process, as they considered how they might use their own artifacts as instructional tools in the classroom. Angela explained that she wanted to do a "good job," because she intended to use her projects as models for her students, to demonstrate the desired functionality of each project and the requirements of each assignment. Angela recalled how Ben had dismissed mistakes he had made on his project by saying he'll just remake the artifact before he started his classroom implementation. That bothered Angela: 'I didn't want to make another one, I don't have time! I felt that I knew enough to make a good one on the first try that I could show my kids.' She also anticipated that "some of them might want to make something similar." Sergio said his goal was to "inspire the students" with his own artifacts. In his final project, he programmed LEDs to light up on his school jersey. He laughed as he predicted how students might react to the lights, that would only light up when he crossed his arms: "They'll be looking at it and say: Look at Mr. Ramirez when he's upset! (laughs)" The teachers made artifacts with their students in mind, to inspire them, with students as their intended audience. This practice also modeled how to generate project ideas, by initially considering potential audiences for the artifact and thinking about who the finished product might be presented to.

Fig. 3. Examples of e-textiles artifacts created by teachers in PD.

3.2.6. *Teachers learned through empathy and reflection*

Rethinking show-and-tell. By spring, all five participants looked forward to implementing the new e-textiles curriculum in their classes either later that year or the following school year. In their final interviews, each teacher told us that they had experienced a shift in their roles as CS educators after participating in the extended PD series. Being positioned as learners in the workshops helped teachers deeply empathize with their students and consider new instructional approaches that might better meet students' needs. Gail reflected after the first workshop, "PD helped me understand my students better. I learned what they are going to go through — their frustrations, needs, etc. - and it helped me empathize and consider what I can do for them in my class." For Gail, this struck a chord at the second PD, when the teachers had to present the sewn artifacts that they had completed for homework: "I don't like feeling forced to share. I also don't want to see other people's projects because I compare myself to them and it affects my confidence." From this experience, she resolved to implement more gallery walks and what she called "organic sharing," as opposed to whole-class sharing in her own classroom. The workshops continued to help her think about how to better serve her students. In her final reflection, Gail said: "The PDs reminded me that this is hard, reminded me to be patient, to scaffold and to give resources. The most important thing about computer science is not so much how I deliver content, but how I build efficacy."

Rethinking lesson pacing and differentiation. Teachers also reflected that their PD experiences impacted how they considered lesson facilitation in their classrooms. Sergio noted that as teachers 'sometimes we just take it for granted, but things are not as easy as they look, it's challenging to learn!' Sergio said in his last interview: 'I don't know enough (laugh). I thought it would be simple, easy. But no, I often felt lost!' He explained that he was self-conscious and doubted his own abilities as he sat with his colleagues in PD: 'I don't think I'm very capable with manual things, creativity, even with programming. What you did in two or three minutes - that flower? It would take me an hour.' These insecurities deepened his "understanding of equity," specifically, he reevaluated lesson pacing and considered how to differentiate instruction in his ECS classes. He spoke about this in the context of his final project: 'I'm proud of it, it's something I want to show as a teacher to the students. But I don't think I'll encourage the students to do such a big project, because some may not be able to or have a harder time, than others in my class.' He thought about giving those students more time and dividing the lessons into smaller steps, like: 'Today, just do this part, the next part will be this.'

Angela also thought about how to pace the e-textiles activities, as she recalled how some of her students exclaim in class: "I don't know what to do!" Reflecting on her own tendencies as a learner, she said: 'I'm one of those students!! I took forever to try to figure out what to do for my projects, I understand that completely because that's exactly how I am! The figuring-out-what-I-wanted-to-do, like my students, takes a while because I wanted to make something good.' This represented a tremendous shift in Angela's perspective. She had previously described her students as 'unmotivated to do anything, they didn't do homework in this class, they barely did classwork in this class.' After experiencing the PDs as a learner, she realized that students not producing work might actually be like her, needing extra think-time to make something meaningful.

Rethinking group work. Mahmud had an epiphany about group work. He had missed the first PD because of a medical emergency. Though Mahmud caught up privately with the PD facilitator, he recalled in his final interview that he felt "unprepared" in required skills and knowledge: 'When I came to the second PD, I was lost.' Reflecting on this experience and paying close attention to group dynamics with fellow teachers at subsequent PDs helped him see from the learner perspective: 'When you're basically dysfunctional because you missed class, your group won't spend a lot of time trying to explain things to you. I realized that the students have even less patience than we teachers do. They're like: Why should I teach you?! Why did they put you in my group if you don't come to class? This kind of group work doesn't work because it's not their job help others catch up.' Mahmud began to wonder if group work is only effective when "everybody's on the same boat and everybody has been trained" to work together. Sergio explained it was very helpful during PD when he got to work 'with someone else on the same assignment, doing different projects but with similar goals.' For Sergio, this inspired him to consider assigning the individual projects to be completed 'in pairs so partners can help each other, especially if somebody is having a hard time. They would do their own projects, but they'd both be responsible to finish these two projects.' These reflections explored when and how student collaboration can be generative and productive, and when other instructional activities would be more appropriate and supportive.

Rethinking scaffolds for programming. Teachers also remarked on the importance of providing instructional scaffolds when teaching ECS students programming. Angela was initially "apprehensive" of e-textiles because of her long-standing fears of coding, a feeling that she knew the majority of her ECS students shared. She noted however, that the "scaffolding" lessons built into the PDs helped her ease into the projects. On those handouts, the first task was "storyboarding" – explaining in words or sketching how their project would function. Gail elaborated: 'I loved the worksheets, they helped me organize my thoughts for text-based programming. It was really difficult for me to storyboard the circuitry. I couldn't see - especially for a 3D project - where the lines would go and how to avoid them crossing over.' But writing her computer commands out in pseudo-code on the storyboard worksheets "felt good," partially because pseudo-coding is an essential activity in prior units of ECS. The new e-textiles curriculum also provided simple starter code (modifiable programs), so learners could focus on personalizing their projects rather than creating code from scratch. Gail found these steps 'really prepared me, scaffolded. I feel like, of all the text-based languages I could teach my students, this Arduino stuff seems very approachable. digitalWrite is not as scary as: Set exposition.x2 whatever for a gaming program.' On her final PD survey, Gail highlighted the utility of these instructional supports and asked facilitators for even "more templates and an emphasis on modifying" to use in her classroom.

3.2.7. Transformative learning to support teaching e-textiles

These teachers' narratives highlight that above all, participating as a learner was the most exciting aspect of the PDs ("It's so cool!!"). New passions for making were developed, and creativity was harnessed in both the designing of handcrafted artifacts and in the teachers' minds as they simultaneously lesson-planned how to unroll these projects in their own ECS classes as they experienced the lessons themselves as learners. While designing, crafting, and debugging their own projects, the teachers anticipated how their students might behave and feel, mistakes that students might make. Rather than a myopic focus on acquiring new CS content knowledge, teachers expressed profound interest in developing pedagogical strategies to increase equity and student engagement in their classrooms.

Teachers also articulated challenges they themselves encountered ('I thought it was simple, but no, I felt lost!') and setbacks. Disorienting dilemmas often trigger reflection (Mezirow, 1991; 1994), and this was evidenced in our findings. As the teachers reflected on their taken-for-granted social roles and expectations in these uncomfortable moments in PDs (most often in interacting with their colleagues), their habitual perceptions, thoughts, and actions were problematized ('When a student has been absent, we put him in a group so the group can help him catch up. But people don't drop everything they're doing'). Further exploration and discourse resulted when the interviewer prompted participants with direct questions to narrate their experiences in PD. Through self-examination in the post-PD interviews, non-functional beliefs and epistemologies were identified (Mezirow, 1981; 1994), and a new critical consciousness was developed as they resolved those dilemmas (Freire, 1973; 2000) through perspective transformation.

4. Discussion

4.1. Critical ingredients for CS PDs

These individuals were on the experimentation and rebellion pathway toward deepening their commitment to their profession, according to Huberman's model (1989). It is not surprising that CS teachers who volunteer for professional workshops to change their curriculum and learn new content and pedagogies, are on the road to mastery and serenity rather than disillusionment and conservatism. What we learned confirmed what literature already hypothesized, that this group of seasoned CS educators experienced professional growth because the PDs were structured around subject-specific interests, their needs from the classroom, and within a professional learning community.

This study also extends our knowledge of how PDs can help teachers undergo profound identity shifts, especially as they learn new content and skills (e.g., Ni, 2011). Our sample attended the series of all-day, Saturday workshops because they were searching for ways to modify their curriculum and teaching approach by incorporating more hands-on, interactive, complex activities. In other words, they entered the PDs with their teacher hats on, and as PD participants, the educators explored different options for how to address problems encountered by their students. Transformative learning often happens when people try on "another's point of view" (Mezirow, 2000, p. 21), and our teachers recognized aspects of themselves reflected in their students because they were oriented as learners and encountered challenges themselves in these collegial, safe spaces. Being positioned as learners not only helped expand the participants' content knowledge of the subject they teach, it informed how they would frame and facilitate their future e-textiles classroom implementation.

These key features of transformative PDs counter the traditional (still common) top-down format of in-service trainings where facilitators convey information and provide answers that teachers must absorb like sponges (Darling-Hammond & Ball, 1998; Quartz, Barraza-Lyons, & Thomas, 2005), a behaviorist practice that neglects adult learners' needs and is a poor model for classroom teaching (Croft, Coggshall, Dolan, & Powers, 2010). Through the lens of transformation theory, we recognized that teachers can develop new truths and (we anticipate) new pedagogies when the PDs and multiple points of data collection encourage them to engage collectively in problem-posing, empathy, critical questioning, discourse, and reflection. Such rich learning may have a lasting impact on experienced teachers and the students they serve.

4.2. The ongoing process of teacher learning

We acknowledge that Mezirow's process of transformative learning was not completed within the context of this study. Such learning can only be evidenced after the educators return to their classroom spaces and apply their altered perspectives to their teaching practice, which is beyond the confines of this paper. The taking of action, of linking theory to praxis, is the crucial part of learning (Habermas, 1973, p. 2). While our findings here add to our knowledge of how teachers approach and experience professional learning in CS, examinations of the different impacts of the PD series and the participating teachers' instruction with ECS students, as well as broad evaluation of the e-textiles program and curriculum, are the foci of recent and upcoming publications cultivated from our longitudinal study (e.g., Fields, Kafai, Nakajima, & Goode, 2017; Fields, Kafai, Nakajima, Goode, & Margolis, 2018; Kafai et al., 2019).

5. Conclusion

This paper contributes a new understanding of the experiences and professional needs of seasoned CS teachers. Though the study is limited in its generalizability, through in-depth interviews and surveys, we uncovered evidence about what CS educators sought to learn and the problems of practice they encountered in their classrooms, problems that computing teachers felt they could solve pedagogically through their own professional growth. The teachers also narrated the powerful and transformative experiences of participating in PDs that advanced their CS content knowledge and skills through hands-on crafting. The making of artifacts additionally helped teachers consider how to successfully operationalize these learning experiences with students, and in particular, anticipate the kinds of support students might need when they implemented the new e-textiles curriculum in their ECS classes. These

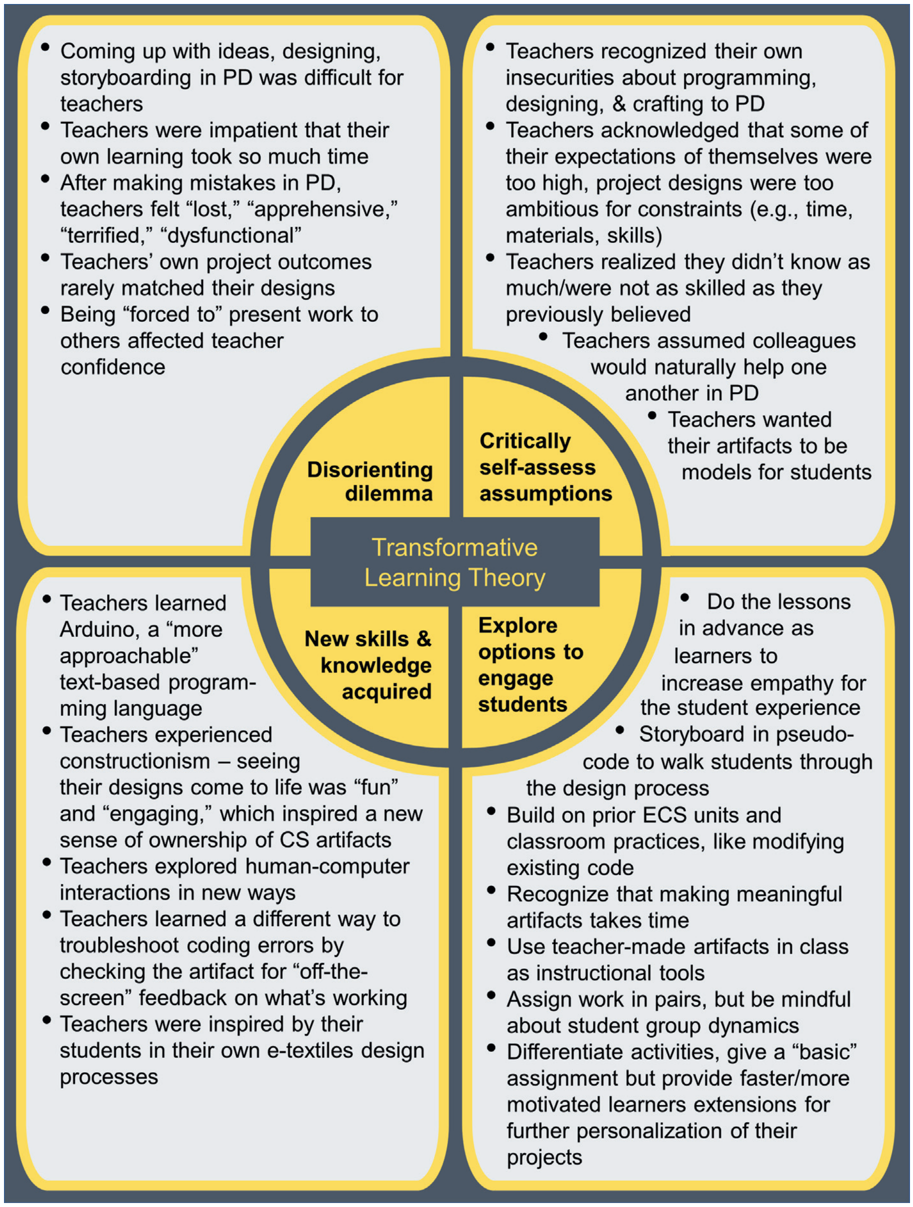

Fig. 4. CS teachers’ problems of practice and transformative learning in PD.
The original theory (1978) was revised by Mezirow and others in countless publications. The original paper outlined ten phases (Disorienting dilemma; Self-examination; Critical assessment of assumptions; Recognize one's discontent/process of transformation in relation to others'; Explore options; Plan a course of action; Acquire knowledge and skills; Try provisional roles; Build competence/self-confidence in new roles/relationships; Reintegrate into one's life dictated by new perspective). However, transformative theory does not require a person to experience these phases or in a set order (Kitchenham, 2008). The elements highlighted here reflect only what was revealed through our data analysis.

ruminations gave special thematic purpose to the informal chats our participants had with one another around the crafting table.

While these findings echo prior research on the positive effects of making in general and e-textiles specifically, our work uniquely reveals how the PDs were experienced and narrated by educators. Rather than framed around student outcomes, our findings cast a light on the ongoing needs of seasoned educators working to engage diverse groups of learners in their CS classrooms. This project is also novel in examining the preparation of classroom teachers to instruct e-textiles lessons alone, which contributes to prior work that examined researchers and makerspace educators serving as instructors in specialized out-of-school learning spaces like museums or libraries.

As computing is integrated in schools around the world, considering the development and sustainability of a high-quality computing teaching corps is of primary importance, and ensuring access to rich professional development opportunities to educators in the field is key. Our narrative study reveals how participants connected aspects of the workshops to their critical reflective processes, particularly in pondering uncomfortable moments experienced in PDs and discussing next steps for classroom implementation. This study represents a first step in investigating the authentic needs, experiences, and perceptions of computer science educators engaged in professional learning.

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Declaration of interest

The authors declare no competing interests.

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