Transformative Learning for Computer Science Teachers: Examining How Educators Learn E-Textiles in Professional Development

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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.

Highlights

- Experienced computer science educators seek professional learning to address specific "problems of practice" from their classroom teaching
- Hands-on making in PD is engaging for teachers and cultivates new pedagogical strategies for student learning
- The collective process of problem-posing, critical assessment and self-examination, exploration of new options, acquisition of new knowledge and skills, and critical discourse and reflection, led to transformative development for experienced computing teachers

Keywords

Computer Science Education; Professional Development; Experienced Teachers; Electronic-Textiles, Transformative Learning

Introduction

In recent years, there has been a global educational movement to strengthen and expand computer science learning opportunities in schools. The United Kingdom has introduced new computing lessons as part of their National Curriculum, and New Zealand recently infused computing as a core school subject. Other nations and regions worldwide are expressing enthusiasm for broadening computing education to a wider group of students. In the United States, the National Science Foundation (NSF) and other entities have made significant investments to expand programs that introduce CS content to secondary educators and prepare them to teach computing (Astrachan & Briggs, 2012; Goode, Margolis, & Chapman, 2014; Cuny, 2012; Menekse, 2015), as part of a nationwide effort to empower all schoolchildren with valuable computational skills to thrive in our digital economy and society. This presents a formidable challenge. The US Department of Education (2016) continues to report large shortages in computer science (CS) educators across the country, but there are few teacher education programs that offer this preparation and many states lack formal credentialing pathways toward a CS teaching authorization (Franke, Century, Lach, Wilson, Guzdial, Chapman, & Astrachan, 2013). This scarcity is perceived as a barrier to providing 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, the emphases on recruitment and preparation 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), and 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 "veteran teachers with computer science teaching experience" as a "crisis" (Ericson, Armoni, Gal-Ezer, Seehorn, Stephenson, & Trees, 2008). Cuny (2015), program director for the NSF's Computing Education division, called for *ongoing* support for computing teachers in order to build "a sustainable ecosystem for CS education" in the US.

We know from the broader field of teacher education 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). Building on what Habermas (1973) called "communicative action" and Freire (2000) called "conscientization," Mezirow theorized that learning can be transformative when critical awareness of social realities awakens new ways to make meaning and alters a person's deeply held perspectives (1981; 1994). The result is a profound, structural shift in the basic premises of a person's thinking, feelings, and actions (OISE, 2016).

Our qualitative study examined a small sample of experienced CS teachers, who all agreed to participate 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?

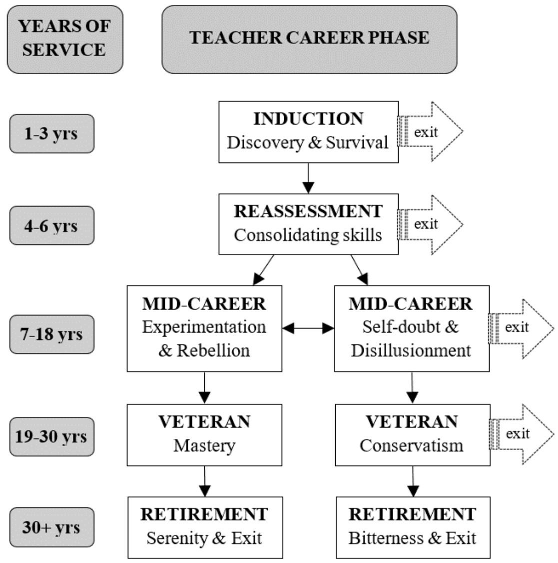
RQ2: What do experienced CS teachers learn in PDs?

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 like mathematics and science, 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.

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) 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 (**Figure 1**).

Figure 1: Phases of a Teacher's Career, Adapted from (Huberman, 1989).



PDs offer opportunities for teachers to learn beyond their classroom walls and experience rich professional growth (Fiarman, 2007; Cochran-Smith, 2004). Effective PDs can help deepen in-service teachers' commitment to their work (Donaldson, 2005), expand their pedagogical content knowledge of the subjects they teach, and hone their ability to foster student learning in their classes (Van Driel & Berry, 2012).

In computer science, PD offerings generally focus on introductory computing content (Goode, Margolis, & Chapman, 2014; Cuny, 2015; Ericson, Guzdial, & Biggers, 2007) because of the aforementioned push to recruit CS educators, especially among those who earned their first credential in other subjects (Goode, 2007). Armoni (2011), in reviewing the literature, warned that many CS PDs introduce only enough content to begin teaching computing, and that subject-specific pedagogy must be acquired by in-service CS educators through "future professional development." Yadav and Korb (2012) further this idea, noting: "There is a critical need to provide in-service CS teachers with opportunities for in-depth and continual training" so that they can continue to teach computing classes that are rigorous and rich with advanced concepts. While PDs that specifically address the needs of experienced computing teachers are sporadically offered, face-to-face meetings for seasoned CS educators are few and often require long travel times, making them particularly prohibitive (Ni, 2011). Such limitations in access to on-going professional learning compelled us to examine how, when given the opportunity, CS educators approach and learn from PD aimed at supporting more seasoned computing teachers.

Key Features of PDs for Experienced CS Educators

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 CS educators. Computing teachers must remain abreast of a unique field that constantly reshapes itself with technological trends and breakthroughs (Cuny, 2015; Ericson, Armoni 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 who need 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 do not meet "the scholarly needs of CS educators" as well as computing-specific workshops could (Tenenberg & Fincher, 2007).

CS education researchers also suggest that PD activities engage computing teachers in a content-specific way (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, Frykholm 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, Frykholm et al., 2005). One fruitful method of blending together pedagogy and concepts in CS PD is the

Teacher-Learner-Observer model, in which teachers take turns leading selected lessons in front of the whole group in the "teacher" role, while other colleagues take on the roles of either learners or observers throughout a short lesson. After the lesson, the three groups reflect, debrief, and dialogue together on the effectiveness of instructional strategies used to teach the lesson (Margolis, Goode, & Chapman, 2014). Given that CS education is still emerging in scholarly literature on PDs, there is a need for further examination for how PDs extend CS educators' computing-specific pedagogical knowledge, increase teacher empathy for the perspectives of their students, and enhance teaching practices that best support learning.

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 also described how the need to resolve problems is often the impetus for people to develop a 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, 2012; Darling-Hammond & McLaughlin, 2011). Additionally, discussions with peers around problems have been found to be key in improving teaching (Elmore & Burney, 1999; Elmore, 1996), by helping educators access new perspectives, conceptualize, grow (Horn & Little, 2010), and ultimately develop instructional interventions that address those problems (Elmore & Burney, 1999; Elmore, 1996). 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 the field in which problem-solving systems are designed based on observations of human behavior (Wing, 2006). In one study of CS PDs, researchers examined college faculty "actively engaging in issues of mutual concern" from their computing classrooms, as they shared and evaluated one another's teaching portfolios. In their post-PD evaluation, participants responded that discussing "teaching issues" was "the most valuable" aspect of the experience (Tenenberg & Fincher, 2007). While this research is informative, it took place in a higher education setting. This calls for more investigation on how K-12 computing teachers can be provided the opportunity to examine and learn from problems, too.

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 (Goode, 2007; Ericson, Guzdial, & McKlin, 2014; Guzdial, 2014; Ni, 2011; Ni, Guzdial, Tew, Morrison, & Galanos, 2011; Ravitz et al., 2017; Schlager & Fusco, 2006; Stephenson et al., 2006). CS teachers often commune in "virtual learning communities" online because so few computing educators work in proximity (Tenenberg & Fincher, 2007). However, studies indicate that educators typically prefer the social and community interactions of "face-to-face" environments to professional learning 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 collaborate in PDs that emphasize a strong professional network and group identity (Fincher & Tenenberg, 2011). In 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 was something that computing teachers rarely experience (Ni, 2011; Ni et al., 2011). A recent study of the Exploring Computer Science PD program discovered 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 who participated in this study remarked that this collegial experience “had a great impact on my professional development.” Similarly, in an examination of the efficacy of a week-long PD program for in-service Advanced Placement CS teachers, researchers found that the bringing together of the participants to learn and work with like-minded teachers in “class meetings” - when participants discussed material and practiced applying new concepts hands-on – was the keystone of the program (Leyzberg & Moretti, 2017). 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 demonstrates that experienced CS educators seek professional opportunities to immerse themselves in subject-specific content, 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. 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.

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 (Margolis & Goode, 2016), a year-long elective class that was created to address a specific problem: the lack of racial and gender diversity in computing (Goode, Chapman, & Margolis 2012). The course welcomes students with no preparatory background in CS to experience an interactive sequence of curricular units including fundamental problem-solving activities to advanced computing and design projects. In the initial PDs to learn how to teach ECS, educators undergo two summers of 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, Margolis, & Chapman, 2014; Margolis, Goode, Chapman, & Ryoo, 2014).

In 2015, our research team authored an 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). The distinctive feature of e-textiles is the sewable, washable Arduino micro-computer 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, Eisenberg, & Elumeze, 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), that disrupts the racial and gender dynamics of the current maker movement, which remains dominated by the White, college-educated, middle-aged male prototype (Kafai, Fields, & Searle, 2014). Thus, e-textiles mirrored the ethos and objectives of the ECS course - to broaden the participation of under-represented diverse learners in computing - and incorporating it effectively as a curricular unit to teach computing was the foremost objective of our greater research team.

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 to learn the lessons themselves for the purpose of 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 ECS mailing list for "veteran" ECS teachers, educators who had completed ECS' 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, based on his knowledge of their diverse teaching styles, range of teaching experience, and different school settings.

Table 1: Study Participants.

Self-Identified Teacher Characteristics				School/Student Demographics									
							Student Race						
Teacher [1]	Gender Ethnicity (Race)	Yrs of Teaching	Yrs of Teaching ECS	Total # of Students	English Learners	Socioeconomically Disadvantaged	Afr. Am. /Black	Native Am.	Asian/ Pac. Isl.	White	Hisp./ Latino	2+ Races	Decline to State
Angela	Female Vietnamese (Asian)	11	3	1570	2.6%	89.4%	42.3%	0.2%	0.6%	0.6%	55.7%	0.1%	0.5%

[1] All names are pseudonyms.

Ben	Male Jewish (White)	6	2	4480	3.2%	53.7%	3.7%	0.2%	28.6%	26.1%	38.7%	1.4%	1.3%
Gail	Female Cambodian (Asian)	5	2	532	22.90%	91.70%	13.7%	0.4%	-	0.4%	85.3%	-	0.2%
Mahmud	Male Persian (Middle-Eastern)	17	4	2377	6.4%	59.1%	1.6%	0.5%	29.0%	10.8%	57.0%	1.2%	-
Sergio	Male Mexican (Hispanic)	18	5	2001	22.5%	94.7%	9.3%	0.2%	-	1.0%	89.2%	0.2%	-

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 participated in 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 the PDs they attended, and a complete set of materials and tools for implementing the e-textiles lessons in one ECS class 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 would later pioneer 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 that year, the other three planned to do so in Year 2, and the third year of the project scaled to 17 teachers.

Data Collection

We adopted a narrative inquiry approach (Clandinin, 2006) to learn what motivated these in-service educators to seek out PDs, what and how they learned in PDs. 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 viewed 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. All of the questions for the surveys were adapted from the post-PD surveys utilized by the ECS program to solicit feedback on their PD workshops. The 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).

Data Analysis

We used a general inductive approach for data analysis (Thomas, 2006), and this process was guided by our lens, the theory that transformative learning involves certain elements like the need to solve a disorienting dilemma, critical assessment of assumptions and traditions, self-examination, exploration of new options, acquisition of knowledge and skills, and reflection (Mezirow, 1981; 1994). The first author initially immersed herself in the interview transcripts and survey responses (Borkan, 1999) to inductively develop a spreadsheet that diagrammed an initial coding frame (Thomas, 2006). The framework was discussed and revised with the second author several times, then the codes were organized into broad themes to address our research questions (Jain & Ogden, 1999). The first author reread all data, highlighted excerpts, and applied the excerpts to the coding frame. Separately, the second author read the excerpts horizontally to group them by themes that emerged (Thomas, 2006), and those themes were compared and informed another revision of the framework. This rigorous, systematic, and iterative process of reading and coding enabled us to analyze data excerpts along several themes that were identified by our participants (Thomas, 2006), to bring forth only themes that were common across all data collection points (Gibson & Brown, 2009, p. 128-129), and to document relationships found between the themes (Thomas, 2006) to answer our research questions.

Results

This exploratory study sampled a small group of veteran ECS teachers that attended a specialized PD series, so we make no attempt to generalize to the greater population. But though educators held very different perspectives, life experiences, and diverse pedagogical approaches, we identified themes consistent among all of the participants. Our findings are organized into two parts to answer our research questions **(**What attracts CS teachers to PDs; What do they learn in PDs?). 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

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

our sample are, their motivations for attending these PDs, what aspects of PDs were helpful to them, what challenged them, and what they learned.

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 about this, all five stated that they were motivated to attend PDs to address problems they had encountered in their practice, that their decision to learn about e-textiles was deeply influenced by the need to develop solutions to these problems of practice from the classroom. Four themes of problems emerged from the pre- and post-PD interviews of our inquiry: 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.

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 students without prior knowledge, skills, or interest in CS or programming. Angela said her main challenge as a teacher is to "get kids in the door, whet their palates, and build interest that they can take further." To her, that meant making the class fun. She had herself been "very intimidated, afraid" of CS and technology 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.' Mahmud also said that his primary task as a teacher is to design fun activities for his students to engage in CS topics. Sergio wondered about how to 'get the students hooked on' computing projects, so that the resulting joy and interest will motivate them to want to learn more.

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 the African American boys in her class that express such fear and an attitude of *I can't*. She said: '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 teacher and administration turnover.' Gail was frustrated because 'there is no strategy for addressing these inequities and contributing to the community's growth mindset in CS education.' Ben talked about gender inequities he observed in his classroom, noting that "the men tend to dominate over their female counterparts" in his classes, and that "it's an uphill battle of trying to take away that dominance from the boys" especially in the programming units of ECS. This phenomenon also "rears its head" in group projects, even when Ben sets up "different systems that allow for equity within the groups." As a CS teacher, Ben believed: 'It's our job to bring the girls up and say: Hey, you know what? We are all equal in this room, we are all doing this together. You are not more important than anybody else because of who you were born as!'

Problem 3: How to encourage students to persist in problem-solving. Our teachers also wanted to learn new ways for encouraging their ECS students to persist in solving ambiguous, open-ended, complex problems. Some of Sergio's students displayed an attitude of: 'Tell me what you want me to do, give me my points.' Gail agreed that the 'ECS class represents new content, new structure, a new way of learning,' not the direct instruction that students are accustomed to in school, where they might have learned to strive for perfection, to answer correctly to questions. They seem to need validation after every step, but Gail wanted them to be autonomous in demonstrating their mastery of CS learning targets in creative ways. Mahmud watched his students 'just doing it to get by,' who were performing the bare minimum of work to pass the course. He wondered how to encourage deeper learning in his ECS classes and provide more opportunities for students to authentically engage with CS content.

Problem 4: How to incorporate hands-on learning into CS class. All of our teachers emphasized how CS should be taught through inquiry-based approaches, one of the three pedagogical principles of ECS. Gail wanted ECS students 'to learn computing content through *doing* something, rather than with textbooks and lessons and worksheets.' For Ben, this conversation led to him talking about his hope for e-textiles:

> 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.

Angela explained that 'it's a powerful thing when students make something and have ownership over it.' 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.' Ben hypothesized that e-textiles would elicit "more of an interaction and actual experience with the world," and that was why he was excited to attend these PD. Angela concurred that the emphasis on making artifacts in e-textiles was why she really wanted to do the PD.

Problems of practice drive teachers to professional learning. 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; rather, 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). Similarly, we noted that our teachers were not describing 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. Freire said that the need to resolve problems is the impetus for people to develop a critical awareness of the world, that the process of transforming one's perspective and personal paradigm begins with problem-posing (1973). 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.

RQ2: 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 with what they had set out to learn. In addition, our RQ2 findings (what teachers learned) could be framed as transformative experiences as well (**Table 2**). For example, when the teachers remarked on the new skills they acquired through PD, these always pertained to strategies for incorporating more hands-on activities in their computing class (Problem #4). The critical self-examination phase of transformative learning was always 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.

Table 2: CS Teachers' Problems of Practice and Transformative Learning in PD.

Transformative Phase [3]	Findings
Disorienting dilemma	● Teachers felt "lost," "terrified," "dysfunctional," "apprehensive" during PD activities ● Coming up with ideas, designing, storyboarding was difficult ● Teachers were impatient that their own learning took so much time ● Teachers worried about making mistakes ● Teachers' own project outcomes did not meet expectations ● Being "forced to" present work to others affected teacher confidence
Critical self-examination and assessment of assumptions	● Teachers recognized that they brought their own insecurities about programming, designing, crafting to PD ● Teachers acknowledged that their expectations of themselves were too high, project designs were too ambitious ● Teachers realized they didn't know as much/were not as skilled as they had previously thought ● Teachers assumed that colleagues would naturally help one another in PD ● Teachers wanted their artifacts to be models for students
New knowledge and skills acquired	● Teachers learned to program in Arduino, a "more approachable" text-based language ● Teachers experienced constructionism – seeing their designs come to life was "fun" and "engaging," making inspired sense of ownership to persist to completion ● Teachers explored human-computer interactions in new ways ● Informal chatter around the craft table foreshadowed issues that might arise with students ● Teachers learned to troubleshoot coding errors by checking the artifact for "off-the-screen," accurate feedback on what's working ● Students can inspire teachers' design ideas
Exploration of options (to better engage students in CS)	● Do the lessons in advance as learners, to increase empathy for student experience ● Storyboard in pseudo-code to walk students through the design process ● Build on prior ECS units and classroom practices, like modifying existing code ● Recognize that making meaningful artifacts takes time ● Use teacher-made artifacts in class as instructional tools ● Assign work in pairs, but be mindful about student group dynamics ● Differentiate activities, give a "basic" assignment but provide faster/more motivated learners extensions for further personalization of their projects

CS Teachers Narrate Their Learning in PD

[3] 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 are ones revealed through our data analysis.

The PDs 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 the 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 hand-crafted 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 to attend. 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!”

Figure 3: CS Teachers Interacting with the Touch Sensors on Their E-textiles Artifacts.

The artifacts represented hours of crafting time in the PDs (and between PDs, as the teachers also had homework to complete designs and crafting), and evidence of the satisfaction garnered from persisting in intellectually challenging activities (**Figure 2**). All of the teachers said they were most proud of making something that worked, i.e., their electronic components were programmed and functioned correctly. 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 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.'

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 that. 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 hand-crafted 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 the problem. 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, rather, 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.'

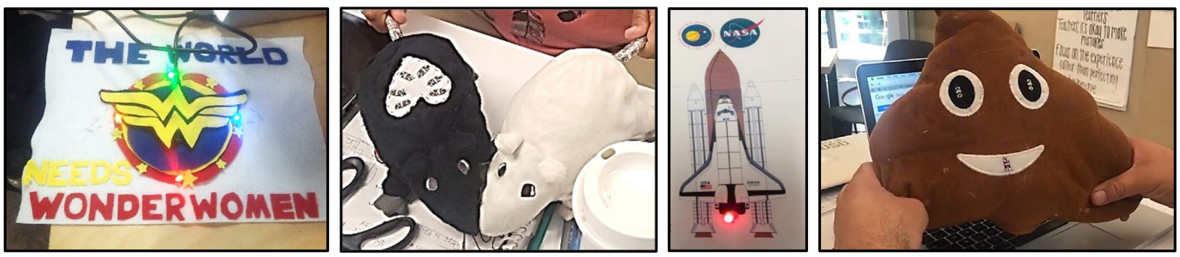
Making teaches CS concepts in a unique way. While the crafting activities were physically and intellectually engaging, the human-computer interaction was equally enthralling for these CS educators, i.e., building a relationship with their artifacts while they were making them. After completing his final 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, we create, we want to collect data first and then figure out what to do based upon the data that we collect. 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.

Students are on Teachers’ Minds During the PDs

Figure 3: Examples of E-Textiles Artifacts Created by Teachers in PD.



Teachers’ design ideas were inspired by students. Our participants often kept their “teacher hats” on, 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 phase of their projects when brainstorming ideas 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!” **Figure 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: "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.

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 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 to 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 were to complete 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 at her school. 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 pacing and differentiation 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 sit there exclaiming: "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 the 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. And 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. These reflections explored when and how student collaboration can be generative and productive, and when other instructional approaches would be more appropriate and supportive.

Sergio also 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.’

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” – writing or drawing how they wished their project to 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 sheets “felt good,” partially because this practice had been reinforced in prior units of ECS. The new e-textiles curriculum also provided starter code (modifiable working 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.

Transformative Learning to Support Teaching E-Textiles

These teachers' learning experiences highlight that for all the teachers, participating as a learner was exciting ("It's so cool!!"). New passions for making were developed, and creativity was harnessed in both the hand-crafted artifacts as well as in the teachers' minds. They simultaneously considered how to implement the e-textiles lessons into their own ECS classes as they experienced the lessons themselves as learners. The teachers anticipated how their students might behave and feel, mistakes that the students might make, while designing, crafting, and debugging their own projects. Rather than a myopic focus on acquiring new CS content knowledge, teachers demonstrated interest in 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. Such disorienting dilemmas often trigger reflection (Mezirow, 1991; 1994), as evidenced in these interviews. As the teachers examined their taken-for-granted social roles and expectations in the uncomfortable moments as learners (most often in interacting with their colleagues at the PDs), 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. But people are not going to drop everything they're doing'). Further exploration and discourse resulted when the interviewer asked the participants to reflect on 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.

Discussion

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 had committed to 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. But as PD participants, the educators explored different options for how to address problems encountered by their students, after experiencing the same challenges themselves in PD. 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 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 recognize that teachers can develop new truths and (we believe) pedagogies when our PDs and multiple points of data collection encouraged 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.

The Ongoing Process of Teacher Learning

We recognize 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 e-textiles PD and instruction on ECS students, as well as the e-textiles program and curriculum evaluation, are the foci of recent and upcoming publications cultivated from the longitudinal study (Fields, Kafai, Nakajima, & Goode, 2017; Fields, Kafai, Nakajima, Goode, & Margolis, 2018).

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 seek to learn, and the problems of practice they encounter in their classrooms, problems that the teachers feel they can solve pedagogically through their own professional growth. The teachers also narrated the powerful and transformative experience of participating in PDs that advanced their CS 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 how to support students when they implement the new e-textiles curriculum in their ECS classes. These perspectives gave special purpose to our participants' hand-crafted creations and their informal chats around the crafting table.

While these findings echo prior research on the positive effects of making in general and e-textiles specifically, this study revealed how the PDs were experienced and narrated by educators, rather than framing our study around student outcomes. This study is also novel in examining the preparation of classroom teachers to instruct e-textiles lessons alone, rather than with outside researchers or makerspace educators serving as "instructors" in specialized learning spaces. The findings from this study cast a light on how to support teacher preparation as e-textiles moves from makerspaces and into CS classrooms with diverse groups of students.

As nations and regions integrate computing in schools, 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 these teachers in the field is key. Our narrative study revealed 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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