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Supporting and Sustaining Equitable STEAM Activities in High School Classrooms: Understanding Computer Science Teachers' Needs and Practices When Implementing an E-Textiles Curriculum to Forge Connections across Communities

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Abstract: While the last two decades have seen an increased interest in STEAM (science, technology, engineering, arts, and mathematics) in K-12 schools, few efforts have focused on the teachers and teaching practices necessary to support these interventions. Even fewer have considered the important work that teachers carry out not just inside classrooms but beyond the classroom walls to sustain such STEAM implementation efforts, from interacting with administrators to recruiting students and persuading parents about the importance of arts and computer science. In order to understand teachers' needs and practices regarding STEAM implementation, in this paper, we focus on eight experienced computer science teachers' reflections on implementing a STEAM unit using electronic textiles, which combine crafting, circuit design, and coding so as to make wearable artifacts. We use a broad lens to examine the practices high school teachers employed not only in their classrooms but also in their schools and communities to keep these equitable learning opportunities going, from communicating with other teachers and admins to building a computer science (CS) teacher community across district and state lines. We also analyzed these reflections to understand teachers' own social and emotional needs—needs important to staying in the field of CS education—better, as they are relevant to engaging with learning new content, applying new pedagogical skills, and obtaining materials and endorsements from their organizations to bring STEAM into their classrooms. In the discussion, we contemplate what teachers' reported practices and needs say about supporting and sustaining equitable STEAM in classrooms.

Keywords: computer science education; teacher education; STEAM; STEM education; e-textiles; connected learning; schools; makerspaces; equity

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1. Introduction

The last two decades have seen increased interest in STEAM (Science, Technology, Engineering, Arts, and Mathematics) activities in K-12 education, promoted through several efforts [1]. For one, government-driven incentives have placed STEAM as part of a larger national effort to maintain national and global competitiveness [2–4]. In conjunction with this effort, a number of initiatives have led to the implementation of makerspaces and activities in schools, with both implicit and explicit prioritization of technological sophistication in interest-driven projects [5,6]. Likewise, the introduction of computing education into K-12 education has expanded STEAM efforts to include computer science education next to science and mathematics activities [7]. A growing aggregation of research has demonstrated that through the integration of the arts within STEM disciplines, many students successfully broaden their perceptions of and attitudes toward STEM while learning critical digital and disciplinary concepts and practices [8]. In other words, efforts to increase access to STEAM are having a positive effect on students.

Much less attention has been paid to the efforts of K-12 teachers implementing STEAM activities in their classrooms and schools [9]. A major recognized challenge in implementing STEAM has been the disciplinary boundary crossing from teachers' home disciplines to new disciplines, i.e., learning enough about art as a science teacher or enough computer science as an art teacher to lead an authentic, interdisciplinary STEAM unit [10]. Teachers need to learn specific knowledge and pedagogy in both STEM and arts domains as well as skills essential to teaching STEAM in an authentically integrated manner [11,12]. These interdisciplinary boundary crossings are especially challenging since existing teacher professional communities are based on discipline (i.e., math teacher communities, science teacher communities, etc.)—where teachers get ideas, exchange lessons, share resources, and provide emotional and social support to one another—and this may not be able to provide the kind of professional connections that are key to supporting and sustaining STEAM interventions both initially and over time. This may be particularly challenging for computer science (CS) teachers since computing is a recent addition to the K-12 curriculum, and CS teachers face particular challenges, including a general lack of available community via the normal venues of school departments and district support. Indeed, there is often only one teacher within a school or even a district teaching CS [13]. Furthermore, CS is currently the least equitable and diverse school discipline [14], often requiring that teachers engage in the recruitment and retention of marginalized students, disrupt societal stereotypes about who belongs in computing classes, and reach out to school leaders to argue for resources and even to explain what CS is (i.e., that is it far different from word processing or slideshow presentations, as many principals assume to be the case [14]). All of this lands on top of the challenges teachers face day to day within their normal disciplinary teaching, especially since the COVID-19 pandemic began in 2020, which added additional stresses to teachers and increased documented retention issues [15,16].

In this paper, we report on the efforts of experienced high school computer science teachers to implement a STEAM curricular unit in their classrooms. Our sample of eight teachers worked in different high schools across rural, urban, and suburban contexts in four different states. The teachers were part of the *Exploring Computer Science* (ECS) program, which introduces high school (e.g., grades 9–12) students to key computer science concepts and activities through a year-long curriculum [17,18], with a relatively new electronic textiles unit as an option at the end of the school year. Electronic textiles (e-textiles hereafter) present a compelling case of a STEAM activity because of the integration of crafts, engineering, and programming amongst projects that center on personal and creative expression through aesthetic-driven design [19,20]. Teachers participated in nine days of e-textiles professional development and in teacher-initiated "buddy groups" during their implementation of the ECS e-textiles unit in their classes. Drawing on hour-long interviews conducted after the teachers finished implementing the e-textiles unit, we examined these teachers' reflections on implementing an e-textiles unit in their computer science classes for the first time, examining the connective practices teachers employed not only in the classroom but in their schools and broader communities at large to build equity in sustainable ways for students. We also consider what these reflections disclose about teachers' own social and emotional needs as they engage with the continuing challenges of teaching while learning new content and pedagogical skills to bring STEAM into their teaching environments. In the discussion, we contemplate what teachers' practices and needs say about implementing STEAM more broadly and how to widen our lens on how to sustain STEAM work in classrooms.

1.1. Building Connections within and beyond Classrooms

We situate our research on supporting and sustaining STEAM teacher needs and practices within the specific context of K-12 computer science education. Like STEAM teachers, CS teachers need to be concerned with promoting equity [14] and integrating disciplinary knowledge [13,21] when successfully implementing, supporting, and sustaining STEAM activities within their classrooms. However, simply using arts activities to attract students into STEM or CS, which is what Mejias and colleagues [1] call a "one-sided instrumental and pedagogical approach", is not enough. The focus must be on supporting students' unique strengths, promoting student achievement, and bolstering students' sense of well-being and belonging in the world while building community within the classroom and beyond [22]. In the context of STEAM activities, teachers also need to make additional connections with new content, such as the arts [8] and other disciplines, which have not been part of their prior professional development and teaching practices. For instance, Bevan and colleagues [8] provide a clear explanation of some of the motivations behind and the opportunities for integrating arts and design alongside science, technology, engineering, and mathematics. They highlight the important art practices of active engagement in the process of learning, personal connection to the work, and creating projects of value to a larger community. Likewise, Matuk and colleagues [23] pointed out difficulties in implementing STEAM through data-art inquiry within the more traditionally established disciplines of math and art. Constraints revolved mostly around curriculum flexibility: "constraints around cross-subject integration, including subject-specific differences in curriculum flexibility, accountability, and instructional time, and administration-level priorities on interdisciplinary instruction". (p. 17). In other words, beyond just learning new disciplinary content, teachers have to figure out within- and beyond-classroom challenges, such as administrative hurdles, when implementing disciplinary-crossing curricula.

Thus, a critical challenge for both CS and STEAM educators is found in building communities in and beyond classrooms to support and sustain such equity- and inquiry-driven work. These disciplinary- and boundary-crossing communities, built through creating "connections between spaces for learning" through the arts and STEM, emphasize "networks and connections" for teachers and students alike [21,24]. Arguing for culturally responsive computing approaches that would support such equity-driven work, Scott, Sheridan, and Clarke [25] suggest attending to how computing teachers construct social relations in their classes, that is, how computing teachers engage with their students and broker a peer culture in which students feel connected to one another and their communities through shared digital and technological expertise and literacies. STEAM may provide a productive means of supporting such connectedness in computing. For instance, Bevan and colleagues [8] highlight the important art practices of active engagement in the process of learning, a personal connection to the work, and creating projects of value to a larger community (p. 24). Similarly, Tucker-Raymond and Gravel [26] argue that core STEM literacies include communicating with others "for help and feedback" during making as well as about making processes and products (p. 35). The underlying social practices of giving and receiving help, showing processes, and communicating the value and/or expressiveness of created products foster connections within classrooms.

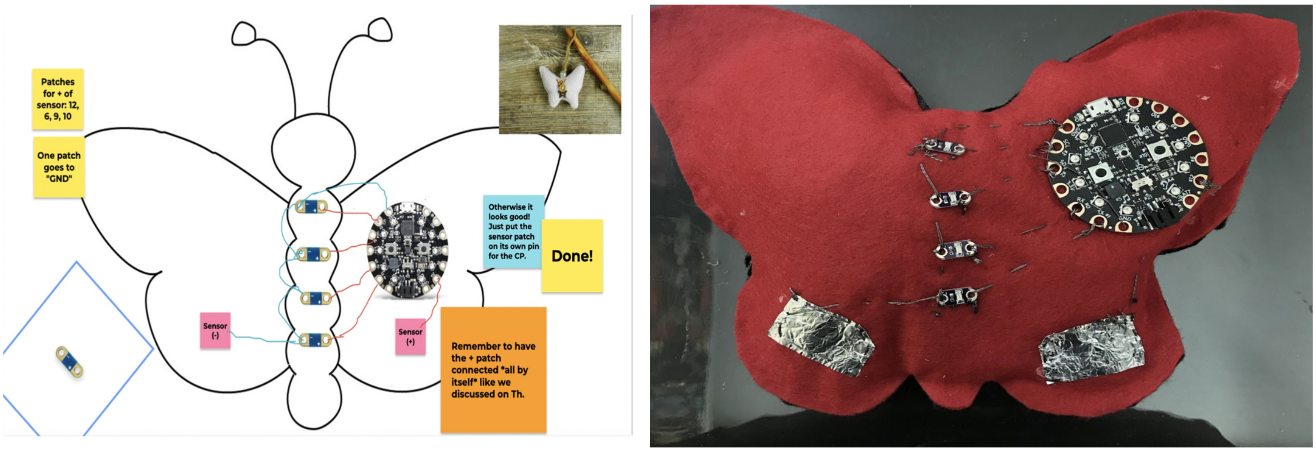
Furthermore, often, teachers and students are siloed in a classroom, isolated by the architecture of school buildings as well as by time and rule structures that discourage crossing rooms (i.e., students not allowed in a class for which they are not registered). For instance, Penuel and colleagues [27] observed the differences in teacher social networks and connections in two school communities that explained varied levels of success of curriculum implementations. Teachers are often further isolated by discipline and role: by discipline, in that meetings largely take place within departments (i.e., within math, career and technical education, art, etc.) and by role, in that teachers have different roles than administrative staff or students, effectively isolating each group because of differing responsibilities, spaces of occupation, and times of availability. Research on teacher community and social capital has shown its importance for teacher growth, retention, and development [28]. Yet such literature has largely considered school organizational supports (or the lack thereof) as scaffolds for community-building supports that are even more absent for CS teachers than for teachers in many other disciplines. Indeed, in a recent nationwide study of CS teachers in the United States, the most reported challenge by CS teachers is "lack of school buy-in" [15]: many CS teachers are not only siloed within a school, but they also lack support from school leadership for their discipline.

Finally, in order to sustain successful, equitable STEAM activities, teachers also have to attend to their professional needs for connection and community. Effective CS and STEAM teaching requires connections to professional communities, which situate subject-specific teacher learning within *communal* contexts [29,30]. This need for community is tremendous for CS educators, as many report feeling isolated because they have no professional colleagues in the same subject area at their schools [31–37]. Further, intensive, sustained, and cohesive professional development (PD) opportunities that are longer in duration have demonstrated shifts in teacher practices that, in turn, support improved student learning [38,39]. Empirical studies reveal that when long-term PD experiences are characterized by active teacher learning and collective participation, there is a moderately positive effect on student achievement [40]. Further, as teachers begin to apply PD learning to their own classroom spaces, ongoing instructional support from experts can help teachers overcome perceived barriers to implementation, including a lack of time for preparation, limited materials, and the availability of local CS teacher colleagues [36,41]. Yadav and Korb [41] pointed out the pressing need to provide in-service CS teachers with opportunities for in-depth and continual professional learning so that they can continue to teach rigorous and rich computing classes infused with advanced concepts. PD that specifically addresses the needs of experienced computing teachers is sporadically offered, and face-to-face meetings are few and often require long travel times, making them particularly prohibitive for seasoned CS educators working full-time [35]. While some of these challenges are particular to the K-12 CS teacher community, we can assume that these challenges are also prominent for teachers involved in STEAM activities for which there does not exist a longstanding professional community.

1.2. This Study

In the context of our study, we addressed these challenges by working with experienced high school CS teachers and building on their histories in dealing with equity issues in the field while introducing them to new STEAM activities in their classrooms. All of the teachers taught and facilitated *Exploring Computer Science* (hereafter ECS), a year-long curriculum specifically developed to challenge the persisting underrepresentation of girls and students of color in computing, as well as the systemic and political barriers that continue to exist in computer science education [42]. In ECS, students learn through inquiry and project-based activities and develop a repertoire of computational practices [17,18], which connect computing with students' everyday experiences [25]. There has been a significant positive impact on engagement, future interest, confidence, and persistence for students learning in ECS classrooms [17,43]. ECS is not just a curriculum; it is a national community of teachers who have engaged in at least two years of professional development (PD) that emphasizes equity, inquiry, and CS content, models pedagogical strategies of active engagement, and directly addresses teacher belief systems through critical reading and reflection [42]. The latter explicitly engages teachers in unpacking systemic issues that have contributed to the inequities in representation in CS. Having participated in the two-year ECS professional development and having implemented ECS for at least three years in public high schools around the country, the teachers were already well-steeped in "a culture of ongoing community learning and reflection" [42] (p. 496). This particular group of teachers was also working as facilitators of ECS; they helped create that very community through local and online PDs with other teachers. Still, these teachers had little prior experience with STEAM.

While our teacher cohort was experienced in teaching computer science with equity- and inquiry-driven mindsets and methods from ECS, they were new to learning aesthetically driven physical computing with e-textiles. The design and development of a new ECS curriculum unit using electronic textiles (hereafter e-textiles), intended as a substitute for the ECS robotics unit at the end of the school year, provides a compelling illustration of a STEAM activity that integrates computer science with engineering and the arts [44]. Regarding e-textiles, students sew lights and sensors onto fabric with conductive thread, connecting them to programmable microcontrollers (see Figure 1). Materials, such as needles, thread, and fabric, rupture any traditionally gendered notions about who can create with electronics and computing [45,46]. At the same time, e-textiles engages students in challenging computing concepts, using switches and sensors as inputs to drive conditional lighting patterns [20]. In other words, e-textiles are expressive not just in a static visual appearance but through interactive, aesthetically driven programming embodied in crafted circuitry and computing [47].



(**a**) (**b**)

Figure 1. ECS teacher Hope's final project in the e-textiles professional development: Hope: "My final project is a butterfly pillow with four sensors. By pressing on the bottom sections of the butterfly, lights will come on. The number of lights will depend on the amount of pressure applied". (**a**) Circuit diagram with annotations; (**b**) picture of final creation.

Prior research on student engagement in the 10–12-week ECS e-textiles unit has demonstrated significant gains in student interest and their sense of capability in CS [48]. Further, the thoughtful integration of arts and CS may be a particularly good way to support connectedness among students as they express themselves in their creations, seek help from each other, and reflect on their set of creations [47,49,50]. We know from other teachers having implemented the ECS e-textiles unit in their high school classrooms that the teachers were attentive to legitimizing student expertise by featuring their e-textile project designs and engaging students in peer pedagogy while also supporting the personalization of their projects [44]. They made many curricular adaptations, such as adding journal prompts for students to reflect on their designs, circuits, and code, or recorded additional sessions while skipping other sessions entirely to meet student needs in completing their projects [51]. They also fostered connections with other teachers outside their classrooms and with student families at home, often engaging families' craft experiences [52]. In this study, we look specifically at the practices of social connection that the teachers employed within and beyond their classrooms, oriented by the following research questions: (1) In what community-building practices do ECS teachers engage so as to promote equity and access with the e-textiles curriculum? In what ways do these practices connect within and beyond the classroom walls? and, (2) What needs do ECS teachers face in implementing the e-textiles curriculum? In what ways do these needs stretch beyond the classroom walls?

2. Materials and Methods

2.1. E-Textiles Unit and Online PD

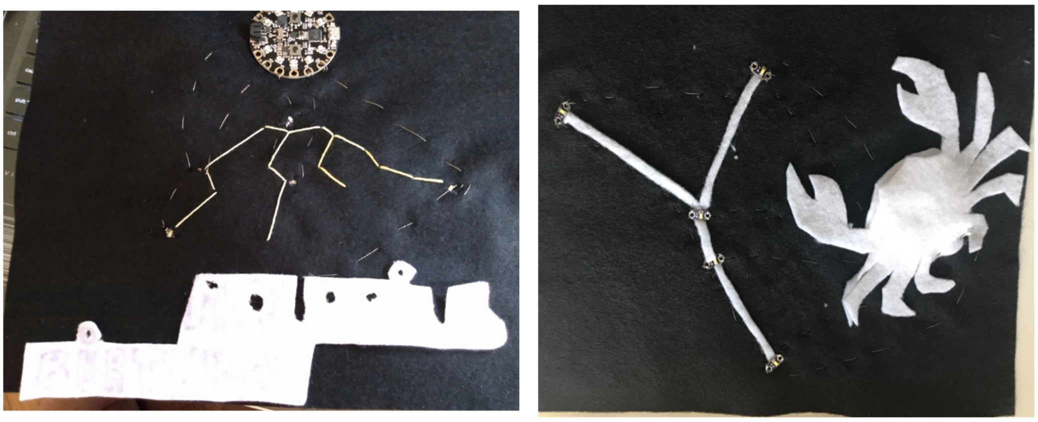
As part of a larger design-based implementation research study [53], our goal was to develop and revise an online professional development for the ECS e-textiles unit with experienced ECS teachers, study their implementation of the unit, and support ECS teachers in becoming facilitators for future PD with the e-textiles unit. Building on the model of ECS, PD included nine days of professional development—five days in Summer 2021 and four days during "quarterly" sessions across Fall 2021 and Spring 2022—with the intention to repeat participation in the following year, using the two-year, nine-days a year ECS model [42]. All PD sessions took place over Zoom, with teachers attending from home or their classrooms, often with children, pets, and family members popping into view (or intentionally participating).

The ECS e-textiles curricular unit centers on a series of four increasingly complex projects that foreground aesthetics and personal expression while introducing challenging concepts in coding, circuitry, and crafting [44,54]. Figures 2–4 show the first three projects of the curriculum, as completed by teachers, while Figure 1 shows an example of the fourth and final project. During the nine days of PD, teachers engaged as learners of the e-textiles unit, creating each project in a manner that students would, with journal entry reflections (e.g., "Take a picture of something you had to fix or change—indicate what & where you made the changes") as well as collaboration (exchanging ideas and reflections with other learners), circuit diagrams critiqued by the lead facilitators, coding, and of course, final reflections. In addition, setting aside times allowed for "teacher hat" reflections where the teachers would consider what they might have to do in their classrooms: accommodations for a variety of students, materials management, classroom management, challenging topics that might need extra support, etc.

(**a**) (**b**)

Figure 2. The first project of the e-textiles unit: paper circuits: (**a**) Megan's rainbow heart card; (**b**) Mary's rainbow mood lamp.

Figure 3. The second project of the e-textiles unit: wristbands: Gabby's "Among Us" wristband.



(**a**) (**b**)

Figure 4. The third project of the e-textiles unit: a collaborative mural with a microcontroller that co-ordinates multiple lighting patterns based on input from two switches. Teachers worked in pairs on mural projects, in this case, on their zodiac constellations. (**a**) Lisa's Aquarius constellation; (**b**) Hope's Cancer constellation.

All the e-textiles projects are interest-driven, with ample room for creative expression within specific design constraints. This combination allows content learning while sharing something about oneself with viewers of one's e-textile project. As an example, Figure 1 shows Hope's design and creation of the fourth and final project. Using the required two aluminum foil patches as a sensor, she created a butterfly pillow that, when squeezed, begins different lighting patterns depending on how hard the user squeezes the foil patches. Her circuit design (Figure 1a) has some facilitator comments on orange and blue squares. She also reflected and documented mistakes during the project, for instance, explaining why she had to resew two lights and how she had to adapt her code to make the sensors work better. Hope documented these reflections in a digital portfolio, just as students do in the unit. Yet as a teacher, she continuously reflected on how her own personal experiences shaped her thinking about implementing this unit with her own students.

The e-textile unit contains similar levels of computational complexity as the existing ECS unit on robotics but provides substantially more room for students' personal and creative expression in designing, crafting, and coding computational artifacts. Pilot implementations of the e-textile unit have demonstrated that ECS teachers used equitable practices such as modeling mistakes, legitimizing student expertise, and promoting connected learning in their public school classrooms [44,51,52]. Studies have demonstrated that students express their personalities and build identities as collaborative CS creators in their e-textiles projects as well as in portfolios about their projects [50] and that community building happens amongst students in class, especially during moments of debugging [49]. However, these prior studies focused on the implementation of e-textiles in individual classrooms with little attention to broader issues that teachers may face, the learning they engage in, or practices they use that go outside of the classroom.

2.2. Participant Demographics

This study focuses on the first cohort of ECS teachers to participate in the online e-textiles PD (2021–2022) and implement the e-textiles unit in Spring 2022. One of the directors of ECS recruited the eight teachers from amongst the experienced ECS facilitators: all eight teachers had at least a year of facilitating ECS in addition to having completed the initial two-year ECS professional development. We intentionally chose experienced ECS facilitators for the first year of online e-textiles PD because of the inherent challenges of teaching learners to sew, design circuits, and code only online and in order to provide the best possible scenario for input on revising the online PD for a broader range of CS teachers in later years. Teachers were selected from four geographical areas so that each teacher would have at least one person they could connect with in the same state and time zone. They worked in public high schools (grades 9–12) from a range of different localities, from deep within one of the largest cities in the United States, to remote rural areas, to suburbs of other large cities. Table 1 shows the teachers' self-identification of gender, race, and ethnicity (using their words, not categories that we pre-selected); years of teaching experience (in general, in CS, and in ECS); broad descriptions of the teachers' school demographics; and the classes in which teachers implemented the e-textiles unit. Given trends of vast underrepresentation in CS education in the United States (for instance, of people of color and communities in rural areas) [13] and trends of representation amongst CS teachers themselves [55] it is important to recognize the diversity of the teachers in our study in terms of gender, race, ethnicity, teaching experience, and high school context (e.g., rural, urban, diversity of student body). Of note, we provided each teacher with enough materials to implement the entire four-project e-textiles unit with 20 students in one class. Several teachers found ways to add to the supplies and chose to implement the e-textiles unit in multiple classes, including not just ECS classes but also other computing courses where they felt using e-textiles would serve the students.

Table 1. Teacher demographics and school information.

Teacher (Pseudonym)	Gender, Race, Ethnicity	Years Teaching (Years Teaching CS, Years Teaching ECS)	High School Description (Grades 9–12)	Classes Implementing E-Textiles Unit
Hope	Female, Black, African American	10 (5 CS, 5 ECS)	Midwest metropolis, public school: 25.1% Black, 24.4% Latino, 16.7% Asian, 29.3% White. ECS is a graduation requirement.	ECS, AP CS Principles
Jackie	Female, White, European	28 (21 CS, 7 ECS)	Large Midwest city, suburban public school: 75.8% White, 6% Hispanic, 5.3% Asian, 5.5% Black, 7.3% Multiethnic. ECS can meet a one-semester CS graduation requirement.	ECS (2), AP CS Principles (2)
Megan	Female, White, European	26 (26 CS, 7 ECS)	Large Midwest city, suburban public school: 60% White, 22% Black, 12% Hispanic/Latino, 9% Asian, 9% Multi-Ethnic, 1% American Indian/Alaska Native. ECS is an elective.	ECS, AP Computer Science Principles
Mary	Female, White, European, Jewish	10 (10 CS, 7 ECS)	Large Northeastern city, suburban public school, 96% White, 4% Black, 14% Hispanic. ECS is an elective in math.	ECS, Cybersecurity, AP Computer Science A, AP Computer Science Principles
Gabby	Female, White, Puerto Rican, Hispanic	8 (8 CS, 7 ECS)	Midwest metropolis, public school: 25.1% Black, 24.4% Latino, 16.7% Asian, 29.3% White. ECS is a graduation requirement.	AP CS Principles
Rachel	Female, White, European	20 (19 CS, 7 ECS)	Large Northeastern city, suburban public school: 66% White, 16% Black, 7% Asian, 7% Hispanic, 4% Multiethnic ECS is an elective in math.	CS Honors
Craig	Male, Black, African-American	3 (3 CS, 3 ECS)	Small Southeastern city, public school, 90% Black, 8% Hispanic, 1% White, 1% American Indian or Multiethnic or Asian ECS is an elective in math.	ECS (1)
Brandy	Female, Black, African American	22 including community college (5 CS, 3 ECS)	Small Southeastern town, rural public school (47% Black, 43% White, 10% other. ECS is an elective in CTE.	ECS (2)

2.3. Data Collection and Analysis

Our data collection focused on hour-long, semi-structured interviews conducted and recorded over Zoom video chat after teachers finished their first year of implementing the e-textiles unit in their classes. The interviews were co-developed with the broader research team and included five topics about implementing the e-textiles unit (including challenges, victories, stories, and advice for future teachers), takeaways from PD after several months' distance, highlights of "community" (a theme emergent from many PD discussions), broad questions about the teachers' journey over the past year, and hopes for the following year of PD and implementation. At the end of each interview, teachers were asked if they had anything else they wanted to mention or any questions they had. The first author conducted all interviews in June 2022, initiating a conversational tone that allowed teachers to bring up new topics, change topics, show their own or students' projects, ask questions, and share anything they felt relevant. The research team corrected and edited the automated Zoom transcripts for accuracy.

Data analysis followed a two-step open coding approach built on grounded theory [56]. First, we analyzed all interviews with open coding, identifying broad categories about community, connections across community, arts and creativity, equity, and "other" as a catch-all for anything that stood out as interesting. Then as a research team, we evaluated the entirety of quotes in each category and, in an axial coding process, considered meaning within and between the categories of codes. Following this, we created a second coding scheme that focused closely on types of connections between communities (within classrooms, within the school, outside of school, and across professional networks), creating a thesaurus of definitions and examples. At this stage, we member-checked the initial findings with two of the teachers and a senior ECS leader, as well as a PD designer. Finally, we conducted a full second sweep of interviews and then counted for frequency (number of instances) and spread (number of teachers) for each code. Appendix A contains the final coding scheme with counts, definitions, and examples.

3. Results

3.1. Supporting STEAM-Empowered Connectedness

In this first section, we share the many types of connections that took place as students and teachers created, shared, and welcomed others into their STEAM activities inside and beyond their classrooms.

3.1.1. Creating a Within-Class Community

Across classes, teachers created supportive, collaborative environments through the physical structure of the class, regular co-operative practices, and classroom management styles that permitted students' casual conversation and expression of achievement or frustration over making e-textiles. Structurally, the teachers often grouped students together at tables with shared supplies, encouraging sharing and the visibility of their projects. Teachers allowed and even encouraged students to talk at their tables and to get up and help others around the room. Brandy described a repeating phenomenon where students would finish a light or some code: "They were so proud of themselves to the point where they were just standing up: 'I did it! I did it!' and they were so excited". These audible exclamations over successes helped create community as much as the audible frustrations over challenges [49]. Community building continued while making e-textiles. As Jackie explained, "[B]ecause they're so engaged and doing their design, there's enough time and space ... [to] have a conversation". With everyone making similar projects and with mistakes that were visible or audible (by exclamations of frustration), student-to-student connections occurred frequently.

Some teachers directly supported student connections by creating a community of support for struggling students. For instance, Hope described,

> "[O]ne of my students, who um he's a diverse learner, so he struggled, and he was somewhat overwhelmed ... We rallied around him, and just helping him

> distract from like those small things and still building up his confidence around the other things that were important".

This is just one example of how a teacher helped unite the classroom around a student who struggled with discouragement at some of the challenges in making e-textiles. Indeed, many of the teachers explicitly mentioned how students struggling with neurodiversity or behavioral challenges thrived during the e-textiles unit, even when faced with the various difficulties of crafting and coding lights. Megan described how one student, who often missed class before, "wanted to dive right in and like look to see what other people were doing, and like was very excited to join in". These examples illustrate just some of the ways that the classes became spaces that invited connections and supported community in the class.

Just as they supported student-to-student relations through a suite of classroom practices, teachers also smoothed the way for their own connections with students. One common practice involved sharing their own e-textiles projects (including their mistakes) in class, sometimes even before starting the e-textile unit:

> "[E]very time I will finish the projects, I would take them to class. I mean right before quarterly [PD] ... well I'm taking it to school and I've already shown my students and we've already talked ... about those projects and I have them in my classroom".
>
> (Brandy)

By sharing her projects early, she built suspense and excitement and gave students a window into the teacher's own struggles and process of making e-textiles [44]. Hope used her projects to start discussions about what students could make, helping some students who struggled to come up with ideas while intentionally encouraging the class to come up with new ideas. Showing their projects felt like a natural way to set norms for valuing the processes and mistakes of creating personally expressive artifacts while connecting with students.

In addition, teachers learned more about their students from overhearing and participating in conversations in the sewing circles. As Brandy explained,

> "I'm able to, you know, to connect with them [the students]. While we were sitting there and they were all sewing ... we would start talking about just everyday things, while they were working on their projects. yeah, and so it became like a personal time to—although you're doing your work we're still just communicating not about school or the lesson, but on a personal level".

These "sewing circle" conversations stood out to the teachers, who, throughout the year, worked to create a collaborative environment with practices learned in ECS PD. "[A]lthough ECS has a lot of collaboration, the collaboration is more [with] e-textiles", explained Brandy. This collection of collaborative practices supported connections between students' and teachers' everyday lives within the school setting, staying on task with disciplinary work while at the same time having casual, personal conversations.

Even amongst these highly experienced teacher-leaders of the ECS community, within-class connections stood out to the teachers who implemented e-textiles for the first time.

3.1.2. Developing Beyond-Class Connections

Outside of class, teacher practices smoothed the way for connections as both the people and STEAM objects traversed across the boundaries of the classroom walls, hallways, and disciplines. One way that teachers encouraged this was by posting students' projects on classroom walls and in hallways:

> "You should see kids' work on the wall and in high school you don't do that very often ... in computer science we don't do that as much ...

I put [the wristbands] into like a little quilt pattern mural and I took a picture of it and students said, 'Can you send that to us?' And I have never had a student ask me to send something from class to them" (Jackie).

Displaying students' work created a connective opportunity Jackie had not experienced in 20+ years of teaching, allowing students to share it even more broadly through a photo of the display. In Megan's class, the students had their projects on display so much that she found herself recharging the batteries daily because students "wanted them to be on like all day as people came in". Displays featuring students' expressive work supported connections beyond classroom walls.

In addition to STEAM displays, teachers allowed e-textile artifacts to leave class, with many students requesting to take their e-textiles projects to lunch or other areas in order to continue working on them or just to show them off. Gabby explained how this happened in her school:

> "[S]ome of the kids . . . begged me if they could take [their e-textiles projects] to lunch, to finish it and I said, 'Sure why not.' They started going around the school spreading the word, 'Oh look what I'm doing,'... and [the other students] they're like, 'Are you sure you're [in] computer science?' . . . I had kids that I did not know come into my classroom just to see what they were doing . . . They're like 'Oh I'm so and so, I'm gonna, I'm thinking about taking your class next year,' . . . Yeah my numbers [for next year] doubled from two classes, now to four".

Mary had a similar experience where her students begged to sneak other students into class to see the e-textile projects:

> "[T]his is a pretty strict school, you're not really supposed to be not where you're supposed to be in the school. But kids will, like, try to sneak in and see their friends' [e-textiles] projects. Then they want to show it to them too . . . , 'Come in and see, come in and see my project' like 'I made this wristband that myself.' And then they run, get [the project], like, from the bins so that they can show it to their friends, because they know their friend can't stay".

With students themselves spreading their excitement about making e-textiles, both Gabby and Mary saw enrollment in their AP Computer Science Principles courses (where they implemented the e-textile unit) double. The teachers' willingness to let students and projects move outside the classroom enabled students to circulate their own creations. It also encouraged new narratives about CS to spread, as surprised peers literally ran to see the desirable objects their friends were making. In CS, where teachers often take on the burden of recruiting students and changing narratives about the discipline to make it more accessible [13,57], these movements enabled student self-advocacy of their own CS STEAM work, with discernible outcomes among their peers.

3.1.3. Expanding to Broader School Community

Just as students crossed the within-school boundaries to connect with others, the teachers also traversed the school to connect with other adults in the school, with tangible benefits for sustaining STEAM endeavors. Sometimes, this was as simple as welcoming curious colleagues into the classroom to see what was happening. Other times, the teachers leveraged students' personally expressive CS artifacts to draw in colleagues. Craig used displays of student work to draw the attention of colleagues and administrators:

> "People can walk by and see what we got going on, so really the student body, because, like I say they pass, and the administration everybody can kind of see what we got going on".

Not just displays but open doors enticed other teachers and even some administrators to curiously inquire about STEAM activities in class. Hope recounted an incident where an open door to her classroom drew in an administrator/coach not only to look more closely but to participate in making a STEAM e-textile himself:

> "[O]ur business manager happened to walk by, and he was like 'Ms. [Smith], what are you guys doing?' and I'm like, 'We're doing a circuit,' and he was like 'A circuit?'... And he was like, 'You mind if I sit in?, 'and I'm like, 'Come on in'. And he sits down and he literally go, step by step, and actually the students are helping *him* create the circuit... I said [to one student], 'Go sit by Coach and help him out.' And so, he literally sat there the whole period and created his circuit, and he was so *pleased* to create that, and literally took it with him and I said, 'You go and you show that to everybody you see, let them know the cool things that we're doing here'".

Not only did the business manager sit down in this class, he later came back to a different class and helped the students with their circuits. A few weeks later, he also approved her supplies and space allocation for the makerspace she was seeking to create. This points to the importance of social capital for teachers' efforts to build equity in CS through STEAM [27] because the relationships within schools are essential to teachers' ability to obtain the supplies, space, time, and institutional legitimacy necessary to support and sustain STEAM interventions.

Some teachers also promoted social connections to support their peers' social and emotional needs to sustain their teaching. For instance, Megan pulled other teachers into her class to encourage her colleagues at the end of a challenging year during the continuing COVID-19 pandemic (Spring 2022). This particular semester, Megan had a group of students who had a reputation in the school for being more "rough", and whom she usually had to supervise constantly. Yet, during the e-textiles unit, Megan found that these students engaged deeply in making the STEAM artifacts, and she could get across the hallway to bring teachers to see her class and coax them to see what the students were doing.

> "[U]sing these kinds of things to show other teachers that like you can have fun and be productive in a classroom. Like it doesn't have to be a grind all the time. We used to just get that, naturally, and I think that people have just got so worn down with so many things on them that, as it starts to become a grind and you lose the fun".

In these ways, Megan, Craig, and the other teachers opened up their STEAM classrooms to build social capital with other staff at their schools. Not only does this demonstrate the teachers' activism to sustain their STEAM interventions through supplies and leadership buy-in, but it also hints at the importance of sustaining STEAM by supporting teachers' social and emotional connections with others.

3.2. Sustaining STEAM through Teachers' Social and Emotional Connections

In this second section, we turn our attention to how the CS teachers built a community with other teachers through PD, connected with friends and family through their STEAM projects, and, in general, developed a stronger connection with the larger professional CS teacher community.

3.2.1. Building Teacher Professional Community through STEAM

All the teachers spoke about connecting with each other through the process of making their STEAM artifacts, complete with mistakes and frustrations as they learned new skills. Being learners—making new projects and learning new disciplinary content (e.g., coding in Arduino, sewing circuitry, designing crafts, etc.)—while sharing mistakes through the entire process was a core part of building this sense of connection. For example, Craig expressed how challenged he was by sewing and how he "messed up a lot of times". Yet those were the moments he remembered the most, in part because he was surrounded by the other teachers and facilitators who gave each other "good energy" and who helped him in his sewing. These social connections primarily happened during online PD "sewing circles", times when smaller groups of teachers simply crafted together for 1–2 h in breakout rooms on Zoom, casually conversing and occasionally exclaiming over something that went wrong with their sewing or coding. As Mary explained, in sewing circles, “I could see where other people were at . . . I think that helped me a lot... to see what each other are doing and to work together”. Just as in the literature, where it has been documented that the challenges of teachers learning new disciplinary content to implement STEAM e.g., [10], Mary found art to be challenging and frustrating. In the past, she rarely finished artistic projects, feeling far more comfortable in the domain of CS. Yet in the context of the e-textiles experience, she attributed her perseverance to the sewing circle groups: “having the community of teachers to me really reduces the overwhelm and stress and [the sense] that I’m just doing this by myself”. In other words, the crafting time in small groups during PD built teacher community and helped them persist through new disciplinary learning. It also gave them experiences that they applied with regard to their students.

Not only did teachers bond over making mistakes in their own e-textiles (as much as students did in the classrooms [49]), but they also bonded through sharing mistakes and challenges during the process of implementing the e-textiles unit. They shared these experiences during teacher-initiated “buddy groups”, where the teachers met in groups of four every other week for the 2–3 months of implementing the e-textiles unit. The entire cohort of teachers consistently pointed to these buddy groups as essential to their perseverance in implementing what, for them, was a challenging unit in a new domain. Gabby explained it this way:

> “I think the best thing is, I have someone to talk to, because I was the only one in my school doing e-textiles . . . [T]he fact that I was able to communicate with other people that are teaching it too. Yeah, we’re not in the same school district, yes, my students are different from their students . . . But the fact that we were able to communicate. We were able, like, ‘I had a bad day, help me out.’ ‘What do you recommend?’ Or, ‘Oh my God, my students with learning disabilities they’re struggling. What would you do? How can we have- add support for them?’... I really felt like you weren’t alone. And I think that that’s the main thing that kept me motivated and kept me going forward”.

All the teachers expressed that the buddy groups were critically important to them and that sharing their trials and challenges, their ideas and pedagogical approaches, and simply encouraging each other helped them press through. This points to the importance of interpersonal teacher connections not just in learning new disciplinary content but in actually implementing new STEAM units. Valuing mistakes, trading ideas, and sharing challenges in a small group built on common experiences and trust was central to the teachers’ perseverance. While much of the research literature points to the necessity of schools providing this type of community for sustainability [26,27], the teachers of this study did not have the option of building disciplinary relationships with other teachers in their school, as they were the only CS teachers in their schools (and sometimes in their district).

The investment in relationships through sewing circles and buddy groups provided a foundation that teachers planned to tap into long after the first year of implementation ended.

> “[N]ow I have a support group . . . I have now telephone numbers of just about every person that I’ve met at e-textiles . . . So, I now have so many contacts. And thinking back [if someone texts] a question or someone would email a question, everyone will respond and even if I didn’t respond I would get information about what worked or didn’t work”.

With phone numbers and email addresses in hand, a set of accepted practices for sharing pedagogical challenges and solutions, and previously established shared goals for the e-textiles unit, teachers had a community they could turn to for future implementations of the e-textiles unit and other endeavors. The teacher community that stretched across state lines and coasts provided hope and a potentially new mode for sustaining their STEAM efforts.

3.2.2. Expanding to Home and Friends with STEAM

Teachers went beyond the connections in the classrooms; they moved across their schools and fellow teachers to connect with family and friends, bringing e-textiles projects home, making these projects relevant to family and friends, and otherwise using these projects to connect with loved ones. Some teachers shared their projects with anyone who was nearby, from "nieces and nephews . . . here on vacation" (Brandy) to "pretty much any friend or family that came over" (Megan) and even "everybody" in social media networks (Brandy). Some teachers made projects specifically for family members, as Mary did, telling us with some chuckles that "one of the original ecards I made for my husband . . . he still has it". The teachers' enthusiasm for what they were creating and learning demonstrates how quickly teachers jumped on the opportunity to share something from their professional lives with family and friends. Research has shown that students take their STEAM artifacts home, make projects to give to family or friends, and generally use their projects to connect with people outside of the class [51], and so too did the teachers, thriving on the personal and social aspects of their STEAM projects.

Some teachers shared not only the artifacts that they made but what their students made as well. As Jackie expressed,

> "I need to be able to be excited about what I'm doing and showing, right. So, I will say, 'Hey look at what my students are doing in class.' . . . I think just having something exciting to talk about that's not politics, and that is not illness and it's not, like, sadness over, like, what's going on in the world about children getting injured. Is really important . . . and it makes me happy".

Jackie's explanation conveys the importance of sharing something positive from her profession with family and friends, disrupting talk about societal ills and biases in computing with empowering stories about students' capabilities as well as some of the "funny stories" of making these projects. It gave her happiness to share these things with the people around her, especially as this teaching took place in the context of the COVID-19 pandemic. The e-textiles unit not only empowered her students but also allowed her to share empowering narratives and images of kids persevering, creating, and learning. The e-textiles unit allowed her to proactively connect her professional and personal lives in a way that made her "happy".

3.2.3. Growing CS Teacher Community

Finally, echoing the research literature, which points out the importance of developing a professional, disciplinary community e.g., [36], the teachers touched on the importance of connecting to other CS teachers. They pointed out how lonely it can be as a computer science teacher, often being the only one in the school. As Megan described, the chance to connect with other CS teachers through PD and the buddy groups was "huge . . . As a computer science teacher, you are on your own, so you like you don't have that department to go commiserate with or to share with". Having these connections with other CS teachers helped them see the national scale of CS and make sure that their students were on track, kept them excited and encouraged, and enabled them to move computer science education forward. In a discipline where few school or sometimes district supports are available for developing teacher social capital, the e-textiles PD and implementation groups met a need across city and state lines and helped enlarge teachers' vision.

Further, gathering with other ECS teachers, in particular, meant that they shared a value in seeking to build equity in CS education. As Hope put it,

> "ECS and the fundamentals around it keeps me centered. And so, anytime I have an opportunity to connect with that group, I'll take it . . . I *have* to stay connected with this community. Because it is my . . . north—it is, it is what encourages me".

This particular group of teachers found that meeting together helped sustain their interest and dedication to pursuing CS education with practices of equity at the core. As they made e-textiles and learned to teach the e-textiles unit, they pursued a vision of equity in CS education and took encouragement from learning with each other about how to do this in each of their individual schools in different areas of the country. This points to the importance of not just communing around a specific discipline [35], such as CS, but being in touch with a teacher community and with a shared social justice agenda [57].

4. Discussion

This investigation focused on the variety of connective practices high school CS teachers employed and needed in order to support and sustain equity- and inquiry-oriented STEAM efforts in their classrooms and schools. While some of the reported practices included already well-documented student–student and teacher–student relationship building inside classrooms [49,50], we paid particular attention to the connections that students and teachers forged beyond the classroom walls within the larger school community and beyond [24]. Our findings are based on teachers' retrospective reflections on their own professional development and implementations of the e-textile unit in their classrooms. While this approach allowed for a broad look across eight teachers in as many schools and across seven school districts in four states, it also faced limitations when compared to direct classroom or school observations; however, these were beyond the scope of our current study. In the following sections, we discuss three aspects that are relevant for further efforts to support and sustain STEAM efforts: (1) developing teachers' professional community, (2) expanding teacher social capital, and (3) facilitating teachers' socio-emotional connections.

First, our study illuminated the importance of not just a disciplinary teacher community but also of a teacher community with shared values of equity and social justice. It shows the potential for STEAM activities not just for students but among teachers themselves to support such community building. Teacher friendships developed and solidified while making expressive STEAM projects with e-textiles, bonding over mistakes and challenges as learners of new content and pedagogy in professional development. In addition, sharing mistakes and challenges while implementing the STEAM unit itself further connected teachers as they built on shared values of developing equity in their classes and schools within CS. One interesting insight from this study comes from this focus on high school CS teachers. As a relatively new field within K-12 education, CS teachers often feel isolated in their schools, without the home departments that many other STEM teachers have access to in science or mathematics [32,33]. This particular situation of CS teachers illustrates the seclusion that many STEAM teachers might also experience when they implement projects that move beyond their home discipline. Thus, hearing how CS teachers tackle a STEAM project in their classes revealed some of the within- and beyond-classroom work that teachers must carry out and the challenges they face. Their reports render transparent much of the work teachers have to carry out beyond disciplinary learning, which has received so much attention in STEAM literature regarding teachers. More research is needed on the kind of beyond-classroom support and work needed to sustain STEAM efforts for students in an equity- and inquiry-minded way.

Second, our work expands the research on supporting social capital development in teacher education. Numerous studies [26,27] have indicated the critical relevance of social capital development during professional pre- and in-service for sustaining successful learning and teaching. In the context of CS education, this takes on particular relevance as CS teachers are often the only teachers in their schools and, thus, do not have peers or even a home department to connect with regarding curricular content and classroom support. But teachers' social capital consists of more than just professional connections with teachers in their discipline; they also have connections with teachers from other disciplines, with school staff, and with school (and district) administrators, as several examples in our study illustrated. These beyond-classroom and beyond-discipline interactions stood out against the norm. The teachers created connections that encouraged other teachers and helped administrators understand the work being carried out in their classrooms. This also touches on some of the many challenges teachers might face in setting up and sustaining STEAM activities in their school, including, but not limited to, top-level support for new endeavors, necessary technology (e.g., computers), tech support (including admin access for permitting software), space, materials, displays, and support staff, in directing students to certain classes and opportunities.

Finally, our findings also made apparent the need for socio-emotional support, which is another equally important dimension that is not often mentioned for sustaining STEAM activities. Here the reflections revealed how STEAM activities could provide teachers with renewal, connectedness, and social/emotional encouragement—just as they provide for their students in the classroom. The research literature often focuses on what teachers need in order to implement STEAM or other new classroom interventions [10,12]. Yet we should also pay attention to the potential benefit of STEAM activities in and of themselves for teachers. The teachers built a community of trust with each other, which helped them persevere through implementing a new curricular unit in a new domain and provided a social network for future endeavors in developing a more equitable CS environment in their schools. They connected with peers and family, sharing affirmative personal expression regarding their own projects and their students' positive experiences in the teachers' professional environments. Just as students have expressed gains from connecting with their peers and identifying with a disciplinary community (i.e., a sense of belonging in CS and in other STEM fields) through creating and sharing STEAM projects, teachers can clearly benefit socially and emotionally from these experiences as well.

In conclusion, our study provided valuable insights into the efforts that CS teachers engage in to support and sustain STEAM activities in their classrooms—efforts that reach far beyond their classroom walls. It furthermore highlighted the unrealized dimensions of STEAM activities regarding building social and emotional connections that invigorated teachers' professional practice and purpose, which are aspects that are worthy of future attention and research.

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Appendix A

Below is our final coding scheme with the counts and frequencies across teachers (see Table A1).

Table A1. Final coding definitions and counts.

Code (#Number of Teachers; Number of Examples)	Explanation	Example
Students to students—within classrooms (6 teachers; 11 instances)	Characterized by students reaching out to other students within a class: e.g., for help, for ideas, or just in casual conversation.	"I mean I hear students talking about stuff because they're engaging their progress- project, they talked about stuff and I hear things that I wouldn't other times of the year".
Students to students across classrooms (5 teachers; 11 instances)	Characterized by students reaching out to other students outside of a class: e.g., dragging a friend into a class (in which the friend is not formally a student) to show a project.	"And then, some of the kids they want, they begged me if they could take them to lunch, to finish it and I said sure why not. They started going around the school spreading the word, 'Oh look what I'm doing,'... and they're like, 'Are you sure you're computer science?' They're like 'Yeah yes it's going to be attached to a circuit so don't worry.' . . . I had kids that I did not know come into my classroom just to see what they were doing . . . They're like 'Oh I'm so and so, I'm gonna, I'm thinking about taking your class next year,' . . . Yeah my numbers [for next year] doubled from two classes, now to four".
Students to teachers: within class (5 teachers; 8 instances)	Characterized by teachers getting new insights into students' lives and/or deeper relationships with students because of sharing projects (i.e., seeing students' projects and/or sharing their own (teacher) projects), working on projects with students (i.e., sharing mistakes, helping).	"Yes, it helped me connect more to my students because we're sitting there and I'm walking around . . . and, although ECS has a lot of collaboration, the collaboration is more when e-textiles . . . So with me being in there I'm able to, you know, to connect with them. While we were sitting there and they were all sewing and I'm like this is like a sewing circle. and so we would start talking about just everyday things, while they were working on their projects. yeah, and so it became like a personal time to—although you're doing your work—we're still just communicating not about school or the lesson, but on a personal level".
Teachers and other staff in school (7 teachers; 11 instances)	Characterized by teachers having more contact with other staff in the school (other teachers, admin staff). Some staff came into the classroom and looked at student projects or sat down and made projects themselves. Others were involved because of co-facilitation or taking over for maternity leave.	"Like I would bring teachers in from the hallway, I'd be like 'Come and see what they're doing,' and like [the other teachers] they don't even know I'm here, well I'm like look I can go down the hallway . . . hopefully like using these kinds of things to show other teachers that like you can have fun and be productive in a classroom like it doesn't have to be a grind all the time".
Students to home (2 teachers, 2 instances)	Evidence of students making connections to home with e-textiles, for instance, taking projects home, showing projects to family, and anything outside of school.	"So he went from being . . . a student that was real defensive and I had to really, really be careful with my approach . . . to opening up, talking and laughing and taking his he took one of his projects home just to show his mother, because he was so excited about it. And he ended up like I said he ended up passing the class".

Table A1. *Cont.*

Code (#Number of Teachers; Number of Examples)	Explanation	Example
Teachers to home, family, friends (6 teachers, 9 instances)	Evidence of teachers sharing e-textiles and otherwise using e-textiles to make connections with family, friends, and pretty much anyone outside of school and professional networks.	"I need to be able to be excited about what I'm doing and showing, right. So I will say, 'Hey look at what my students are doing in class.' . . . I think just having something exciting to talk about that's not politics, and that is not illness and it's not, like, sadness over, like, what's going on in the world about children getting injured. Is really important . . . It's fun to show the designs and the creativity of students there's. And there's also you know, sometimes some funny stories . . . So I really do talk about this with friends and family quite a bit because I love to show the pictures and it makes me happy".
General CS community (6 teachers; 8 instances)	Expressing connections with other CS teachers, i.e., general CS community. For instance, gaining perspectives on challenges other CS teachers face, knowing one is not alone.	"As a computer science teacher, you are on your own so you like you don't have that department to go commiserate with or to share with. So I loved like hearing from other people . . . so at least just hearing other people's experiences . . . There was no utopia everywhere and anywhere, so at least I felt like, 'Okay it's not just me,'... like I just think having that community of teachers who are also teaching what I teach to know that, 'Okay, we just have to figure this out together there's not this great place.' Like we can stay where we're at and just work together to make each situation better".
E-textiles specific CS community (8 teachers; 19 instances)	Expressing connections with other CS teachers who are learning and teaching *e-textiles.* For instance, learning from implementing the unit with each other, sharing mistakes in projects or in implementation, bonding over e-textiles specifically.	"Yeah we're not in the same school district. Yes, my students are different from their students. But we're still trying to teach this type of a lesson. It's a similar—you know we're teaching the same lesson. Maybe we introduce it a little different because you know everyone has different teaching styles. But the fact that we were able to communicate. We were able, like, 'I had a bad day, help me out. What do you recommend?' Or, 'Oh my God, my students with learning disabilities they're struggling. What would you do? How can we have- add support for them?' All those little things I really felt like you weren't alone. And I think that that's the main thing that kept me motivated and kept me going forward". "Well just the process, you know sewing, that was always fun . . . so sewing and then having you come in the breakout rooms, to help ole slow [me] out. Those moments were very good too. Messing up- you know I messed up a lot of times . . . I do remember the times when I messed up, like I mentioned about sewing, the conductive thread all over the place and stuff like that. Just a PD the people, the teachers, uh everybody, it was just a good group. Good energy and everything so. I enjoyed the whole experience".

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