Professional Development for Secondary Science Teachers: A Faded Scaffolding Approach to Preparing Teachers to Integrate Computing

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Abstract: Though we often think of computing as a discrete discipline, computing competencies are integral to professional practices in STEM fields. The Next Generation Science Standards demonstrate the importance of these disciplinary tools by directly incorporating science, mathematics, and engineering with computing in grades K-12. To assist children with learning the knowledge and skills authentic to these disciplines, we need teachers with appropriate content and pedagogical knowledge of computing. However, most K-12 teachers have little to no computing background. This design-based research study explores how designing professional development (PD) with faded scaffolds and worked examples can further teacher training efforts to bring computing to core content classes. Forty-six teachers participated in summer PD opportunities that introduced them to electronic textiles as a vehicle for integrating computing into their science classrooms. The professional and curriculum development processes evolved through an iterative design intended to build better scaffolds for teacher and student learning.

As science, technology, engineering, and mathematics (STEM) education focuses increasingly on engaging students with content in ways that align with the real-world practices of the disciplines, it is clear that computational thinking and computing play major roles. For instance, the Next Generation Science Standards (NGSS) used in K-12 education in the United States identify computational thinking as one of eight key science and engineering practices. Further, evidence suggests that supporting students' development of disciplinary identities across contexts is a promising approach to broadening participation in STEM fields (Allen & Eisenhart, 2017; VanHorne & Bell, 2017). Accordingly, most research in the learning sciences has focused largely on how to design learning environments and activities to support students in developing these identities (Bell, Van Horne, & Cheng, 2017). Hands-on making activities that merge the physical and the digital have shown particular promise in terms of supporting students' acquisition of disciplinary practices and identities by bringing together knowledge and skills from multiple arenas of youths' lives and providing for the investigation of real-world problems (Tofel-Grehl et al., 2017).

By definition, making activities tend to be interest-driven, open-ended, and exploratory, lending themselves more frequently to out-of-school spaces or elective courses (Peppler et al., 2016; Sheridan et al., 2014). Given their promise for supporting youths' disciplinary identities and, thus, their participation in STEM fields, we argue that making activities integrating computing need to move into the classroom in core content areas like mathematics and science. To do so, however, requires a teaching workforce prepared with sufficient content and pedagogical knowledge to integrate making activities. Such knowledge includes an understanding of the iterative design process and computing, as well as the ability to integrate them meaningfully into core K-12 content areas. Such practices are slowly appearing in preservice teacher preparation programs, but the vast majority of inservice teachers lack such training. Further, inservice teachers have limited time to engage in professional development (PD) activities given the ongoing time demands of their classrooms. As a preliminary step towards identifying and validating appropriate scaffolds to assist science teachers in developing computational content and pedagogical knowledge, this paper reports the results of a design-based research study on teacher professional development integrating electronic textiles materials and computing in secondary science classrooms. We are guided by the following research question: How can we design professional learning environments to scaffold making and computational thinking for classroom teachers with limited computing experience?

E-textiles as a making medium for learning and engagement

Social perceptions that STEM professions are mostly the domain of Caucasian males, sometimes referred to as "locked clubhouses," often discourage girls and underrepresented minorities when they make decisions about engaging in STEM activities (Malcolm & Malcolm-Piqueux, 2013; Margolis & Fisher, 2001). Numerous approaches have attempted to broaden the participation of girls and underrepresented minorities in STEM, including mentorship, the design of more appealing activities (e.g. storytelling instead of programming; designing for one's community), and the use of novel tools (Calabrese Barton et al., 2017; Huffling et al., 2016; Kelleher & Pausch, 2007). Electronic textiles (e-textiles), which combine traditional aspects of fabric crafts with sewable, programmable electronic components, represent one such category of novel tools intended to disrupt stereotypes about what STEM looks like and who can do it. The use of crafting frequently challenges conceptions of gendered stereotypes and engages more diverse socioeconomic and cultural groups (Kafai, Fields, & Searle, 2014).

In contrast to learning about circuitry using conventional wires and breadboards, students working with e-textiles materials create circuits using conductive fibers or conductive Velcro, sensors for light, sound, and pressure, and actuators such as LEDs and speakers, combined with traditional aspects of fabric crafts like needles, thread, felt, and embroidery floss. Students sew circuits using these materials to produce wearable items (e.g. t-shirts) with embedded computing for controlling the behavior of fabric artifacts. In so doing, they engage directly with STEM content and skills through the design, prototyping, creation, and debugging of objects that are relevant to their interests and needs (Peppler & Bender, 2013; Vossoughi & Bevan, 2014). Because students personalize e-textiles designs to reflect their own aesthetic preferences, even within a specified project, no single design solution is inherently correct; students may find many pathways to making their particular project functional.

E-textile activities can promote learning by revealing the underlying structures and mechanisms of circuits in tangible and observable ways, because students must deliberately determine paths for conductive thread and the placement of components (LEDs, microprocessors, etc.) to build functioning circuits (Buechley, 2010). Through iterative development of design and testing of prototypes, e-textiles also engage students in debugging activities that are uncommon in existing curricula but essential skills in the fields of engineering and computing (Fields et al., 2012). For example, loose threads become short circuits, LEDs are incorrectly oriented relative to the direction of current flow, or computer programs do not work as expected. Frequently there are combinations of problems with circuitry, programming, and physical structure, forcing students to iteratively isolate and test multiple potential problems before identifying solutions. Further, because materials are not prearranged (versus nails preconfigured on a breadboard), students conceptualize the circuit as a whole rather than focusing only on an arrangement of individual components.

The growing body of research on e-textiles has shown that students not only learn science content as well or in more meaningful ways (Tofel-Grehl et al., 2017), but also find ways to bridge home and school environments through e-textiles projects (Howell et al., 2016; Searle & Kafai, 2015). Given these positive results, efforts are underway to develop an e-textiles curricular unit for the Exploring Computer Science curriculum, a pre-AP computer science course (Fields, Lui, & Kafai, 2017). Yet, we know that many schools do not offer computer science, and among those that do not, many administrators cite a lack of qualified teachers and/or a need to focus on test-related subjects (Google & Gallup, 2016). As such, we focus on the challenge of preparing inservice teachers to incorporate e-textiles materials and activities into secondary science courses.

Addressing challenges of bringing e-textiles to science classrooms

Incorporating e-textiles projects into core content areas like science presents several challenges. First, the open-ended nature of the design endeavor necessitates a project-based learning approach that may not be familiar or comfortable for many teachers. During preservice preparation, extensive training in such pedagogies is uncommon, and even when teachers do receive such training, their implementation is usually limited (Simmons et al., 1999). Second, the integration of science instruction with computing is often novel for teachers. Teaching integrated STEM units, teachers can create learning environments that are more aligned with conditions outside of school, breaking down the artificial boundaries of separate subjects and creating an experience that more closely mirrors professional practice in STEM disciplines—a major goal of the Next Generation Science Standards. Integrated STEM units can also help students form deeper understandings, see the "big picture," make the curriculum more aligned to students' interests, and increase students' motivation in school (Berlin, 1994; Czemiak et al., 1999). However, as with project-based learning, teachers do not usually receive training in strategies for effective implementation (Mason, 1996). Third, while teachers at the high school level are usually well-versed in their science content knowledge, very few have received training in computational thinking, including specific programming skills (Epstein & Miller, 2011; Hargrave & Hsus, 2000). As such, they need additional training to support their students' learning appropriately.

To accommodate both the extent of training needed for teachers to be adequately prepared for an implementation of a high quality e-textiles curriculum and the limited opportunities available for professional development, the design of such training requires attention to both effectiveness and efficiency. While learning outcomes for more directed and more exploratory instructional strategies are often equivalent (e.g., Chase & Klahr, 2017; Klahr & Nigam, 2004; Likourezos & Kalyuga, 2017), the attainment of those outcomes typically occurs more quickly under higher levels of instructional guidance. Thus, to accommodate the constraints on learning time for inservice teachers, we adopted training strategies that engaged higher levels of explicit guidance—specifically a faded scaffolding approach.

Faded scaffolding entails providing learners with supportive task structures and materials to guide their early learning endeavors. As they begin to master elements of the task, those supports are gradually withdrawn until learners are demonstrating successful use of the target knowledge without aid. One form of faded scaffolding that has a strong track record of success is the use of faded worked examples (Atkinson, Derry, Renkl, & Wortham, 2000). In this model, a fully worked out example is provided to learners as a narrated or annotated demonstration, illustrating a successful performance. After the worked example has been studied or rehearsed, another is provided that presents a partially completed task. Building on the previous model, the learners then perform the necessary steps to complete the partial task. In successive examples, learners take on increasing levels of autonomy by completing greater proportions of the constituent task elements without direct guidance, until they are ultimately performing effectively without direct instructional support.

The rationale for this approach is that learners can focus narrowly on specific elements of a task to master the necessary application of knowledge and skills in manageable pieces while maintaining an authentic whole-task context. By progressively expanding the scope of application for aspects of the larger task as they become more proficient, learners will neither be overwhelmed by the magnitude of a complex task, nor will they risk floundering unproductively (Renkl & Atkinson, 2003). Given the inherent complexity of managing both new content and new pedagogical strategies (Feldon, 2007), we designed professional development materials according to this model, asking teachers to begin working through fully developed curricular materials and gradually take on greater independence and creativity in crafting with e-textiles and coding the microprocessors.

Methods

The iterative development of PD detailed in this study had two primary goals: (1) the design of a professional learning environment to scaffold making skills and strategies and (2) the development of teachers' pedagogical skills such that they could integrate computational thinking in their classrooms using e-textiles materials. These efforts were mindful that many inservice teachers not only have limited computing experience, but also may have relevant gaps in their core content knowledge. Using a design-based research (DBR) approach, we focus on designing and implementing professional development using faded scaffolding to prepare teachers for integrating computing and STEM content in the context of their standards-driven, public school classrooms. DBR is particularly useful for helping us to understand the underlying reasons why something is happening, the conditions under which a particular type of learning or interaction can take place, and the ways in which an individual's mind interacts with the environment and any available tools. Most importantly, DBR sees interventions that change features of environments, activities or tools as part of the process to be studied. It is both *prospective* and *reflective,* meaning that designs are initially implemented based upon some hypothesized learning mechanism and means of supporting it through a particular design or design feature (Cobb et al., 2003). Later, as the design is implemented, new features emerge as salient and both design and implementation may be refined, resulting in iterative cycles of design, implementation, analysis, redesign, reimplementation, and analysis.

Participants

Over three of implementations of the professional development workshop, 108 teachers participated. Teachers came from 9 school districts across three states of the intermountain Western United States. For the initial (pilot) implementation of the PD workshop, eleven teachers from three districts in two states participated. In the second workshop, 35 teachers participated from across three states and represented eight districts. In the third implementation of the professional development workshop, we had 72 teachers from 17 districts participate. Of those 72 teachers, 10 were returning master teachers from the second professional development workshop. The remaining 62 participated for the first time. Teachers' schools were located in rural or suburban districts. Districts were selected for participation based on population demographics; we sought to include teachers from highly rural spaces with high percentages of students on free and reduced lunch. Participants' years of teaching experience ranged from 2 years to over 40.

Data collection

Qualitative data and analysis

Observations were conducted at each of the professional development workshops by experienced PD providers and documented via written and/or audio field notes. Workshops were also video and audio recorded; portions of those workshops were identified for transcription. Interviews were conducted with all participating teachers in the pilot workshop and 12 teachers at the first full implementation of the workshop. In full implementation, interviewees were selected based on the research team's best guess about how they would adopt the curricular materials from the PD in their classrooms. We sought to interview teachers whom we thought were likely to represent the full spectrum from high to low levels of implementation. Within this group, we also sought a range of teaching experiences and diversity by race, ethnicity, and gender. In addition to teacher participant interviews, one member of the research team interviewed members of the PD team to identify challenges from the provider perspective. Initial coding was completed using broad categories such as areas of confusion, areas requiring further practices, and areas missing needed supports.

A grounded theory (Lincoln & Guba, 1995) framework was used to establish trending patterns within both the observed responses to the professional development as well as teacher interviews. Differences between areas of challenges were discussed between research team members until consensus was achieved as the correct problem isolation and the best method of scaffolding that issue going forward.

Quantitative data and analysis

Prior to and directly after completing the professional development workshop, teachers completed a content knowledge test that intended to capture possible gaps in teacher knowledge about circuitry (DIRECT; Determining and Interpreting Resistive Electric Circuits Concepts Test; Engelhardt & Beichner, 2004). Teachers' pre- and post-tests were scored based on the percentage of correct responses.

Overview of design and iterative development strategy

We began by developing an e-textiles curriculum based on a somewhat established progression of e-textiles projects from the literature (Buechley & Qiu, 2013; Kafai et al., 2014). Further, because most microprocessors designed for sewing e-textiles projects, including the LilyPad Arduino used in the curriculum, run on the Arduino programming language, we assumed that teachers would learn Arduino (Buechley & Eisenberg, 2008). We then tested our suppositions about an appropriately scaffolded curriculum and professional learning experience for secondary science teachers through successive cycles of implementation, analysis, and redesign, spanning a smaller pilot and two years of full implementation. To document the design process, we provided participants in each professional development workshop with hard copies of the curriculum and asked them to take notes on what worked and what was confusing. At the end of each implementation cycle, we examined these notes alongside our own observations, field notes, and debriefing sessions and made appropriate changes to the curriculum prior to the next implementation. Taken together, these data sources helped us to understand where learning was appropriately scaffolded for teachers and where more support was needed. We reflected these changes in how the PD was implemented during the next design cycle and in the curriculum itself.

Our initial development of the curriculum and PD, informed by a panel of master teachers who reviewed and critiqued it, struggled with two challenges. Firstly, all parties were concerned with the length of time sewable projects would take. For both in class instruction and the professional development workshop, concerns revolved around how to provide teachers and students enough content knowledge in addition to basic training in computational concepts and practices, as well as crafting time, while still being mindful of the constraints of the school day. Master panel teachers reported that they only allocate 1-2.5 weeks to teach electricity and energy.

In addition, having teachers take a five-day professional development workshop caused concern. Because our target PD population was middle school and high school science teachers, we decided to streamline the science content sections of the PD and focus more of our time on coding and crafting with the teachers. Our pilot PD workshop ran 24 total hours with approximately 3 hours on content, 12 hours on constructing and designing the projects, and 9 hours on coding. In the initial professional development, we began by having teachers make paper circuit greeting cards, then made simple circuit bracelets with a snap switch, had teachers "hack" their bracelets, and finally made a temperature sensing lunchbox. Of all these activities, we view the "bracelet hack" (Searle, Tofel-Grehl, & Allan, 2016) as the most crucial and it has remained a mainstay of our professional development model and classroom implementations.

The "bracelet hack" is intended to better scaffold the teachers' ability to modify code by segregating questions about functional circuitry from questions about whether or not code was written correctly. Using alligator clips, participants attach a microprocessor to a completed, functional snap switch bracelet project. By ensuring functional circuitry, the hack allows teachers to engage with code earlier in the instructional sequence without imposing a need to split attention between coding and crafting (i.e., avoiding the need to determine whether a malfunction was the result of a short circuit or a coding error).

Findings: data-driven, iterative PD development

After completing the pilot workshop, our team met to discuss the challenges and mechanisms we could engage to improve our model (see Table 1 for overview). We identified two areas of challenge. Firstly, we noted both from our conversations with teachers and from their pre-test scores that teachers lacked sufficient content knowledge to engage the projects most successfully. Several teachers indicated during their conversations with PD providers during the construction time of the workshop that they did not feel like they knew the content on the pre-test; as one teacher stated, "I think I got a zero. Please don't judge me for that." Another commented, "I have a physics degree, and I couldn't answer those questions. I wonder how my kids will do." Specifically, we found teachers lacked knowledge of circuit types, as well as an understanding of electron transfer and how batteries store energy.

To address these issues we added time to subsequent implementations of the PD workshop to bolster the time focused on scientific content knowledge. We also moved away from the aesthetically pleasing paper circuit project of making a greeting card to having ready-made templates of the various types of circuits to facilitate teachers' rapid prototyping of various circuits and learning about resistance and polarity more concretely. We also increased the amount of time spent on content from 3 hours to 4.5 hours.

Table 1: Summary of data-driven iterative PD development

PD set up	Challenges	Modifications to Address Challenges
Pilot Year: 1Teacher Participated in district PD on e-textiles	Design process was personalized but time consuming.	Used the deep work with teacher 1 as basis for training PD design.
Year 1 PD 1: 11 teachers 3.5 day PD Follow up support	Content knowledge weakness Failure to engage follow-up help Difficulty in beginning to read code Difficulty Understanding coding components	Added Content knowledge training to PD Commenting code worksheets Introduced Coding Sandwich
Year 1 PD 2: 46 teachers 4 day PD Follow up support	Continued content knowledge weakness Teacher	Added more scaffolded classroom instruction for content knowledge-demos

The second area of challenge we identified from the pilot PD workshop was that teachers struggled to read even the most basic of code. Despite focused instruction from a computer scientist with extensive undergraduate teaching experience, there appeared to be a literacy gap between reading the code and understanding what it meant. While teachers could read the words, within the context of the code they had little idea what the syntax and words meant. Teachers reported feeling overwhelmed by simply looking at the code. As one teacher noted, "this looks like a foreign language, except a foreign language at least uses the same punctuation and sentence structure." Teachers struggled with reading more than a few words of code before reporting and being observed to be overloaded (e.g., putting head on table or closing the code file). We realized we needed to begin at a much more basic place than the typical undergraduate introduction to computing; we hypothesized that because our teacher population was older than the digital natives that populate undergraduate classes, we needed to introduce teachers more slowly to looking at and reading code. Thus, we developed a system of code reading and commenting that allowed teachers to engage the code more slowly through the use of faded scaffolds.

To do this in the second implementation (Year One PD in Table 1), we used the Arduino Blink code first as a group and discussed it together, much in the way a teacher might diagram a sentence in a grammar lesson. Then, we talked with teachers about the existing comments and what they might mean. In pairs, teachers rewrote the comments in their own words. Finally, they worked in pairs to comment new lines of code based on the understandings they had developed in their earlier practice.

We also saw teachers struggle with understanding just how specific they needed to be with what they asked a computer to do. The teachers in the first professional development workshop, with the exception of one who had copious CS experience, did not understand conceptually how code works to provide instructions to the computer. To help facilitate teachers' understanding of how code works and why it needs to be specific, we engaged teachers in the process of "coding" one of the PD staff to make a sandwich. Teachers quickly learned that when they said, "open the mayo," the PD provider would use a knife to saw open the bottle rather than twist off the top. Teachers learned that specificity of directions is essential in computing and that each part of the code performs a very specific job.

These scaffolds added an additional two hours of support for teachers to learn coding with the hope that earlier engagement with a more scaffolded approach would facilitate better outcomes for teachers. More broadly, in teaching teachers who have never read code how to comprehend and teach the content, we have found a faded scaffolding approach that emphasizes the importance of tracing, commenting, and explaining code as a means for developing understanding (Lopez et al., 2008; Murphy et al., 2012; Teague & Lister, 2014) to be most effective.

Upon completion of the second workshop, we found that while coding outcomes were better, teachers still needed more support in understanding the physics around electricity. Therefore, we built 15-minute content acquisition podcast (CAP) videos (Kennedy et al., 2014) that we shared and discussed as part of the PD in its third iteration. We coupled these CAP videos with classroom demonstrations that allowed teachers to see activities they could use in their own instruction as worked examples. These scaffolds added an additional 2 hours of professional development time focused on content.

We also noted that teachers were still struggling with commenting and modifying code. Instead of proceeding with teaching variables and set up, we created two worksheets that provided teachers with fading worked examples of commenting and modifying code, respectively. We developed the worksheets with the intent of providing the teachers tools to document their attempts at modification and commenting. These worksheets allowed teachers to track their efforts over the course of the workshop. The modification worksheet was relatively simple. Using a T-chart design, it provided a framework for teachers to document what their coding goal was (what they wanted the lights to do) on one side and what modifications they made to the code on the other. The first line of the T-chart was filled in with an example for them; this example was discussed and attempted as a whole group during the PD to provide a fully worked example. The commenting worksheet also proved relatively simple; on the left side was the code pulled from Arduino and on the right were blank lines for teachers to fill in their own comments. Within this process, we modeled reading a line of code and writing a comment that explained what it meant. After working through a set of lines of code and commenting them as a larger group, we assigned the next ten lines of code for the teachers to comment in pairs. We checked in with the pairs and found that nearly all teachers were now capable of commenting the code with reasonable levels of accuracy. With these worksheets, the teachers ended up trying many more modifications and became more facile at knowing which pieces of code were needed to replicate for their specified goal.

After developing the professional development workshop over multiple iterations, we have found it most successful to use a three-stage faded scaffold to introduce teachers to the reading and commenting of code. In the first stage, teachers receive a piece of code for a "basic blink" program, which turns an LED on and off in one second increments, with the entirety of the comments included. The professional development leaders read and discuss the code, explicating what each line does and what the comments tell us about the code. Teachers then attempt to use the "basic blink" code with a completed project, in our case their bracelets, and modify it to make the lights blink in different sequences or frequencies. At that point, professional development leaders walk the teachers through the process of modifying the comments on the provided code so that their comments now match the modifications they have made. In the second stage, teachers receive the entire code and comments for the set up section of the code. They must then comment the lines of code that do not have comments. Answers and comments are checked for correctness and accuracy. In the final stage of the training, teachers receive a section of code and are asked to comment every line. Teacher ability and comprehension are checked a final time before teachers begin learning the next process—writing code for themselves.

The process of developing integrated scaffolds for teachers across science and computing can prove complex and arduous. However, the value of building teacher trainings and materials in this way are multifaceted. By working with teachers in this way core skills and practices across STEM disciplines are integrated in authentic ways. It also provides teachers a model of successful strategies and instructional practices they can implement in their classrooms. By engaging teachers in learning through faded scaffolds and worked examples we can influence their use of those same instructional support strategies in their classrooms.

Discussion

Within the context of teacher knowledge there were several cogent trends distilled from the data. First, we observed multiple knowledge gaps related to teacher content knowledge around circuits and electricity. Despite being secondary teachers holding degrees in relevant content areas, teachers often lacked the knowledge to make hands-on projects involving circuits successfully. In addition to a lack of science content knowledge, teachers also lacked computing knowledge. While this was expected, we were surprised to find that the level of content standard for introductory computer science at the undergraduate level far surpassed teachers' comfort levels.

In thinking about efforts to support teachers with the myriad of challenges they face in classrooms, researchers and professional development providers must be mindful of several things. First, it is important to manage teacher learning in a fashion that teachers feel supported and secure in moving from the role of teacher to learner. While we may argue that the roles of teacher and learner ought be intertwined, many educators' self-concept as teachers involve the belief that they need to be an expert and knowledge giver. For teachers, being able to correctly answer student questions is not just an issue of pride, but an issue of identity. Another issue for consideration is managing the amount of learning and load with which teachers engage during professional development. Such PD often asks teachers to learn new pedagogical skills, curricular content, and disciplinary approaches. This quantity of information imposes a highly taxing load on teachers that can leave them frustrated and insufficiently prepared to adopt new approaches to integrated learning effectively within their classrooms. By engaging teachers in professional development that was constructed to scaffold learning using fading worked examples, teachers are provided multiple advantages in their professional learning. In addition to benefitting their own learning, those same scaffolds and examples can serve as meaningful tools for their students during classroom instruction.

By using faded scaffolds and worked examples in teacher training, we were able to provide teachers training on a complex yet manageable set of interrelated projects that incorporate STEM practices along with classroom science content. As we integrate the content and the practices for teachers in their own trainings, future work can explore the way teachers engage and model this integration process in their own instructional practices.

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