The Use of E-Textiles in Ontario Education

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Abstract

The purpose of this iterative design-based research study was to determine best practices when using e-textiles for learning in four diverse contexts. We employed a qualitative, ethnographic case study approach, and used interviews, observations, journals, and audiovisual materials in our data collection to explore student engagement with e-textile materials over a two-year period. The data from each iteration were coded using a thematic coding system. Results indicated that collaboration, choice, and making with purpose were the most important factors for student engagement and learning. Importantly, we found that different demographics of students require different supports in the learning process with e-textiles, and that student-driven making is critical when using e-textiles for learning.

Keywords: e-textiles, crafts, making, makerspaces, at-promise, inquiry, constructionism, DIY

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Résumé

Le but de cette recherche itérative, basée sur la conception, visait à déterminer les meilleures pratiques lors de l'utilisation de textiles électroniques pour l'apprentissage dans quatre contextes différents. Nous avons utilisé une approche d'étude de cas ethnographique qualitative et nous avons utilisé des entrevues, des observations, des revues, et des documents audiovisuels dans notre collection de données pour explorer l'engagement des élèves avec des matériaux électroniques pendant une période de deux ans. Les données de chaque itération ont été codées à l'aide d'un système de codage thématique. Les résultats ont indiqué que la collaboration, le choix, et «making» avec un but prédéterminé étaient les facteurs les plus importants pour l'engagement des élèves et pour l'apprentissage en général. Il est important de noter que nous avons constaté que les différentes données démographiques des étudiant(e)s requièrent des soutiens différents dans le processus d'apprentissage avec les textiles électroniques et que la fabrication dirigée par les élèves est essentielle pour l'apprentissage des textiles électroniques.

Mots-clés : textiles intelligents (e-textiles), le bricolage, fabriquer, les makerspaces, à promesse, l'enquête, le constructionnisme, faire soi-même

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Introduction

Making (or creating/building) as a way of learning is gaining traction in the Canadian education system as makerspaces and a return to a do-it-yourself (DIY) ethos spread in society (Hughes, 2017). Some schools in Ontario have begun to build physical makerspaces, and others are adopting the pedagogy associated with these learning spaces—a pedagogy which draws heavily on collaboration, inquiry, constructionism, and self-directed learning (Halverson & Sheridan, 2014). Part of the appeal and efficacy associated with a maker-oriented approach to teaching and learning is that students become active participants in their learning process and often develop a sense of agency through making (i.e., by producing a tangible artifact reflective of their learning). Oftentimes, learners' identities can shift from "recipient of information" to "maker" and co-developer of knowledge in the learning community. Within these makerspaces, students can draw on a variety of digital and physical tools in their constructing and learning processes.

A commonly found tool is the e-textile kit, which can come in many forms. E-textiles, or electronic textiles, refer to "fabric artifacts that include embedded computers and other electronics" (Peppler, 2013, p. 38). E-textile programs for youth are currently being implemented, although infrequently, in a variety of settings, including classrooms, makerspaces, and libraries. As this crafts-based medium gains popularity, it raises a question: In what ways are e-textiles influencing student learning in formal and informal learning environments in Ontario? We address this question through an examination of existing literature and identify common themes related to student interaction with e-textiles and similar media. We then offer four ethnographic case studies, based on our own design-based research working with students in Grades 3–9 (ages 8–14) in two informal settings (maker camps) and two formal classroom settings in Ontario, Canada. We highlight the benefits and challenges of using e-textiles with these students, and share the stories of how our own thinking shifted based on each subsequent iteration of the research. We present an analysis of the types of 21st-century skills and competencies, which include communication, and that are being fostered through the use of e-textiles. Finally, this paper addresses some of the challenges in implementing e-textiles in schools, concluding with recommendations about the direction of future research.

Literature Review

Locations for Learning

The majority of research on e-textiles in education has been conducted in the United States. While some e-textiles workshops can be found in Canada, prior to our work in this area there has been no associated educational research. In Canada, Berzowska (2005) has done some interesting work related to the development of technology for e-textiles using conductive yarns, knitting, embroidery, and sewing, but there is a dearth of recent Canadian research related to the use of these materials in K–12 education. Many of the findings in American studies can be related to Ontario students, and have been used as a starting point for our research. In a study performed by Buechley (2009) concerning the distribution of LilyPad (an e-textile creating kit) and Arduino sales, less than 13% of customers came from Canada. This indicates that the use of e-textiles is still an emerging practice in Canada.

E-textile studies have been conducted with adolescents from 6 to 18 years old, from a variety of cultural backgrounds, in Midwestern US cities (Peppler & Glosson, 2012; Buchholz, Shively, Peppler, & Wohlwend, 2014; Kafai, Fields, & Searle, 2012). Participants volunteered for the studies, which started with basic circuitry tutorials before moving into complex, personalized, and creative projects. Participants' skills with electronics, programming, and e-textiles varied. While some had completed simple electricity units in school, others had experienced programming and e-textiles in previous workshops and desired further knowledge. The voluntary workshops did not give feedback regarding connections to curriculum or best practices for an involuntary setting like the classroom.

Global Competencies

Several provinces in Canada have been working on defining competencies (knowledge, skills, dispositions) that students need to develop and apply for successful learning, living, and working. In September 2017, the Ontario Ministry of Education announced that a curriculum "refresh" will include an emphasis on "transferable life skills" such as communication, problem solving, critical thinking, creativity, and global citizenship (OME, 2016). In the Ontario Ministry of Education's *21st Century Competencies: Foundation Document for Discussion* (2016), six categories were identified: critical thinking and problem solving; innovation, creativity, and entrepreneurship; learning to learn/self-aware and self-directed learning; collaboration; communication; and global citizenship.

Making as a pedagogical approach is gaining momentum in education as a way to help students develop these requisite competencies. Emergent themes from recent studies include how the use of e-textiles can help students develop transferable skills, such as risk-taking and critical and creative thinking and problem solving (Buchholz et al., 2014; Kafai, Fields, & Searle, 2012; Kafai, Lee, et al., 2014; Peppler, 2013; Peppler & Glosson, 2012). The debugging cycle (the process of testing, finding mistakes, fixing, and testing again) inherent in e-textile projects engages learners in critical thinking and complex problem solving (Kafai, Lee, et al., 2014; Griffin, Kaplan, & Burke, 2012). Constructivist, problem-based, collaborative learning with e-textiles allows students to focus on the process rather than the end product, and to learn from failures (Peppler, 2013; Peppler & Glosson, 2012).

The Rise of STEAM Learning

Circuit building has been traditionally associated with STEM education (science, technology, engineering, and mathematics); however, we are beginning to see the rise of STEAM learning, where arts + literacy are being incorporated into STEM. The authors of the New Media Consortium's 2017 *Horizon Report* identify the "rise of STEAM" as one of the key trends accelerating technology adoption in K–12 education over the next one to two years (Freeman, Adams Becker, Cummins, Davis, & Hall Giesinger, 2017). E-textiles represent a fusion of digital and handcrafted technologies, and enable students to express their identities through the personalization of their belongings, specifically clothing (Buechley, 2007; Buechley, Eisenberg, Catchen, & Crockett, 2008). Research in the field of craft suggests that the multi-sensory elements of making promote an intimate conversation between maker and artifact (Koplos, 2002; Owen, 2011). Perner-Wilson, Buechley, and Satomi (2011) argue that craft materials "enable us to personalize our technology in new ways—allowing for electronics that are fuzzy, stretchy, and colorful" (p. 61), and that using craft materials can facilitate the connection between existing skills and knowledge and "technology creation and customization" (p. 61). When students are given the freedom to use STEAM-based tools and craft materials, multiple studies find that the projects students create reflect their interests and identities. Students put more energy and creativity into assignments like these, and are more likely to take pride in the outcomes (Buechley, Eisenberg, & Elumeze, 2007; Fields, Kafai, & Searle, 2012; Peppler, 2013). Hughes and Thompson (2013) note that when students are given the opportunity to express themselves through their learning, connections are created between in-school and out-of-school experiences, making the learning more relevant and engaging (an important factor in constructivist learning). E-textile projects that can be incorporated into students' daily lives provide new and exciting alternatives to traditional circuitry (Buechley, 2007; Buechley et al., 2007).

The balance between functionality and aesthetics in design can also be particularly motivating (Fields et al., 2012). As Buechley and Perner-Wilson (2012) point out, a long-held assumption views aesthetic experiences and constructive physical experiences as central components of what it means to be human, and holds that "making things and encountering and appreciating beauty [are] critical elements of a well-lived life" (p. 2). Traditionally, aesthetics have not been given much credit in STEM learning (Buechley, 2007; Fields et al., 2012). However, e-textiles focus on aesthetic concerns and customizability while teaching theory, which builds stronger connections between students and their learning (Buechley, 2009; Buechley et al., 2008; Kafai, Lee, et al., 2014). While all studies report on the value of student input in the design and criteria of the projects, Kafai, Lee, and colleagues (2014) note that the students' "aesthetic motivations promoted learning by remixing circuit designs" (p. 11). Researchers noticed that when aesthetics played a role in design, participants were more mindful of electronic component placement, would spend more time problem solving, and were inspired to create challenging circuitry (Fields et al., 2012; Kafai, Peppler, Lemke, & Warschauer, 2011).

Theoretical Frameworks

Learners today differ greatly from their predecessors due to changes in access to information in the digital age and the democratization of the teaching and learning process synonymous with the new online participatory culture. The following research investigates cases that use e-textiles as a medium to support the constructivist methodologies of production pedagogies in order to reach young adolescent learners.

Production Pedagogies

According to Thumlert et al. (2014), a production pedagogy is "one in which learning actors are enabled to engage (multi)literacy, artistic, and/or practical design challenges and aptitudes through the making of authentic cultural artefacts—and with correspondingly real audiences similarly enabled to witness such acts of art and knowledge production" (p. 12). Production pedagogies engage learners in the "activity of production, enabling actors to deconstruct and reconstruct, interpret and refigure, and to make both meanings and 'things' within the context of appreciably meaningful cultural/aesthetic interventions" (Thumlert et al., 2014, p. 13). A key feature of production pedagogies is a focus on the cultivation of participatory and equitable spaces, where students can engage with ideas and issues as joint seekers and co-creators of knowledge and producers, not just consumers. The maker movement places an emphasis on deep learning through digital technology and community interaction. Kafai (2006) situates making within a constructionist approach to education based on the notion that learning is most effective when learners are active in making tangible objects in the real world, drawing their own conclusions through experimentation with various media, and constructing new relationships with knowledge. Unlike more traditional instructionist approaches to learning (where the knowledge to be received by students is already embedded in objects delivered by teachers), constructionist learning supports learners in practices of knowledge building based on active engagement with raw materials, which include both tangible and virtual materials.

The 2015 *Horizon Report* indicates that "makerspaces are places where anyone, regardless of age or experience, can exercise their ingenuity to construct tangible products. For this reason, many schools are seeing their potential to engage learners in hands-on learning activities" (Johnson, Adams Becker, Estrada, & Freeman, 2015, p. 38). Maker pedagogies offer the potential to revolutionize the traditional approach of education towards teaching and learning practices (Kurti, Kurti, & Fleming, 2014). This is in part due to the fact that makerspace pedagogies are characterized by a certain maker culture mindset rooted in the following traits: inquiry-based, self-directed, playful, growth-minded, failure-positive, and collaborative (Dougherty, 2013; Martin, 2015; Kurti et al., 2014).

Martin (2015) notes that "one of the most readily apparent features of the makerspace movement is the celebration and use of new...digital tools" (p. 32). These digital tools include but are not limited to 3D printers, tablets, e-textiles, programmable robots, green-screen video production, and augmented reality (Range & Schmidt, 2014; Martin, 2015). Drawing on Papert's (1980) path-breaking work on teaching computational thinking to even the youngest children, we propose a learning environment that employs a "low floor," allowing student engagement with computational thinking with minimal prerequisite knowledge, and a "high ceiling," providing opportunities to explore more complex concepts, relationships, and representations. Resnick et al. (2009) suggest the added dimension of "wide walls," which can support "many different types of projects so people with many different interests and learning styles can all become engaged" (p. 63). To this, we add that wide walls allow and motivate students to engage with a larger audience, as opposed to just their classroom peers.

In the context of this research, the creation of e-textiles affords learners opportunities to "combine and juxtapose surprisingly disparate elements: physical and digital; soft and hard; low-tech and high-tech," and enable construction practices that "bring together hand and mind, informal and formal education, visible and invisible technology" (Buechley, Peppler, Eisenberg, & Kafai, 2013, p. 2). It is these elements, when introduced properly (as uncovered by and described in our iterative attempts below), that facilitate student engagement and deep learning.

Methodology

To explore our research question as to how e-textile activities might be influencing student learning in formal and informal learning environments in Ontario, we used a design-based research (DBR) approach that focused on the fabrication processes of individual students. One of our primary goals was to produce "new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings" (Barab & Squire, 2004, p. 2). The DBR approach has a number of features that were suitable for this study: (1) it involves an interventionist approach; (2) it takes place in naturalistic contexts; (3) it is iterative; and (4) it results in the production of theories related to learning and teaching with e-textiles. Using this kind of iterative approach allowed us to "adjust various aspects of the designed context so that each adjustment served as a type of experimentation that allowed the researchers to test and generate theory in naturalistic contexts" (Barab & Squire, 2004, p. 3). We used DBR in conjunction with ethnographic case study methodology. We adhere to Annette Markham's (2018) definition of ethnography as "an approach that seeks to find meanings of cultural phenomena by getting close to the experience of these phenomena…[and the study of] the details of localized cultural experience, through a range of techniques intended to get close and detailed understandings" (p. 653). As a result, we situated ourselves close to participants in all four contexts, acting not only as researchers but also as teachers and facilitators. We were situated within the research context and not merely outside of it as detached observers. We worked closely with the students, talking to them about their learning processes, assisting them throughout their learning, and capturing their design and reflection work and their experiences on a daily basis through photo, video, interviews, and field notes. We captured this type of open-ended data with the objective of developing common themes (Creswell, 2003) in the analysis stage. We also used case study methodology, which is "the study of a social phenomenon carried out within the boundaries of one social system" (Schwandt & Gates, 2018, p. 343). More specifically, its object of study may be an "incident, or unit of something and can be anything—a person, an organization, an event" (Schwandt & Gates, 2018, p. 341). For our purposes, we use ethnographic case study methodology in reference to our four research sites—two classrooms and two March break camps. This type of research objective matched our goal of "[developing] a complete, detailed portrayal of some phenomenon" (Schwandt & Gates, 2018, p. 346).

Analysis of the data required several different layers of coding and interpretation. Using a thematic coding system, we coded the interview transcripts following traditional coding procedures (Strauss & Corbin, 1990). We then compared themes across the different cases in order to identify recurring and overlapping thematic and structural patterns (Black, 2007), and we compared our case studies against existing research in this area as outlined in the literature review. The data were read and coded for major themes across data sources, and the codes were revised and expanded as more themes emerged. The research and workshops were constantly evolving to accommodate findings from previous groups and workshops.

Case Studies

There are subtle, yet critical, differences in the ways in which we have used Arduino LilyPad e-textiles in our research over the course of the last two years. We implemented four iterations of e-textile-centred research during this time, and what evolved during each iteration informed the following iterations. What had the greatest impact on student engagement and learning was the shift from a traditional learning model to an inquiry-based approach, and the reasons given for creating the e-textile end products. Of particular note was how differences in student demographics made for interesting, and unexpected, differences in tool engagement and use.

Iteration One: Pilot Project (January 2015)

In January 2015, we introduced the Arduino LilyPad kits to our first group of students in our research lab. This group consisted of eight 11- and 12-year-olds (four males and four females) from a Canadian alternative school that provides educational programming for students from government-approved care, treatment, custody, and correctional facilities. The students were identified with cognitive, behavioural, emotional, and developmental exceptionalities, which included fetal alcohol syndrome, oppositional defiant disorder, learning disabilities, anxiety, and post-traumatic stress disorder. The primary purpose of this alternative program is to provide students with effective instruction that leads to their reintegration into community schools, post-secondary institutions, or employment.

We introduced the students to the LilyPad kits only shortly after brushing up on our own understanding of basic circuitry by making a simple LED bookmark. We were sceptical and excited about learning to use the kits, but the learning was rewarding as we crafted together and helped each other throughout the creation process. During this process, we problem solved and discussed how the kits could be used with the class of "at-promise" students. Following Swadener (2010), we agree that the term "at-risk" has been overused and tends to suggest a deficit model, positioning these youth as "other" in "dominant education and policy discourses" (p. 8). We choose to think of them as "at promise" for success, rather than "at risk" of failure (Hughes, 2017; Swadener, 2010).

In our work with the LilyPad kits, we created of our own volition, creating together and creating for purpose—three key elements that, through the research, we have discovered are necessary when introducing any makerspace tools or activities. However, in this first iteration of the e-textile research, the pedagogy resembled a traditional model rather than a transformation-based model. We told the students we were going to create bookmarks (that was the only craft we knew how to make). This was limiting, and thus most students were not excited about the prospect of creating a bookmark, especially as struggling readers.

What appeared to occupy most of the students' attention was the idea of sewing. We heard many remarks, both during and after, like "I hate sewing" and "Sewing was my least favourite part." We should have either become more adept with the equipment, so we could have offered a wider range of projects, or been comfortable allowing the students to explore without a prescribed end product. However, being unfamiliar with the tools and pedagogy at the beginning, we took a very limited approach. We explained to the students the tools in the kit and how a circuit worked. We showed them our final products as examples, and asked them to replicate what we had created.

We also interjected when the students got frustrated, and acquiesced when they asked us to help them sew and to "fix" mistakes—like crossed wires, untied knots, and so on. While we still feel that, in order to best support students, a deep understanding of theoretical concepts is necessary when introducing makerspace tools like e-textiles, taking a rigid approach as we initially did is not the answer. When students take the learning process into their own hands, space is created for deeper, more meaningful, and more lasting understanding of theoretical concepts and ideas.

Finally, from this first iteration, we realized that creating for deeply personal reasons better sustains learners throughout the making process, adding the necessary drive to work through challenges. If there is a strong enough vision for the final product, the work it takes to fail, problem solve, and try again is considered worth it—a cost–benefit ratio of great importance when working with students with learning exceptionalities. Unfortunately, the bookmark did not offer enough purpose to keep them engaged—primarily because it was a "purpose" imposed on them and not an internal motivator. If we wanted students to maintain their focus until the end, the students needed to have their own purpose for creating. The lessons that we learned in this initial project were of great importance and informed how we proceeded in our next three iterations of introducing e-textiles to various groups of students.

Iteration Two: March Break Digital Literacies Camp (March 2015)

Our second attempt at using e-textiles with students was during a week-long March break camp held in our research lab in 2015. This group of participants consisted of two females and three males and the students' abilities and skill levels with digital tools ranged from novice to advanced. One student was legally blind, one was diagnosed with ADD, one was on an Individualized Education Program (IEP), and the remaining students were considered "mainstream." Students were recruited through a school-circulated advertisement in two of our partner schools (local schools we collaborate with for research purposes). These schools have been identified as lower-achieving, so our research looks at ways to increase student engagement and achievement through interventions using technology and constructionist pedagogies. We also recruited a group of five university students from the math/science stream at the Faculty of Education, who were interested in working with the students and were keen to learn the new maker tools featured in this research project.

This iteration incorporated changes based on lessons learned from the pilot project, and, instead of positioning ourselves within a classroom, we offered a digital literacies-focused informal learning environment. Also, while the first group consisted of students with learning exceptionalities, this second group was more diverse. The makeup of this group shed new light on how e-textiles could be leveraged in a classroom containing student diversity. During the camp, we used various digital tools, including Scratch, Makey Makey, Arduinos, and LilyPad kits to create tangible and digital products. Each day, the students engaged in a new project using one of the aforementioned digital tools. We were particularly interested to see how the students would engage with the e-textiles when we refrained from stipulating what they should create. We also did not explicitly review how the circuit would work using the parts in the LilyPad kits. We did, however, give the students a more conceptual introduction to circuits using a kinesthetic game called the "Electron Runaround" (Singh, 2010). This game involved a representation of a circuit taped to the floor and the students moving through the circuit as electrons, responding appropriately when the circuit switched from "open" to "closed." This type of embodied learning was important in terms of student engagement and deeper learning. Jewitt (2008) describes how we must consider the gestural in communication and the learning process. It is the various tools, contexts, and activities that work together to assist students in learning new, and often challenging, concepts and skills. As a result, we then had a discussion about the components that make up a simple circuit, to flesh out the students' understanding, and had the students work together to transfer this knowledge to the kits. In referencing the embodied exercise, we asked the students to explain how the parts of the LilyPad kit might work together to make up a circuit. Unlike the first group of students, who saw "sewing" and shut down, this group saw circuits, and sewing became simply a means to create their circuit. In the exit interviews, two students explained what they learned about circuits as a result of the embodied learning, and their desire for school worksheets to be replaced with this hands-on approach:

> Question: Do you think any of the programs you experienced during the week might help you in school?
> Student B: Um, the electricity will…
> Question: How will the electricity…?
> Students A&B: In science…
> Student A: ...we're learning about electrons and protons, so this will definitely help us.
> Student B: ...we did like a worksheet with the exact same thing as, um, the thing [LilyPad], the tape on the ground, like the battery, and the, the resistor.
> Question: So you did a worksheet in school, and you did the activity here?
> Student B: [We] learned that protons don't move and that electrons are really fast.
> Question: Any additional comments that you have, or questions?
> Student B: I think it was just really fun.
> Student A: I wish like, this was replaced instead of school, because yeah. This is a lot better than school. Like it's actually fun learning.
> Student B: We should— we should do some of this in school.

As reflected in these students' comments, their engagement in the creation process was evident. One teacher candidate shared in a post-project interview, "I found that I was actually surprised by how much they did explore on their own and they found things out." Comfortable with the tools and how to build a circuit, the students were then free to create whatever they wanted with the kits.

One of the major differences from the initial iteration was our providing the students with the time and space to create what they wanted. However, in retrospect, as this was only our second attempt at implementing the maker tools, there was still much hands-on and transmission-based intervention (in terms of assistance) from the volunteer teacher candidates. As a result, there was less failure and troubleshooting than typically associated with maker pedagogies. If part of the purpose in working with these tools is to develop a growth mindset and resiliency, our approach still needed tweaking. With an almost one-to-one student to teacher candidate ratio, it was easier for the teacher candidates to interject and correct when the students wanted to give up, rather than to take a more hands-off approach.

Consistent with the first iteration, this group also had difficulty with the fine motor skills involved in sewing, like tying a secure knot, sewing neatly, and not accidentally crossing wires. Because of these kinds of difficulties, the kits were not as "low-floor" (Papert, 1980) as some other circuit kits. The sometimes very delayed gratification that came from finally completing a circuit failed to keep some students engaged—this was clear with both the identified and mainstream students alike. Some students needed to see the cause and effect more immediately to be engaged in the process. The time it took to try, have the circuit fail, and then try something new prevented them from staying on task. As a result, we determined from this iteration that a highly meaningful end goal or product, along with less direct intervention from an authority figure, would be necessary in the next iteration to sustain the students' interest.

Iteration Three: March Break Makerspace Camp (March 2016)

In the third iteration, we again used an informal learning setting in the form of a five-day March break maker camp, and asked teacher candidate volunteers to help facilitate. Throughout the week, 15 teacher candidates (12 females and three males) assisted with the various maker sessions. The sessions had one common theme: How can we spread positive power to others (metaphorically and literally)? The students worked with a different maker tool each day to respond to subquestions related to this theme. In this third attempt, introducing the e-textiles to a group of 16 gifted and mainstream students (five females and 11 males, ranging in age from 8 to 13), we had a few unexpected results that made this iteration of particular interest. In general, the students did not comment on their distaste for or lack of knowledge about sewing (they accepted the kit as another building material), nor did they give up during the learning/making process when it was challenging. The biggest difference this time in introducing the maker tools, and what we believe had the greatest impact, was the pedagogical approach we used throughout the camp. While we attempted a student-centred approach in the other two iterations, with this group we specifically attempted to foster a maker culture or mindset. Maker culture can be described as a learning environment where failures are celebrated as learning opportunities, peer-to-peer collaboration is emphasized, and the artifacts created are innovative, meaningful, and personal. The pedagogical approach was not only student-centred, but focused on making as learning—within a community of learners and with real-world application.

To achieve this maker culture, we relied heavily on the design process, which was scaffolded and included the following steps: (1) pose an inquiry-based and real-world-situated question—something meaningful to the student that would drive their learning and creation; (2) collect important information to inform their construction process; (3) brainstorm a prototype model, analyzing whether or not it would work and responded to their original question; and (4) develop a prototype and present it to their peers to receive feedback. After this, they made any necessary revisions based on the feedback and shared their final product with peers, instructors, and parents during a gallery walk.

The project focus and the choice of materials students could use were embedded in the process, as was collaborative learning. Instructors were asked to position themselves as facilitators, prompting the students to work through challenges with guiding questions and encouraging them to seek assistance from peers when necessary. As the camp progressed over the course of the week, the students became accustomed to using reflective questioning to work through problems, and also to relying on the distributed knowledge of their peers before looking to an adult. This appeared not only to change the dynamic in the camp but also increased the sense of community and ownership over their work. One teacher candidate commented in her post-project interview, “I saw in the students the problem solving skills they had when something didn’t go right.” Another teacher candidate shared, “Their independence was refreshing, and they were all very accepting of one another. It really made me smile to see how willing they were to help each other out, which made the room feel like a safe learning environment.” Collaborative learning and the development of student agency through problem solving and perseverance converged to make this particular learning environment rich, creative, dynamic, personal, and a safe space to take risks in learning.

Finally, creation for meaningful, real-world purposes seemed to contribute to student engagement. Each student responded to the question of creation by asking, “What have I always wanted to wear or own that I could create with the LilyPad kits?” One student started working on circuit-embedded winter gloves that light up at night. A hockey-loving student started working on a light-up hockey stick he could add to his collection of hockey paraphernalia, and a third student started creating decorative birthday tags for her mother’s birthday.

All three elements—creating by choice, creating collaboratively, and creating with real-world purpose—were at work in this third iteration. However, it is also noteworthy to reiterate that the demographic of students in this iteration was a mix of mainstream and gifted students. Undoubtedly, the differences in content-knowledge, previous exposure to electronics (at school and home), and skillsets (most notably, their problem-solving skills) made the process of learning by doing more organic. In general, we believe these students’ abilities to make a project personally meaningful and to persevere through failure enabled them to more frequently realize their end-project goals and final products. Additional analysis regarding the demographics involved in each of the iterations is addressed in further detail in the discussion section below.

Iteration Four: School-based Makerspace Research Project (February–March 2016)

In our fourth iteration using the LilyPad e-textile kits, we drew on our previous experiences and implemented maker pedagogies with a class of Grade 6 students at a local elementary school. This class was made up of 21 students, 10 of whom were on IEPs with various learning exceptionalities (ADHD and cognitive processing impairments). As with the third iteration, we scaffolded the design process, having the students pose questions, plan, create, share, revise, and finally, share their completed products, and we offered a variety of materials they could choose from and projects they could create. We framed the creation of their e-textile products within a unit exploring bullying—what it means to have and exercise negative or positive power, the various roles in a bullying situation, and intervention and prevention strategies. The e-textiles the students created responded to the question: What might we create to spread a message of positive power to students in the school? The e-textiles were to act as a visual representation of why bullying is wrong and should not be perpetuated. The proposed product was a far cry from the mandatory bookmarks we insisted on in iteration one. Furthermore, in this iteration we started the e-textile creation process from a place of familiarity—unplugged arts and crafts. We had the students envision and design their final products first without the circuits (on separate paper or directly on the fabric). We did this as a way to hook the students, and to provide them with a creative and low-floor entry point into circuit work in general. In this way, learning to embed the circuits became the means to the end of a personally creative project. Without this initial artistic envisioning, having the students create circuits simply for the sake of creating circuits may not have been as engaging. We know from previous studies that the creativity involved in a task (often with physical crafting materials), multiple entry points, and personal relevance are major indicators for engagement (Somanath, Morrison, Hughes, Sharlin, & Sousa, 2016).

The choice of end product generated excitement about using the e-textiles and acted as an initial hook, but the difficulties that came with using e-textiles with this demographic of students arose when fine motor skills were required (accuracy and neatness in stitching and knot tying, specifically). While collaborative learning and the creation of personally meaningful artifacts were again important to make the learning process effective, unlike in the other iterations increased teacher intervention and support appeared *necessary* during difficult or frustrating points in the sewing process. We found that in order to help build the students' problem-solving and fine motor skills, we had to interject to facilitate the continuation of their creation process. Otherwise, widespread abandonment of projects was a real possibility (based on previously observed behaviour), and the learning that did end up taking place, we feel, would not have occurred.

Without targeted intervention and assistance, one particular student would have abandoned the work and the subsequent learning involved, as she had demonstrated this kind of behaviour previously with other activities. However, with some assistance, she completed her project and shared that she felt very proud of what she had created. When asked to describe how it felt to complete the project, she commented, "It feels pretty awesome." And when asked if she ever thought she would have been able to do something like this—with circuits and sewing—she said, "No, not really." It was obvious this student enjoyed the crafting element of this project, because she was keen to plan her visual design. She was motivated to then add the circuits because she had a purpose for them, and the original vision would not have been complete without them. In this way, the circuits were a means to an end. When her peers were able to see what she was designing and offer encouragement and positive reinforcement like "That will be so cool!" extra incentive was added. When questioned about the challenges she encountered, she shared her strategy to "keep doing it." We noted other students developing similar perseverance. We felt that helping this student realize her end product and feel a sense of pride for accomplishing it was more important than not intervening at all and risking her disengagement. In the disengagement scenario, she most likely would have learned nothing about circuits and sewing, whereas in reality she is now that much closer to understanding these two concepts and internalizing the rewarding feeling that comes with seeing a project to completion. The intersection of just-in-time support, creative freedom, and creating for many eyes (not just the teacher's) offered this student the right circumstances for engagement and perseverance.

Derek was another student who similarly stood out because of his dispositional trajectory during the learning process. Derek started his work with the LilyPad kits with a negative attitude and minimal engagement. He was heard saying things like "I don't know how to do this," "I don't want to do this," and "Why are we doing this?" However, with support from one of the teachers who posed guiding questions, he observably took more ownership over the circuit sewing task and he more willingly engaged in problem solving. The help the teacher provided was as follows: The teacher first asked Derek to observe a circuit (previously stitched by an adult) on one side of the fabric, and to describe what he saw and thought was happening to make the circuit work. This was a low-floor entry point that allowed Derek to situate himself in the familiar and to start from a place of knowing. After describing the circuit successfully, he then attempted it on his own on the other side. When the circuit worked, he appeared pleased with himself, smiling and sharing, "It worked!" At one point, however, the light turned off and he exclaimed, "It's not working!" and again became disengaged and frustrated, and responded as though the broken circuit was not something he could control or change. However, he did some additional problem solving with the teacher and figured out that it was not working because one of the threads on the back of his fabric was too long and at times crossed over to touch the other side. When Derek was asked what he thought was wrong, he shared, "The positive is touching the negative." Through repeat exposure to these kinds of activities that involve reflective thinking and troubleshooting, by the end of the project Derek showed emerging signs of being able to meet and work through challenges on his own. In this case, the intersection of just-in-time support, a safe learning environment, and hands-on materials helped Derek engage with the learning.

Discussion

Providing students with opportunities to experiment with a range of technologies and to explore making alongside their peers helps students develop the 21st-century skills and competencies they will need to be successful in school, at work, and in life. Exploring teaching and learning with e-textiles in the four previously outlined contexts has led us to draw a number of important conclusions about making as learning, and specifically about the use of e-textiles. Most importantly, we understand that choice, collaboration, and making for purpose are three vital elements that promote engagement and deep learning (surface learning being equated to replication and deep learning to innovation and conceptual understanding).

Three Elements to Promote Engagement

Choice. In the last three iterations, having the creative freedom to decide what to make encouraged student engagement, motivation to see the project through, and agency. The first iteration, unlike the last three, had the least amount of choice and also the least amount of buy-in or connection to the work. In contrast, the students in the last three iterations had a very different experience with the LilyPad kits—for the most part, they were excited at the prospect of creating their own designs using the kits. This choice was also important in terms of allowing the students multiple entry points into their designs and learning, which adheres to Resnick et al.'s (2009) theory of "wide walls," and the idea that choice accommodates a diversity of learners and preferred learning approaches. Furthermore, the choice meant that students, depending on their previous experiences, knowledge, and comfort levels with coding, sewing, and artistic design, could make their artifacts as simple (low-floor) or elaborate (high-ceiling) as they wanted.

Collaboration. In the iterations where collaboration was encouraged most prominently (primarily iterations three and four), the students were also more engaged in the learning. This appears to be due to the shift in classroom dynamic from teacher-centred or initiated to learner-centred, with a focus on distributed knowledge. With this levelling of the playing field for learning, more space was created for students to inhabit the role of "teacher." Undoubtedly, this influenced students' feelings of efficacy and their social presence in the classroom and learning process, and it also helped build a community of practice.

Making for purpose. Finally, making with purpose, or to solve a real-world problem, revealed itself to be the other main element influencing student engagement. Making for purpose provided students with a personal connection to, and therefore investment in, their work. What was being made had a potential use beyond the classroom walls. The students created something of relevance both to themselves and the real world, which is part of critical making and more specifically part of the "Critical Thinking" category on the draft of the yet-to-be-published Ontario report card: "plans and manages a project to solve a real-world problem." The resultant motivation that arises out of this real-world connection is a sustaining factor when it comes to engagement, making, and, ultimately, learning.

Three other key elements that emerged from these four iterations include (1) the need for just-in-time support (especially for struggling students); (2) fostering a maker culture in one's classroom to encourage trial and error, promote failure as a way of learning, and help build perseverance; and, finally, (3) the incorporation of additional kinesthetic learning activities to help support the conceptual knowledge being built (for example, in iteration two the use of the "Electron Runaround" activity to supplement students' understanding of how electrons flow in a circuit).

Considerations

The design process was new for some students in the third and fourth iterations, and at times the unfamiliarity, or rather the relative freedom of choice, appeared to paralyze some of them. This was an interesting finding, though not entirely surprising. This paralysis seemed to be the result of our current transmission-based system, which fosters a generation of students hesitant to take risks when control is handed over to them. For us, it highlighted the need for a new way of "doing school," and the role makerspace tools and pedagogies can play in large-scale education reform. Should schools begin to adopt makerspace tools, like e-textiles, it is important to remember that student motivation to create occurs when there is a balance of choice, creating for purpose, and collaboration. From our research exploring the implementation of e-textiles, these three elements also appear to sustain a student's interest in problem solving during the creative process, and then lay the groundwork for meaningful, student-centred learning.

It is important, also, to note that the demographics in each of the case studies varied widely, from students removed from the mainstream, to students in the mainstream on IEPs, to gifted students. We noted that students who came from a mainstream or gifted program appeared to be already familiar with some of the concepts associated with the design process, for example what it means to pre-plan; what it means to take ownership over a self-directed project; what it means to self-regulate when emotions begin to impact the creation process; what it means to collaborate with others; what it means to use problem-solving skills to troubleshoot issues that arise during the creation and learning process; and what it means to create a positive and supportive learning environment where ideas and people are respected. We believe these understandings had an impact on the way in which the students engaged with the content, tools, and learning process. Students in the first and fourth iterations, who did not exhibit the same understandings, were primarily from low socio-economic, "high priority" neighbourhoods. The school these students attended is centrally located within an area identified as at "high risk" as determined by the Durham Region's Social Risk Index (Durham Region Health Department, 2015), which indicates that the area has the lowest average household income and lowest proportion of owner-occupied dwellings. In addition, the community has a very high number of lone parent families and a high reliance on government support payments. The unemployment rate is also high in comparison to the rest of the region.

The link between low education rates and poverty is clear (Ciuffetelli Parker & Flessa, 2011). The strategies that Brown and Giles (2012) recommend for addressing poverty in elementary schools include creating a learning environment that enables students to experience success, setting high expectations while keeping the environment "low in threat, to counter the high-stress living environment" (p. 30) that many of these students live in, encouraging students to practice tasks independently, with sufficient scaffolding to help them complete projects successfully, and building resilience by "triumphing over challenge" (p. 34). A maker culture facilitates all of these strategies.

We also feel the differences between these groups (advantaged vs. less advantaged) led to the incredibly varied end products and results across the iterations, in part because the students did not have the same schema from which to draw ideas and inspiration. We noted a gap in understanding between "at-promise" students and those in mainstream or gifted larger than any gap based on gender. As noted in our comments describing iteration two, there was no discernible difference between the male and female students when it came to preconceived notions of sewing. When e-textiles were presented as simply a way to create a circuit on fabric, we observed no resistance to sewing from the males. In fact, in the fourth iteration, the majority of the males and females demonstrated a higher level of engagement in the e-textiles project than they typically exhibited for other projects. As previously stated, we attributed this to the fact that the circuit building was embedded into the "real world" application of an anti-bullying initiative.

It is clear from our research that a current need in this area is to define best practices and to better understand how to utilize making more generally, and e-textiles specifically, for the purpose of learning (Halverson & Sheridan, 2014), and how making can be made accessible to all. The vast majority of technology kits (including e-textiles kits) are quite expensive. In the case of our projects, we also purchased items such as canvas tote bags, hats, T-shirts, gloves, and scarves for the students to use as a foundation for their creations. The high costs cannot be ignored and give rise to the question of whether e-textiles are meant for everyone to use and enjoy or if they are merely meant to serve as a playground for the affluent.

Many schools with low socio-economic status (SES) and students from families with low SES simply do not have the resources necessary to be able to fund these kinds of projects. Schools attended by students whose families live in poverty have less access to most kinds of technology (Morse, 2004). Many underprivileged schools and communities are not able to create makerspaces, thus widening the digital divide. To create equal opportunities for their students, these schools need to think creatively to find ways to acquire materials or equipment, including placing an emphasis on recycling, upcycling, and do-it-yourself (DIY), or personally created, e-textile components, using materials found in local hardware and craft stores (Buechley & Eisenberg, 2009). This approach requires more foundational knowledge, whereas premade kits offer users of all abilities the opportunity to focus on design and function without having to create the tools to begin their project.

Finally, the success of the fourth iteration, with a group of typically struggling students, speaks to the importance of bridging curricular expectations in multiple subject areas by creating inquiry based design challenges, which require students to have knowledge in multiple areas. It is easy to cover science expectations with e-textiles in Grade 6 because of the emphasis on circuits, design, and construction in the Ontario curriculum. However, using e-textiles to make cross-curricular connections, and having students create connections between subjects, could be key to helping students think globally and preparing them for the job market they will face upon graduation. The kind of constructivist maker pedagogy used in the fourth iteration has the potential to engage and inspire students because of its real-life applications. Students are able to create something personally meaningful that they can see changing life for others around them.

Conclusion

As Peppler (2013) notes, students using e-textiles "garner expertise in several content areas as well as the skill sets to think across traditional disciplinary boundaries" (p. 41). This indicates that many cross-curricular connections can be made. However, the existing research does not touch on curriculum connections other than circuitry, computer sciences, and programming. Researchers acknowledge fields that already benefit from the use of e-textiles, such as music, fashion, theatre, sports, and biology (Buechley, 2009; Buechley & Eisenberg, 2008; Peppler, 2013). A recent report prepared by the Brookfield Institute for Innovation and Entrepreneurship (Lamb & Doyle, 2017) emphasizes the value of preparing students for careers in a global and internet-based economy. Wearable technologies in the areas of sports, health, medicine, and education have a promising future, and introduction to e-textiles at an early age can promote interest in this field.

This leads to the question, Are elementary students engaging with e-textiles in ways that can be connected to Ontario curriculum beyond Grade 6 science? This question should be answered through additional situated learning based studies, such as the one described in iteration four, because e-textiles offer possibilities for students to design wearable technology for real-life situations that are not applicable to only one discipline at a time. Students should be given chances to problem solve for real challenges in a variety of fields and to pool their knowledge with one another.

Research that stems from the discussion of community that can be developed around the reflection, presentation, and critique of e-textiles projects involves the literacy skills developed in the e-textiles design process. Peppler (2013) found that students "develop technical writing skills and learn the fundamentals of multimedia design, such as how to tie images to video to text" (p. 43), but no formal study has been found that speaks in-depth about this concept. Specifically, more studies are needed on e-textile processes in the elementary classroom and direct relations between multiliteracies and hands-on, craft-based mediums, such as e-textiles. A question can be asked about the ways that the e-textiles design process impacts students' development of multiliteracies. In a multiliteracies framework, there are many aspects of literacy embodied in the choices that someone makes while they are formulating ideas, creating, and sharing (Hughes & Thompson, 2013; Kafai, Peppler, et al., 2011). A study is needed to investigate the types of literacies that the e-textiles design process promotes and the ways they can be translated between one another.

There are many affordances for using e-textiles in the classroom; however, some significant challenges also exist, specifically the need for teacher professional development (Buechley et al., 2008; Kafai, Peppler, et al., 2011). More Canadian in-class data are needed, as most existing studies focus on extra-curricular workshops. While many makerspaces in Ontario schools have begun in school libraries or as lunch and after school clubs, more teachers are embracing makerspaces and maker pedagogies in their classrooms; as a result, the use of e-textiles will also become more prevalent in Ontario classrooms. E-textiles are useful for teaching students through embodied cognition because they bridge the gap between the physical state of creating and the theoretical knowledge students must apply (i.e., to ensure that their circuit or programming is functional). E-textiles promote many of the global skills and competencies outlined by the Ontario Ministry of Education (2016)—most prominently, problem solving, creativity, metacognition, and collaboration. If students are to truly develop in these competencies, then choice, collaboration, just-in-time instruction, and purposeful making are necessary elements to consider when using e-textiles in the classroom.

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