Handbook of Research on the Societal Impact of Digital Media

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A volume in the Advances in Media, Entertainment, and the Arts (AMEA) Book Series

Information Science REFERENCE
An Imprint of IGI Global

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Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA, USA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

Library of Congress Cataloging-in-Publication Data

Handbook of research on the societal impact of digital media / Barbara Guzzetti and Mellinee Lesley, editors.
pages cm
Includes bibliographical references and index.
ISBN 978-1-4666-8310-5 (hardcover) -- ISBN 978-1-4666-8311-2 (ebook) 1. Information society. 2. Digital media--Social aspects. 3. Information technology--Social aspects. 4. Educational innovations. I. Guzzetti, Barbara J. II. Lesley, Mellinee, 1965-
HM851.H34836 2016
302.23'1--dc23

2015019888

This book is published in the IGI Global book series Advances in Media, Entertainment, and the Arts (AMEA) (ISSN: Pending; eISSN: pending)

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

For electronic access to this publication, please contact: eresources@igi-global.com.

Chapter 11
A Review of E-Textiles in Education and Society

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ABSTRACT

The recent emergence of digital creativity that extends beyond the screen and into the physical world, engendering new forms of creative production, has transformed educational and professional fields. From AT&T's bio-tracking clothing to Lady Gaga's smart-hydraulic "Living Dress," e-textiles infuse fashion with electronics to produce unique and aesthetic effects using new conductive materials, including thread, yarn, paint, and fabrics woven from copper, silver, or other highly conductive fibers. This chapter outlines both the educational and societal implications of these new materials in the field of e-textile creation like consumer-ready e-textile toolkits, high-profile displays of imaginative e-textile creations and an increasing body of Do-It-Yourself (DIY) literature on e-textile design that have emerged in the past decade. It also looks at ways in which e-textiles are transforming new solutions to old and persistent problems of underrepresentation of women and minorities in STEM fields and providing a vehicle in which to rethink teaching and learning in these disciplines.

INTRODUCTION

Recent years have marked the emergence of digital creativity that extends beyond the screen and into the physical world, engendering new forms of creative production that are transforming educational and professional fields. This trend is exemplified with particular gusto in the rise of e-textiles: fabric artifacts that include embedded computers and other electronics. From AT&T's bio-tracking clothing to Lady Gaga's smart-hydraulic "Living Dress," e-textiles infuse fashion with electronics to produce unique and aesthetic effects using new conductive materials, including thread, yarn, paint, and fabrics woven from copper, silver, or other highly conductive fibers (Buechley, Peppler, Eisenberg & Kafai, 2013).

While computing and textiles have a longstanding—though rarely acknowledged—relationship, the domain of e-textiles historically has been considered a highly specialized niche area of design. However, changing the possibilities and perceptions of a broader field of e-textile creation are new sets of consumer-ready e-textile toolkits

DOI: 10.4018/978-1-4666-8310-5.ch011

(Buechley, Elumeze, & Eisenberg, 2006; Reichel et al., 2006), high-profile displays of imaginative e-textile creations (e.g., Chalayan, 2011) and an increasing body of Do-It-Yourself (DIY) literature on e-textile design (Lewis & Lin, 2008; Pakhchyan, 2008; Eng, 2009) that have emerged in the past decade.

This chapter outlines both the educational and societal implications of these new materials, including how e-textiles are transforming the ways in which we re-envision new solutions to old and persistent problems of underrepresentation of women and minorities in science, technology, engineering, and mathematics (STEM) fields as well as enable us to radically rethink teaching and learning in these disciplines.

BACKGROUND: E-TEXTILES IN PRACTICE

E-textile projects can range from computationally enhanced articles of clothing to home furnishings to architecture, underscoring through tacit or explicit means how computing can be soft, colorful, approachable, and beautiful. E-textile artifacts can range from the whimsical (for example, dresses that expand in circumference when personal space is encroached upon, traditional embroideries that glow and sing) to the mission-critical (for example, smart military uniforms, sportswear that monitors health indicators, portable medical devices). Examples below help to situate e-textiles for those unfamiliar with this emerging domain.

- **Wearable Workout Buddy:** A knitted arm band embedded with a circular sensor and wireless transmitter detects whether its wearer's arm is bent or straight. This band communicates via Bluetooth with an application running on an Android phone, which keeps a running tally of the repetitions—a useful aid to workout sessions that involve push-ups, pull-ups, or other upper body exercises (Kaufmann & Buechley, 2010). Circular sensors are nicely suited to a range of wearable applications since tubular structures make up the sleeves, torsos, and legs of garments.
- **Music-Improvisation Dance Costume:** A collaboration between multiple artists and software designers resulted in the development of a computationally enhanced dance costume and accompanying musical environment (Lindsay, 2013). The dance costume is augmented with a microcontroller, a wireless transmitter, and various sensors that detect and transmit the movements of the dancer to a laptop, which then converts dance data to sound parameters in MAX/MSP, a programming language for interactive music and multimedia. The e-textiles facilitate interactivity between dancers' movements and the music that accompanies their dancing, transforming the power dynamic between composer and choreographer by putting the power of live musical improvisation in the hands (bodies) of dancers. Like the development of a traditional instrument, designing a dance costume to facilitate musical improvisation requires careful cross-disciplinary consideration of its functional components as well as its expressive capabilities; sensors have to track the most communicative motions of the dancers, the music controls have to be sensitive to the gestures onstage but conspicuous enough so as to ensure the audience know what movements elicit which kinds of sounds, and the costumes have to withstand duress from stretching, heat, and perspiration.
- **Fairytale Fashion:** To promote science and technology learning through fashion design, a fashion collection was created using technology to make "magical" clothing that functions in real life (Eng, 2013). The resulting e-textile designs

employ various combinations of motion-controlled electroluminescent (EL) wire, moving biomimetic deployable structures, audio-controlled twinkling, and inflation. The electroluminescent motion-controlled garments, inspired by bioluminescent sea creatures, are made from silk chiffon edged in EL wire to have the same motion as jellyfish. The EL wire is powered by custom accelerometer-controlled drivers paired with an Arduino Duemilanove encased in a 3D printed housing. As the wearer walks, the garment flows and illuminates in reaction to their movements. Similarly, twinkle garments sparkle in reaction to sound, particularly the wearer's voice. LEDs, hand-embroidered to the garments, light up to create the twinkling effect.

- **Embedding Knitting Patterns in Knitted Objects:** Despite associations with antiquated traditions, knitting communities are often hotbeds of innovative approaches to high-tech textile production. Blending traditional craft with modern science, the "Know-It-All Bag" is a knitting bag embedded with a programmable microcontroller and 10 LEDs that express a series of knit stitches in light patterns (Craig, 2013). The programmable patterns help knitters to keep track of their stitching pattern while presenting an interpretation of knitting as software engineering.
- **Haute Couture Meets High Tech:** Bringing together experts from diverse fields such as microelectronics, wireless communication, embroidery, fashion design, and interaction design, the "Climate Dress" is an interactive dress that reacts to CO2 changes in the nearby surroundings (Diffus Design, 2013). Using several microcontrollers and a CO2 sensor, the dress responds to the CO2 concentration in the air by producing diverse light patterns with over a hundred LEDs—varying from slow light pulsations to hectic flashes. The Climate Dress is a statement that, through an aesthetic representation of environmental data, contributes to the ongoing debate about environmental issues.

Though the applications of e-textiles are varied, virtually all projects are unified in their incongruity, their unique combination of surprisingly disparate elements and construction practices. These juxtapositions serve as an invitation—for expertise across physical and digital domains to coalesce and spark new connections, for newcomers to engage in unfamiliar modes of production, as well as for upending stereotypes of who constructs technology and for what (and whom) they are designed.

E-Textiles as the Intersection of Coding, Crafting, and Circuitry Construction

E-textile designs involve the multiple disciplines of computer science, engineering, and the arts as designers engage in the three intersecting domains of coding, crafting, and circuitry (Kafai, Fields, & Searle, 2012; Peppler, 2013). However, despite sharing many common roots with robotic constructions (whose appearance is often secondary—if considered at all—to their ability to execute a task), e-textile artifacts are frequently conceived of as aesthetically compelling designs with electronically enhanced capabilities.

As a backbone to nearly any project at the intersection of physical and digital media, computer programming or "coding" is essential to more interactive forms of e-textile design (Peppler, 2010). However, e-textile designers are less concerned with coding efficiency valued in computer science and engineering—i.e., having as few lines of codes as possible—than with the aesthetics of the design, aiming to achieve a particular artistic effect. For example, what feelings do LEDs sewn into a fabric induce in a viewer when they are programmed to glimmer softly as opposed to blink rapidly? Coding can take on many forms in e-textile projects, ranging from text-based coding environments, like Arduino (Banzi, 2008), to more novice-friendly graphical programming block environments, like Modkit (Baafi & Millner, 2011).

In addition to coding, when e-textile designers create new works, they must make educated guesses about what material to use or craft with in their designs. In most cases, novices to e-textiles do not fully understand the energy-transfer capabilities of physical objects and have difficulty distinguishing conductive from insulating materials. For example, even adult designers will incorrectly hypothesize that oil-based clay will be conductive (as they consider it to be "wet" [Peppler, Sharpe & Glosson, 2013]). Designers also often have to envision novel uses for existing materials (for example, glass beads to insulate the conductive thread, a zipper on a hoodie to act as a switch in the circuit, or a patch of conductive fabric as a capacitor) or turn to new materials such as conductive yarn, paint, or thread. Coming up with new uses for mundane materials, or understanding the physical properties of unfamiliar materials, can take considerable trial and error. Novice designers who forget about the material properties of thick, metallic-conductive thread and use it for decorative stitching as well as to sew their electronic circuits will unintentionally create shorts in the circuitry.

Creating e-textiles requires a firm understanding of electronic circuitry, yet even simple circuits can pose a challenge to new designers. For example, balancing the number of LEDs that can be lit by a 3V battery, accounting for Ohm's law, and wiring components in series and in parallel are all considerations that affect even the most basic e-textile construction (Peppler, Salen-Tekinbaş, Gresalfi, & Santo, 2014). New materials also offer unique possibilities in electronic designs—for example, the natural resistance of conductive thread can be used instead of a traditional resistor or in place of a commercially available dimmer switch (i.e., the longer the thread, the greater the resistance in the circuit, and the shorter the thread, the less resistance in the circuit, which will cause the light to grow brighter). Much innovation in e-textile designs comes from creating textile analogues of traditional electronic components: soft speakers from magnets and conductive thread, switches from conductive beads, and so on (Perner-Wilson & Buechley, 2013).

By merging sewing and electronics practices, e-textiles meaningfully combine two sets of gendered practices and expectations associated with craft and electronic materials. Drawing upon mediated discourse theory, each set of e-textiles practices and materials is situated in a *nexus of practice* (Scollon, 2001), a set of social practices and artifacts tacitly-shared and valued among members in a cultural group. Each cultural practice—with related tools and materials—carries distinct expectations for whom and what constitutes experts and expertise. For example, skillful sewing with needles and fabric signals expertise in crafting or fashion cultures, while successful construction of a working circuit signals expertise in electrical engineering or STEM learning communities. Additionally, these practices signal femininities and masculinities in gendered communities of practice (Connell & Messerschmidt, 2005; Paechter, 2003) through histories of sewing (Beaudry, 2006) for girls and electronics for boys (Foster, 1995a/1995b) along with their contemporary traces in expectations for female consumers of craft kits and fashion and for male consumers of video games and robotics. This new nexus of e-textiles practice has implications for both participation and learning over time.

Textiles + Electronics: A Symbiotic History

Contemporary e-textiles represent a unique juxtaposition of high-tech (for example, sensors, electronics and code) and low-tech (i.e., traditional crafting) materials. Despite the chasm implied by these diverse materials, high-tech computing has a long and intimate relationship with crafting practice, arcing back to the development of the Jacquard loom in the early 1800s. The Jacquard loom—the first "programmed" mechanical device—enabled the user to feed customizable reels of punched paper into the loom that would result in the weaving of specific patterns. These looms, in turn, inspired the design of the first machine, Babbage's Analytical Engine (Essinger, 2007).

Similarly, the integration of electronics and textiles has rich historical precedents. The best electrical conductors, metals, have been incorporated into textiles for over a thousand years (Fisch, 1996; Harris, 1993). From armor to decorative clothing to wall hangings, metal of various sizes has been sewn into clothing for a variety of aesthetic and functional purposes. Cultures around the world have long celebrated the work of artisans, some of the earliest pioneers of metal-textile integration, who embroidered fine fabrics with threads wrapped in fine metal foils like gold and silver (Chung, 2005; Digby, 1964). By the late 1800s, engineers were imbuing electrical novelty into the design of electricity-enhanced clothing and jewelry, such as illuminated and/or motorized necklaces, hats, broaches, and costumes (Marvin, 1990; Gere & Rudoe, 2010).

Worldwide fascination with space exploration in the 1960s sparked an invigorated interest in the relationship between technology and apparel. The Museum of Contemporary Craft in New York City encapsulated this trend with a groundbreaking exhibition in 1968 that featured astronauts' space suits along with clothing that could inflate and deflate, light up, and heat and cool itself (Smith, 1968). Diana Dew, a designer who created an entire line of electronic fashion, including electro-luminescent party dresses and belts that could sound alarm sirens, was particularly noteworthy figure in this era.

The 1990s saw another leap forward in the advancement of textile-electronic interaction, led by two different research groups at MIT. One team, led by researchers Steve Mann, Thad Starner, and Sandy Pentland, coined the term "wearable computers," which referred to traditional computer hardware that could attach to and be carried on the body (Starner, 2002). A second team, led by Maggie Orth, integrated far-reaching perspectives ranging from medical applications to toy design to fashion to car manufacturing into the exploration of how computationally enhanced electronics could be gracefully integrated into clothing and made relevant across industry verticals (Post & Orth, 1997; Orth, Post, & Cooper, 1998; Post et al., 2000). This later approach represented a notable shift in the concept of e-textiles with its equal focus on material design and technological innovation, an honoring of both engineering and traditional craft lineages.

Since these initial investigations, a small but growing community of scientists and engineers in materials science, electrical engineering, and health sciences, along with a handful of pioneers in art and design, has been exploring e-textiles (e.g., Post et al., 2000; Marculescu et al., 2003; Pacelli et al., 2006; Papadopoulos, 2007). The field remained highly specialized and inaccessible until the recent introduction of e-textile construction kits (Buechley, 2006; Buechley et al., 2008), which made the previously prohibitively complex domain accessible to educators, hobbyist DIYers, and youth designers.

The Design and Democratization of E-Textile Construction Kits

Today, the market for consumer-ready e-textile design toolkits is wide and ever-expanding. Though there are several such kits worthy of attention, this chapter focuses on the design and development of four compelling examples: the *LilyPad Arduino* (Buechley, Elumeze, & Eisenberg, 2006), *i*CATch* (Ngai, Chan & Ng, 2013), *Schemer* (Elumeze, 2013), and "*a kit of no parts*" (Perner-Wilson & Buechley, 2013). Each of these kits takes a strikingly different approach to the blending of crafts, coding and electronic circuitry construction inherent in e-textile design (Peppler, 2013).

In 2008, an open-source design appeared on Instructables.com featuring a jacket with turn signals that could be illuminated by the bike rider (Instructables.com, 2008). The signals were powered by a LilyPad Arduino kit (or simply "LilyPad"), the first e-textiles toolkit created for a consumer market (Buechley & Eisenberg, 2009; Buechley, 2006). Designed by MIT Professor Leah Buechley, the LilyPad Arduino was conceived in a similar fashion as the Lego Mindstorms (LEGO) kit for robotics, requiring a basic understanding of programming and electronics, but allowed people to build interactive fashion instead of robots. The kit features a small, programmable computer—a variation of the popular Arduino microcontroller (Banzi, 2008) called the LilyPad Simple Board—in addition to LED lights, switches, motors, and sensors. The kit's custom electronics are recognizable by their colorful and round designs as well as the large sewable petals. The electronic pieces can then be stitched together with conductive thread to create soft, interactive devices, such as electronically enhanced t-shirts, electronic cuffs, and solar-powered backpacks (Peppler, Gresalfi, Salen Tekinbaş, & Santo, 2014).

The LilyPad was designed to overcome two substantive challenges facing consumer-ready e-textiles projects. The first was the redesign of everyday electronics to make them both sewable and washable. This included material substitutions so that, for example, the two legs found on a typical LED could be replaced with flat, sewable holes that could be easily stitched into clothing. The second challenge was the development of a sewable microcontroller—and an accompanying easy-to-use programming language—so that even young learners could code complex interactivity into their creations. The resulting wearable computer was handmade out of circular pieces of fabric where designers could literally sew through the fabric of the computer to create a connection rather than snapping or soldering connections. The LilyPad board was named because of its resemblance to a flower, with sewable petals arranged around a central computing device (Buechley, 2013). In response to growing consumer demand, Buechley teamed up with SparkFun Electronics to transform the textile circuit board into a small, thin metal circle with 22 sew-holes around its circumference while maintaining the flower-like layout. With its dual emphasis on sewing and programming, the LilyPad enables the construction of highly customizable projects, making it popular with designers, engineers, artists, and educators alike.

The LilyPad Arduino, though immensely popular in today's landscape, represents one of many approaches to combining textiles and electronics. Another kit, i*CATch, designed by Grace Ngai and colleagues, emphasizes the computational ideas and processes in e-textiles creation (Ngai et al., 2010). Users of this kit employ snap-on electronic modules that attach to pre-made garments, like vests and t-shirts. The garments contain lengths of a special tape that carry electrical signals from one place to another. The kit is designed so that novices can be freed from the arduous task of designing and sewing electrical connections, and focus instead on defining the behavior of their constructions using a visual programming environment. Analyses of novices' projects in workshops indicate that i*CATch successfully facilitates the creation of computationally complex projects and encourages iterative experimentation and trial-and-error learning, as well as collaborative learning (Ngai, Chan, & Ng, 2013). For example, Ngai and colleagues noticed children reusing code from introductory tasks in their final projects, and the complexity of their projects also increased from task to task because of the affordances of the i*CATch designs.

Taking a different approach to programming e-textile construction kits, Schemer (Elumeze, 2013) is a set of sewable electronic modules similarly constructed to the LilyPad designs but offering more versatile approaches to programming. For instance, designers can compile code for their e-textile creations using a screen-based application, as well as create them physically by drawing pictures, tapping musical notes and melodies, scanning barcodes printed on various surfaces like paper, cloth, or walls, or by using a range of colored pieces of felt, paper, and cloth. These "physical programs" are then uploaded to a wearable computer wirelessly by waving Schemer constructions across the surface so that a light sensor can read the program or playing a tune that can be heard by a sound sensor and interpreted by Schemer. This kit presents a glimpse into an exciting future of tangible programming, where people will not need to shift their focus from their physical environment to onscreen devices in order to code and reprogram their devices.

Hannah Perner-Wilson and Leah Buechley further explore the relationships between construction kits and raw materials in their "kit of no parts" (2013), a kit notable for its lack of prefabricated electronic components. In their place, electronic components can be constructed out of raw crafting materials like conductive and non-conductive thread, fabric, yarn, and beads. Over the course of several years, Perner-Wilson and Buechley designed, developed, and tested their sensor library consisting of four basic categories: tilt sensors, stroke sensors, stretch sensors, and pressure/bend sensors. The "stroke sensor," by way of example, is a soft carpet-like fabric that can detect when it is touched. When the tufts of conductive yarn or thread are stroked or compressed, the threads brush against one another, thus decreasing the resistance between the two strips of conductive fabric and sensing touch. This kit encourages the repurposing of everyday and low-cost materials in e-textile designs, affording novel opportunities for personalization and learning. Because every element of a sensor is made by hand, designers achieve a rich understanding of basic electronic and sensing principles. Moreover, completed designs exhibit a functional transparency that supports understanding—all of the functional elements of the sensors remain visible in the finished artifacts (Perner-Wilson & Buechley, 2013; Kafai & Peppler, 2014).

The kits showcased here represent a variety of ways to engage with the tensions between mixing textiles and electronics, each emphasizing different intellectual, cultural, and aesthetic affordances that exist at this intersection. For example, the LilyPad Arduino and a "kit of no parts" introduce tools that emphasize traditional crafts and make visible electrical connections, while i*CATch works primarily to deepen computational experiences by lowering barriers to entry by minimizing craft and electronic activities and concealing and abstracting electrical connections. Schemer sits on the opposite end of the spectrum in its approach to programming that takes computation to the physical world, providing a provocative alternative to the screen-based programming environments used by LilyPad Arduino and i*CATch. The "kit of no parts," by contrast, stresses the kinds of material creativity possible without the addition of computation. This tension is present even in the language used by the designers themselves; where most designers use "electronic textiles" to refer to their projects, the i*CATch creators prefer "wearable computers" when describing their approach to e-textile designs.

Taken together, this collection of e-textile construction kits begins to illustrate the broad and diverse potential of e-textiles, which can be used to explore ideas in a range of fields including design, art, computer science, and engineering, and the unique affordances of each of these different kits help support different educational approaches.

E-Textiles in Education

While new e-textile construction kits offer an exciting new range of tools and materials, novice educators and students need a set of compelling sample projects, new guiding pedagogies and workshop models, and clear ties to the existing education system (for example, to the Common Core State Standards and/or the Next Generation Science Standards) in order for e-textiles to be used in educational settings. Speaking to the gap between the first encounter with e-textiles and initial design ideas, Maggie Orth reports that the general public tends to view e-textiles as "magic" and is unable to imagine what could be realistically designed with these new tools and materials:

To the general public electronic textiles seem fantastic. I have never forgotten the doctor who asked me, "Can you make a coat that will detect how my patients will react to chemotherapy?"

"What technology do you use now?" I responded.

"There is none," he said. This man of science hoped that electronic textiles might do something that no existing 1000 lb. piece of commercial lab equipment could do. He thought electronic textiles might be magic (Orth, 2013, p. 201).

This speaks to the general challenge that new tools and materials confront as they are first being adopted by the broader public but particularly as we seek to excite the imaginations of young children and inspire them to create working prototypes with e-textiles.

Seeking to help populate the collective imagination and lower barriers to getting started with e-textile creation, a series of DIY books on e-textiles have been published over the last decade (Lewis & Lin, 2008; Pakhchyan, 2008; Eng, 2009; Buechley & Qiu, 2013). In addition, the authors have also co-designed new curricular toolkits along with leading national educators from the National Writing Project to help bridge the gap between e-textile activities and creating an educational curriculum (Peppler, Gresalfi, Salen Tekinbaş, & Santo, 2014; Peppler, Salen Tekinbaş, Gresalfi, & Santo, 2014). The *Interconnections* curricular toolkit, for example, supports a design-based approach to learning about ways that e-textiles aligns with current Common Core and Next Generation Science Standards while still being relevant to youth interests in fashion, storytelling, and puppetry (ibid.). The series teaches design and systems thinking concepts and skills in the context of e-textiles and includes four design challenges or learning projects in each volume.

Consequently, given the new tools and supporting materials now available, as well as the general push for more hands-on making in educational settings spurred on by the larger Maker Movement (Peppler & Bender, 2013; Dougherty, 2013; Anderson, 2012; Kafai, Fields, & Searle, 2014; Kafai, et al, 2013, 2014), the use of e-textiles is rapidly expanding in educational contexts. This can be seen in workshops and applications ranging from early childhood science classrooms (Peppler & Danish, 2013) to out-of-school fine arts programs (Peppler, Sharpe, & Glosson, 2013) to college engineering courses (Eisenberg, Eisenberg, & Huang, 2013). Across these settings, e-textiles represent opportunities to revisit misperceptions perpetuated by traditional tools and materials or to spark creative exploration at the intersection of two or more domains.

Opportunities to learn with e-textiles can extend to students considered too young to design with thread and electronic components. For instance, I have worked with learning scientist Joshua Danish on the creation of computationally enhanced puppets that engage children in complex systems learning via participatory simulation (Peppler & Danish, 2013). Using bee puppets embedded with sensors, students become a bee in search of honey. E-textile sensors embedded in the puppets keep track of nectar collected while children forage for more nectar before returning to a computationally enhanced "hive." Such embodied participatory simulations turn e-textiles into prototyping tools that educators can use to design and customize their own simulations in a variety of content areas. This takes e-textiles into the realm of augmented learning and moves that genre of educational technology past tablets and smartphones into other softer forms.

In more advanced grade levels, educators have introduced e-textile design to promote deeper learning and connections across disciplines. For example, there are few opportunities for youth to learn about computing and engineering in high school classes, especially ones that introduce computing with non-traditional materials. Many efforts have focused on game design or robotics activities that are popular with boys but limited in appeal to girls. In response, Yasmin Kafai, Deborah Fields, and Kristin Searle introduced e-textiles to high school youth in a series of workshops designed to examine how youth forge connections across crafting, engineering, and computing in the process of e-textiles creation (Kafai, Fields, & Searle, 2012). The researchers discovered that designing across disciplines promoted transparency of learning across stages of their projects—the designers would reflect upon and rethink how to code their programs as they stitched their circuits, and vice versa.

Other learning settings have explored the affordances of body sensing and other aspects of physical computing in youth sports and theater projects (Schelhowe et al, 2013). Using a construction kit called EduWear, researchers Heidi Schelhowe, Eva-Sophie Katterfeldt, Nadine Dittert, and Milena Reichel used e-textiles to help youth keep track of and learn from their body movements in sports. Similarly, a multidisciplinary team of artists, fashion designers, and computer programmers studying at Indiana University used a similar method of body sensors and wireless transmitters in a contemporary dance performance that facilitated multiple levels of interactivity between dancers, costumes, and the environment (Lindsay, 2013).

E-textiles have been used more broadly in fine arts classrooms to examine how students reconcile the tensions between artistic expression and developing technical skillsets in a new domain, pushing the boundaries of traditional digital and visual arts education (Peppler, Sharpe, & Glosson, 2013). In such settings, young artists transform formerly static objects into interactive canvases, as well as extend opportunities for artists to work their way into computing as they explore new languages and materials. By contrast, Mike Eisenberg, Ann Eisenberg, and Yingdan Huang have shown how e-textiles can be used in engineering courses to develop complex projects and ideas at the college level and beyond (2013). In higher education, e-textiles not only bring new materials to think with (Papert, 1980) but also have been shown to challenge students' thinking about their disciplines.

E-Textiles in Society

E-textiles play an important role in the national landscape, particularly in helping to bridge traditional gendered divides between high- and low-tech fields and interests. While the last decade has seen a resurgence in vibrant Do-It-Yourself (DIY) communities in a range of disciplines, including electronics and textiles (Kuznetsov & Paulos, 2010; Levine & Heimerl, 2008; Frauenfelder, 2010), there continues to be a split in the kinds of online communities frequented by men and women (Buechley, Jacobs, & Mako Hill, 2013). For example, technology-driven DIY communities—such as popular electronics blogs like Hack-a-day (over 700,000 unique visitors per month), Gizmodo (approximately 5.8 million visitors), and MAKE (more than 100,000 visitors)—attract predominantly male members (ibid.). Meanwhile, there has been a resurgence of interest in crafts within a number of notable online communities. Burda Style, a site that allows people to share and remix sewing patterns, is accessed monthly by around 350,000. Ravelry.com enables people to share knitting patterns and projects and is visited by over 700,000 unique individuals each month. Lookbook.nu, a site where users share photos of themselves dressed in their favorite outfits, draws over 800,000 visitors a month. Across these communities, women make up the majority of participants, with current estimates that cite approximately 70% of each of these communities as being women (ibid.). While these are just a sampling of online DIY communities, they generally demonstrate that the electronics and textile DIY communities have a sharp gender divide with textile and crafts dominated by women and electronics communities by men.

These larger trends in online DIY communities also mirror the persistently lopsided gender makeup of computer and information science programs in US universities and colleges, suggesting that the gender gap in computing education is still obstinately wide and has been getting progressively worse since the 1980s (Weaver & Prey, 2013). Yet despite several national initiatives to diversify participation in STEM fields, the underlying culture of computing education remains relatively stagnant, with curriculum, tools, and materials that continue to emphasize areas historically aligned more closely with male interests than women's (Margolis & Fisher, 2003).

Within this larger landscape, the field of e-textiles offers a notable exception. The capacity for e-textiles to diversify participation and pull more women into high-tech making and online communities, was first documented by Leah Buechley and Benjamin Mako Hill (2010), who discovered that e-textiles were arguably becoming the first-ever female-dominated computing industry. While males created the majority of traditional Arduino projects posted on Vimeo, YouTube, Flickr, and other sites (85% vs. about 1% by female designers), women created most of the e-textile projects created with the LilyPad Arduino projects (65% vs. about 25% male designers). What is striking about this comparison is that both types of projects share the same microprocessor and are programmed in the same language. Researchers posit that the resulting gender discrepancy could be due to some combination of the tools and materials used, the construction practices employed, and the nature of the products.

Further, e-textiles demonstrate a great deal of promise for transforming classroom practice in similar ways to transforming the DIY landscape. For example, a series of e-textile design experiments in middle school settings were conducted and the gender dynamics and participation patterns of girls and boys were observed (Peppler, 2013; Buccholz, Shively, Peppler, & Wohlwend, 2014). From videotaped observations of subjects working in mixed-gender pairs, the authors found that both boys and girls equally engaged in e-textile activity, as evidenced by body language, gaze, talk-on-task, and other indicators, but girls tended to play a greater leadership role. Furthermore, the projects were positioned in front of the girls 81% of the time; the girls also spent 58% of the time directing activity, troubleshooting, and deciding next steps and made only 39% of the requests for help from teachers and peers. Moreover, this early leadership was predictive of having more sophisticated command of the technology in subsequent projects, requiring less troubleshooting, time, and assistance from others. Upon further analyses, the authors also found that pairs determined who would take the lead on the activity based on the practice (and its gendered history) that they were to engage, with girls placed in the leadership role when it was time to sew or craft and boys placed in a leadership role when it was time to test or solder the connections (ibid). This division of labor was consistent but not negotiated within the groups, even when the boys had more prior experience and were more proficient in sewing than the girls.

Taken together, these studies suggest e-textiles can impact the computing culture in both "the wild" and in the classroom. This can be largely attributed to e-textiles being a unique nexus of three distinct and historically gendered practices: crafting, coding, and circuitry (Peppler, 2013). Each cultural practice—with related tools and materials—carries distinct expectations for whom and what constitutes experts and expertise. For example, skillful sewing with needles and fabric signals expertise in crafting or fashion cultures, while successful construction of a working circuit signals expertise in electrical engineering or STEM learning communities (ibid).

E-Textiles: Promoting Transparency and Improving Learning Outcomes

Within this landscape, current research suggests that e-textiles are not only effective tools for broadening participation in computing, but might also offer greater transparency into STEM disciplinary content (Kafai & Peppler, 2014). Most of today's technology designs intentionally hide or make invisible what makes them work. Think of the iPhone or iPad, for example. While consumers love these devices for their ease of use, users are encouraged to consult an expert for assistance—even changing the battery. While this type of "invisibility" into the inner workings of the device can aid consumption, especially for the novice user, we need to think critically about the kind of learning that is enabled and circumvented in these types of experiences, especially as we begin to rethink schooling in the 21st century. What are youth learning about new technologies in these types of interactions? And, more importantly, what are they not learning that is critical to high-quality educational experiences, and how can we better design for high-quality learning and engagement?

Consequently, Buechley and others argue that—particularly for educational purposes—we need to privilege "visibility" or transparency as more beneficial in promoting understanding and high-quality learning (Buechley, 2010; Kafai, & Peppler, 2014). Moreover, e-textiles present particularly compelling examples of high-quality and transparent learning tools in that they make technology visible for the learner. For example, the uninsulated threads allow for shorts that are oftentimes prevented with our typical electronics toolkits, where we might snap circuits together with alligator clips or other similar devices. While these types of kits may be useful for helping the learner to meet the goal (i.e., illuminating a light bulb), the same designs that allow for easy entry and a high probability of success also appear to be detrimental to conceptual engagement, circumventing high-quality learning experiences.

Over the past few decades, traditional circuitry construction kits have been failing young learners, as they are arriving at college without an understanding of the big ideas important to electronics and computing (for a review, see Peppler & Glosson, 2013a as well as Maloney et al., 2008). Fortunately, contemporary electronics and computing is rife with new tools and materials that are spurring shifts in the ways we interact with technology, presenting opportunities for us to reshape learning and participation. To offer a compelling (but not an isolated) example, I have explored how this type of visibility in e-textiles is particularly suitable for engaging learners in high-quality conceptual engagement in circuitry (Peppler & Glosson, 2013a, 2013b; Peppler, 2014), which will be further presented below. Similar types of explorations into the role of conceptual understanding of coding and crafting are warranted and have been explored by Kafai and colleagues (Kafai, Fields, & Searle, 2013).

Transparency, E-Textiles, and Conceptual Understanding of Circuits

Central to our understanding of learning is the relationship between various tools and technologies and the structuring of disciplinary subject matter. Papert, for example, invited closer investigation of the specific tools we have available (i.e., "objects to think with") as they highly impact our ontological perspectives (1980). Emerging empirical research exists to inform our understanding of how our tools and materials shape learning and participation across this emerging technological landscape.

For instance, conceptual understanding of electrical circuitry is foundational to later engagement in many fields, including physics, engineering, and computer science, and is part of a broader investigation of energy within the physical sciences in the National Science Standards. Research over the years, however, has consistently shown how students have misconceptions about circuitry concepts and procedural knowledge stemming from the tools and materials used in classroom learning experiences. Andersson and Karrqvist (1979), for example, showed how 15-year-olds had difficulty understanding how the light bulb worked due to the invisibility of the two terminals of the bulb (i.e., it's unclear how the light bulb truly connects to the battery source). The same "invisibility factor" applies to light sockets, and some types of batteries. In further probing for misconceptions among undergraduates enrolled in introductory physics and engineering courses, Fredette and Lockhead (1980) concluded that schools needed to be more explicit in helping students understand how all elements of a circuit require voltage to pass through an IN and an OUT terminal in early physics education.

Leveraging new materials to inform youths' understanding of electronics is especially apt given the historical prevalence of youths' conceptual misunderstandings of simple circuitry (Evans, 1978; Thiberghien & Delacorte, 1976). In sum, students need in-depth understanding of the anatomy of each component in a circuit—an electrical power source, a load, and some wire to connect them in the most basic configuration—as well as fundamental concepts of how these components interact with each other; namely current flow (Osborne, 1981; Osborne, 1983; Shipstone, 1984), battery polarity (Osborne et al., 1991), and circuit connections (Osborne, 1983; Shepardson & Moje, 1994; Asoko, 1996), further defined below:

- *Current flow* is traditionally defined as a current (i.e., flow) around a circuit (i.e., following one of the simple circuit current models) (Osborne, 1981).
- *Polarity* is used when discussing connections, when the proper battery terminals are connected to the proper LED terminals in a simple circuit. It was defined in the 1991 Electricity report as "the necessity for any circuit to have two connections to a device and an electrical power source" (Osborne et al., 1981, p. 43).
- *Connection* refers to the joining of electrical parts to form a working circuit, thus lighting the bulb (Osborne, 1983; Osborne et al., 1981; Shepardson & Moje, 1994).

In prior work (Peppler & Glosson, 2013a), youth engagement in a 20-hour e-textile activities, involving the sewing of electronics into fabric-based materials using conductive thread, had shown gains in their ability to diagram working circuits, as well as specific circuitry concepts like current flow, connections, and polarity. While it's clear that e-textiles can contribute to conceptual learning about circuitry, it is unclear whether e-textiles can outperform traditional or other new circuitry toolkits that are on the market today. Further, it is unclear how long youth needed to engage the materials before walking away with this understanding. Further study should attempt to examine both a comparative view of the commercially available tools and materials as well as to determine whether any significant gains in understanding can be made in a much smaller timescale.

Circuit Diagrams: Assessing Learning

Historically, knowledge of circuits is usually assessed through circuit diagrams (Osborne, 1983). Students are tasked with diagraming a sample circuit with the materials used to create it—in most cases, this includes a 9V battery, a small light bulb, and wiring—and then indicate the direction of current flow. However, such assessments are historically tightly tied to the tools that are used in the learning experience, meaning that circuit diagrams consist of the same types of tools and materials used in the hands-on learning. Consequently, new assessments need to reflect the new materials when we move from using traditional electric circuit drawings that use light bulbs and batteries to draw upon pieces from the LilyPad e-textiles sewing kit (for example, a battery holder, LED, and switch), which the learner would be using in e-textile workshops.

In our recent study of conceptual understanding of circuitry after e-textile experience, youth were asked to use a set of LilyPad part stickers marked with clear positive and negative terminals to create a functioning circuit by drawing lines between the appropriate terminals. This assessment tests their knowledge of basic circuitry, specifically whether youth could create an overall working circuit, but more specifically, whether they understood three core concepts: current flow (i.e., completed circular paths with no redundancy or shorts), connections (i.e., completed lines successfully connecting one component to another and attention paid to the particular points of conductivity), and polarity (i.e., being mindful that the battery and LED have a positive side and a negative side).

In this work, we found that even those students with prior experience constructing simple circuits could not translate this understanding to the new materials. However, after creating with e-textile materials, we found that students significantly increased their understanding of key circuitry concepts (Peppler & Glosson, 2013a). Results demonstrated that students were able to diagram a working circuit considerably better in post-assessments than in pre-assessments. In addition, the students significantly increased their knowledge of current flow ($p < .05$), circuit polarity or directionality ($p < .05$), and connection ($p < .05$)—concepts even college undergraduates in introductory physics and engineering courses have persistent misunderstandings about (Fredette & Lochhead, 1980). Taken together, this work suggests e-textiles as a compelling case for transparency in the learning process.

New vs. Existing "Clubhouses"

Collectively, this body of research raises several key issues in the field. The first issue pertains to the endgame of introducing, or even replacing, traditional toolkits with new tools and materials in STEM, arts, and other classrooms. Specifically, what do e-textiles represent for the current and future issue of gender in computing? Despite the calls in recent decades to address the shrinking pipeline of underrepresented groups in engineering and computing professions, these fields remain male dominated. E-textiles signify an entirely different approach to diversifying these fields and what people can produce in them. This stands in stark contrast to prior endeavors to make monolithically gendered STEM cultures more accessible to women, as highlighted in Margolis and Fisher's groundbreaking study, "Unlocking the Clubhouse" (Margolis & Fisher, 2001; Fisher & Margolis, 2002). Instead of trying to fit people into existing cultures, current research on e-textiles provides us with a glimpse of what a "new clubhouse" may look like—one where decorative, feminine or otherwise "non-robotics" forms of engineering are not only encouraged but are poised to disrupt what we know about and who participates in STEM careers in the 21st century. In this view, the pipeline challenge of gender participation in STEM exists not because STEM cultures are unfairly exclusive but because they're limited in intellectual and cultural breadth. Some of the most revealing research in diversity has found that women and other minorities don't join communities, not because they are intimidated or unqualified but rather because they're simply uninterested (Weinberger, 2004). This is where the concept of e-textiles as a nexus of gendered practice shows promise as an attractive pathway to the rich intellectual possibilities of computation, engineering, craft, and design. This serves to benefit not only women and other underrepresented populations in STEM, but for the technical and cultural growth of the disciplines, themselves, re-contextualized by new tools and reenvisioned by new participants.

Feminist vs. Feminine Technologies

Implied in the current research is a cautious optimism that such women's participation in STEM may result in more widespread appreciation for the relevance, complexity, and importance of traditionally female-dominated pursuits. However, another key tension in this work pertains to the relationship between contemporary women and traditional "women's skills," like crafting and sewing. A number of women in academia and STEM fields, for example, see such skills as reinforcements of exhausted stereotypes and see them as retrogressions in the quest for greater respect from the broader STEM community. Bardzell speaks to this tension in her distinction between "feminine" and "feminist" technology (Bardzell, 2010, 2013; Layne et al., 2010). The latter describes explicit and intentional integration of feminist theory (and goals) with human-computer interaction research and practice. Feminist technologies include "tools and knowledge that enhance women's ability to develop, expand, and express their capacity" (Layne et al., 2010) while feminine technologies are "technologies associated with women by virtue of their biology" (McGaw, 2003, 1996, cited in Layne et al., 2010). Because of their complicated history and diverse applications, e-textiles can be both feminine technology and feminist technology, depending on the context of use; inasmuch as e-textiles enable designers to develop and expand embodied interactive experiences or generate strategies to increase the participation of historically marginalized users, they can be understood as feminist technologies.

WHAT ARE THE GAPS IN THE EXTANT RESEARCH AND DIRECTION FOR FUTURE RESEARCH?

The studies above suggest that we need to better understand a wider range of tools and materials (for example, those toolkits that are more masculine and/or gender neutral have yet to be systematically investigated). Early pilot data suggests that on tools and materials that are seen as tools for boys, boys will take the lead, reversing the patterns seen with e-textiles. This signals a call for additional research exploring the vast range of materials and tools being utilized within the educational spaces in order to better understand how cultural expectations materialize as mediated actions and authorize particular tool uses and tool users. More research is also needed to better understand the specific design features that are associated with gendered histories of tool use so that we might better be able to design tools in the future.

Similarly, there are some noticeable limitations of the early studies on transparency in learning. They have not yet revealed the specific design features that support learning, a comparative sense of whether e-textiles are more efficacious than other toolkits for learning about circuitry and computing more broadly, and whether the improved understanding of circuits is retained over time (i.e., does this new training impact long-term learning outcomes?), among other emergent questions in this line of inquiry. Seeking to address some of the prior limitations, we have currently developed new assessments to test for transfer of conceptual understanding to a broader range of electronic toolkits (testing for near and far transfer) (Peppler et al., 2015). However, there is also a need for a similar set of assessments to be developed to test for understanding of code or computation necessary in e-textile construction toolkits and how this might be transferred to other languages, tools, and materials.

In addition to the gaps in the prior research outlined above, there are four main gaps in the existing research and practice: (1) There is a gap in understanding of how to bridge DIY e-textile culture and classroom practice— though there are a number of emerging sites that are using e-textiles in schools and even across whole school districts. More research is needed on the efficacy of e-textile integration in schools as pathways into learning. (2) While there is an abundance of anecdotal evidence, there is no research on the long-term impact of e-textiles for learning and participation and there is subsequently a need for longitudinal studies that track the impact of early e-textiles design opportunities on subsequent careers, identities, and interests. (3) There is a need for more research on the intersection of the physical and the digital world. How does this translation between the physical and the digital support learning? What are the key challenges and what needs to be understood by today's youth? Lastly, (4) how can we use the set of emerging design principles outlined above to look at our existing classroom toolkits as well as envision new materials to support learning that is more open to expressive, iterative, and production-centered ways of participating in the classroom?

Implications for Learning

E-textiles serve to highlight that tools fundamentally change the way one relates to disciplinary content and that moving to a new set of tools makes visible concepts that otherwise may have been invisible to the learner. Such a shift is evident in the prior research, especially, where youths' conceptual understandings of current flow, connections and battery polarity were challenged and revised upon the move from designing circuits using traditional toolkits to fabricating them using e-textile materials.

In some ways, the additional challenges posed by the e-textile materials (for example, the sewing and other fine motor activities) themselves, are compensated by the deeper relationships to content that can be forged through troubleshooting. In contrast to this is the relative simplicity of more traditional tools for teaching introductory circuitry; though perhaps quicker to prototype with (for example, insulated wires, simplified design of bulbs vs. LED components, etc.), these toolkits unnecessarily limit the number and variety of mistakes that can be made in circuit construction. This may explain why prior research has repeatedly shown the limitation of these materials for providing deep insights into how connections, polarity, and current flow work. By contrast, the use of the LilyPad Arduino toolkit allows for more diverse ways for youth to "short" or "break" their circuit, creating manifold opportunities for discussion and questioning of misconceptions. What results is a deeper conceptual understanding through the mistakes and reasoning to fix those mistakes providing opportunities to fix those lingering conceptual misconceptions.

This constitutes a larger rationale for rethinking educational toolkits to support learning in other domains as well. Arguably, the most effective toolkits for educational settings allow learners to make a large number of mistakes (i.e., are more expressive) and should do less to scaffold the learning process. Underpinning this approach is a fundamental view that learning happens best when toolkits afford a sense of transparency by providing opportunities for concretizing knowledge through tinkering with the materials. This "revaluation of the concrete" (Turkle & Papert, 1992) is an epistemological stance towards knowledge—the relationships that learners build with knowledge and pathways that facilitate such knowledge construction.

There are also other reasons to consider the addition of e-textile toolkits in education. Given the recent emergence of national standards in science education that explicitly task educators to organize and present core content with many different emphases and perspectives in order to develop curricula that appeals to *all* students, "regardless of age, gender, cultural or ethnic background, disabilities, aspirations, or interest and motivation in science" (National Research Council of the National Academies, 2011, p. 2), now is an especially apt time to rethink the scope of what tools for scientific inquiry are included in the classroom so as to best support the diverse interests and experiences of youth, especially those in populations that science education in the United States has traditionally failed to engage—namely, women and students of color. E-textiles, as one example of a new domain to support science and engineering practices, has already demonstrated its capacity in the professional realm to invite and sustain participation from women (Buechley & Mako Hill, 2010). Thus, the emergence of e-textiles as a magnet for creative engineering from traditionally underrepresented groups represents the impact that a richer range of materials in early science education can have on the demographics and perspectives of the next generation of STEM professionals.

In contrast to theorizing that gender disparities evident particularly in STEM fields demonstrate an inherent "lack" in girls (i.e., girls *lack* the skills, interest, or confidence necessary to participate equitably with male counterparts), we should be reconceptualizing these disparities by looking at tacit expectations for cultural practices and social actors that are concretized through historical uses of tools, materials, and gendered communities of practice (Paechter, 2003; Buccholz, Shively, Peppler, & Wohlwend, 2014). Rather than viewing gender as a static identity marker that defines participation in electronics and computing projects, research is demonstrating that histories of materials, tools, and practices influenced which member of the dyads was implicitly granted hands-on access. In this case of e-textiles, the replacement of the traditional circuitry toolkit with new materials and tools like needles, fabric, and conductive thread ruptured traditional gender scripts around electronics and computing. In turn, girls take on leadership roles in completing highly complex electronics projects by engaging in practices historically embedded within communities of practice with gendered histories.

Implications for Participation

To date, efforts to draw more female youth into STEM-related pathways and experiences have largely revolved around two major efforts: (a) keeping male and female youth/children separated in STEM-related classes or clubs (e.g., Khoja, Wainwright, Brosing, & Barlow, 2012; Marcu et al., 2010) and (b) encouraging female youth/children to play with "boys'" toys and tools (i.e., toys and tools with masculinized identity markers; e.g., Clegg, 2001; Hartmann, Wiesner, & Wiesner-Steiner, 2007; Stepulevage, 2001). The first effort, to keep males and females separated, is exemplified in "girls only day" at a local computer club or same-sex math and science classes in some schools. The assumption is that creating a bounded and protected space for female youth will ensure that females are not intimidated by males who may appear to be more confident and competent. The intention is to provide equitable access to tools and materials in mixed-gender settings. The second effort is based on children's gendered toy preferences from a very young age. The assumption is that if only girls would take up LEGOs and science kits instead of Barbie dolls and crafting kits, we would not see the stark gender disparities in STEM pathways later; in other words, if girls just played more with boys' toys, gender scripts would change.

Both of these efforts are problematic, positioning girls within a cultural deficit model that either presupposes that girls need to be protected because they are weak and/or that girls need to change to become more like their male counterparts. Current research suggests a new path forward, one that takes a strength orientation to girls and the tools, materials, and practices that have historically been valued in feminine communities of practice. Across the dyads studied, we found that that gender scripts within electronics and computing were not absolutely fixed, as is assumed in much of the research, but rather that gender scripts are socially situated within tools, materials, and practices.

CONCLUSION

This work offers a glimpse of the transformative power of considering how tools—bearing traces of their histories of use and access—mediate youth's interactions and participation in classroom spaces. In this case, e-textile toolkits successfully flip the gendered scripts about who had hands-on access to electronics materials and tools by honoring girls' historic practices and, in doing so, expanded the ways into complex electronics and computing content. This seemingly small change in the materials and tools produces a rippling effect on the youth's classroom practices. Moreover, classrooms, clubs, and after-school settings should consider how altering materials and tools may situate STEM practices in cultural contexts that broaden participation patterns and offer youth multiple entry points and opportunities to perform identities that are socially valued across communities of practice and their gendered histories.

REFERENCES

Anderson, C. (2012). *Makers: The new industrial revolution*. New York, NY: Random House.

Andersson, B., & Karrqvist, C. (1979). *Elektriska Kretsar* (Electric Circuits). EKNA Report No 2, University of Gothenburg, Mölndal, Sweden.

Asoko, H. (1996). Developing scientific concepts in the primary classroom: Teaching about electric circuits. In G. Welford, J. Osborne, & P. Scott (Eds.), *Research in science education in Europe* (pp. 36–49). London: Falmer Press.

Baafi, E., & Millner, A. (2011). Modkit: A toolkit for tinkering with tangibles & connecting communities. In *Proc. 5th Int'l Conf. Tangible, Embedded, and Embodied Interaction* (TEI 11) (349-352). ACM.

Banzi, M. (2008). *Getting Started with Arduino* (1st ed.). Text Only.

Bardzell, S. (2010). Feminist HCI: Taking Stock and Outlining an Agenda for Design. In *Proceedings of the 28th International Conference on Human Factors in Computing Systems* (pp. 1301–1310). Atlanta, GA: ACM. doi:10.1145/1753326.1753521

Bardzell, S. (2013). E-Textiles and the body: Feminist technologies in design research. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), Textile Messages: Dispatches from the World of E-Textiles and Education. Academic Press.

Beaudry, M. C. (2006). *Findings: The material culture of needlework and sewing*. Princeton, NJ: Yale University Press.

Buccholz, B., Shively, K., Peppler, K., & Wohlwend, K. (2014). Hands on, hands off: Gendered access in sewing and electronics practices. *Mind, Culture, and Activity*, *21*(4), 278–297. doi:10.1080/10749039.2014.939762

Buechley, L. (2006). A construction kit for electronic textiles. In *Proceedings of IEEE International Symposium on Wearable Computers* (ISWC). Montreux, Switzerland: IEEE.

Buechley, L. (2010). Questioning invisibility. *Computer*, *43*(4), 84–86. doi:10.1109/MC.2010.114

Buechley, L. (2013). Lilypad arduino: E-textiles for everyone. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), Textile Messages: Dispatches from the World of E-Textiles and Education. Academic Press.

Buechley, L., & Eisenberg, M. (2009). Fabric PCBs, electronic sequins, and socket buttons: Techniques for e-textile craft. *Personal and Ubiquitous Computing*, *13*(2), 133–150. doi:10.1007/s00779-007-0181-0

Buechley, L., Elumeze, N., & Eisenberg, M. (2006). Electronic/computational textiles and children's crafts. In *Proceedings of the 2006 Conference on Interaction Design and Children* (pp. 49-56). Tampere, Finland: ACM. doi:10.1145/1139073.1139091

Buechley, L., Jacobs, J., & Mako Hill, B. (2013). Lilypad in the wild: Technology DIY, e-textiles, and gender. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), Textile Messages: Dispatches from the World of E-Textiles and Education. Academic Press.

Buechley, L., & Mako Hill, B. (2010). LilyPad in the wild: How hardware's long tail is supporting new engineering and design communities. In *Proceedings of the Conference on Designing Interactive Systems* (pp. 199-207). ACM Press. doi:10.1145/1858171.1858206

Buechley, L., Peppler, K. A., Eisenberg, M., & Kafai, Y. B. (Eds.). (2013). *Textile Messages: Dispatches from the World of E-Textiles and Education*. New York: Peter Lang.

Buechley, L., & Qiu, J. (2013). *Sew Electric*. Cambridge, MA: HLT Press.

Chalayan, H. (2011). *From Fashion and Back*. Bss Bijutsu.

Chung, Y. (2005). *Silken Threads: A History of Embroidery in China, Korea, Japan, and Vietnam*. New York: Harry N. Abrams.

Clegg, S. (2001). Theorising the machine: Gender, education and computing. *Gender and Education*, *13*(3), 307–324. doi:10.1080/09540250120063580

Connell, R. W., & Messerschmidt, J. W. (2005). Hegemonic masculinity: Rethinking the concept. *Gender & Society*, *19*(6), 829–859. doi:10.1177/0891243205278639

Craig, K. (2013). *Know It All Bag*. Retrieved from http://www.knitty.com/ISSUEss10/PATTknowitall.php

Design, D. (2013). *When technology meets sensuality*. Paper presented at the Smart Fabrics Conference, Barcelona, Spain.

Digby, G. (1964). *Elizabethan Embroidery*. New York: Yoseloff.

Dougherty, D. (2013). The maker mindset. In M. Honey & D. E. Kanter (Eds.), *Design, make, play: Growing the next generation of STEM innovators* (pp. 7–11). New York, NY: Routledge.

Eisenberg, M., Eisenberg, A., & Huang, Y. (2013). Bringing e-textiles into engineering education. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), *Textile Messages: Dispatches from the World of E-Textiles and Education*.

Elumeze, N. (2013). Traveling light: Making textiles programmable "through the air.". In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), *Textile Messages: Dispatches from the World of E-Textiles and Education*.

Eng, D. (2009). *Fashion Geek: Clothes Accessories Tech*. Cincinnati, OH: North Lights Books.

Eng, D. (2013). *Fairytale Fashion*. Retrieved from www.FairytaleFashion.org

Essinger, J. (2007). *Jacquard's Web: How a Hand-Loom Led to the Birth of the Information Age*. New York: Oxford University Press.

Evans, J. (1978). Teaching electricity with batteries and bulbs. *The Physics Teacher*, *16*(1), 15–22. doi:10.1119/1.2339794

Fisch, A. (1996). *Textile Techniques in Metal*. Asheville, NC: Lark Books.

Fisher, A., & Margolis, J. (2002). Unlocking the clubhouse: The Carnegie Mellon experience. ACM SIGCSE Bulletin Women and Computing, 34(2), 79-83.

Foster, P. N. (1995a). Industrial arts/technology education as a social study: The original intent? *Journal of Technology Education*, *6*(2), 4–18.

Foster, P. N. (1995b). The founders of industrial arts in the US. *Journal of Technology Education*, *7*(1), 6–21.

Frauenfelder, M. (2010). *Made by Hand: Searching for Meaning in a Throwaway World*. Portfolio Hardcover.

Fredette, N., & Lochhead, J. (1980). Students' conceptions of simple circuits. *The Physics Teacher*, *18*(3), 194–198. doi:10.1119/1.2340470

Gere, C., & Rudoe, J. (2010). *Jewelry in the Age of Queen Victoria: A Mirror to the World*. London: British Museum Press.

Harris, J. (Ed.). (1993). *Textiles, 5,000 Years: An International History and Illustrated Survey*. New York: H.N. Abrams.

Hartmann, S., Wiesner, H., & Wiesner-Steiner, A. (2007). Robotics and gender: The use of robotics for the advancement of equal opportunities in the classroom. In Gender Designs IT Construction and Deconstruction of Information Society (pp. 175-188). Academic Press.

Instructables.com & the Editors at MAKE Magazine. (2008). The Best of Instructables Volume I: Do-It-Yourself Projects from the World's Biggest Show & Tell. Authors.

Kafai, Y., Fields, D., & Searle, K. (2012). Making technology visible: Connecting the learning of crafts, circuitry, and coding in youth e-textile designs. In *Proceedings of the International Conference of the Learning Sciences (ICLS)*. Sydney, Australia: Academic Press.

Kafai, Y., Fields, D., & Searle, K. (2014). Electronic textiles as disruptive designs: Supporting and challenging maker activities in schools. *Harvard Educational Review*, *84*(4), 532–556. doi:10.17763/haer.84.4.46m7372370214783

Kafai, Y., Lee, E., Searle, K., Fields, D., Kaplan, E., and Lui, D. (2014). A crafts-oriented approach to computing in high school: Introducing computational concepts, practices, and perspectives with electronic textiles. *ACM Transactions on Computing Education, 14*(1). DOI: 10.1145/2576874

Kafai, Y., & Peppler, K. (2014). Transparency reconsidered: Creative, critical, and connected making with e-textiles. In M. Boler & M. Ratto (Eds.), *DIY Citizenship* (pp. 179–188). Cambridge, MA: MIT Press.

Kafai, Y., Searle, K., Kaplan, E., Fields, D., Lee, E., & Lui, D. (2013). Cupcake cushions, Scooby Doo shirts, and soft boomboxes: E-textiles in high school to promote computational concepts, practices, and perceptions. In *Proceeding of the 44th ACM Technical Symposium on Computer Science Education*. ACM. Doi:10.1145/2445196.2445291

Kaufmann, B., & Buechley, L. 2010. Amarino: A toolkit for the rapid prototyping of mobile ubiquitous computing. In Proceedings of Mobile HCI. Lisbon, Portugal: Academic Press. doi:10.1145/1851600.1851652

Khoja, S., Wainwright, C., Brosing, J., & Barlow, J. (2012). Changing girls' attitudes towards computer science. *Journal of Computing Sciences in Colleges*, *28*(1), 210–216.

Kuznetsov, S., and Paulos, E. (2010). *Rise of the Expert Amateur: DIY Projects, Communities, and Cultures.* Paper presented at ACM NordiCHI, Reykjavík, Iceland.

Layne, L., Vostral, S., & Boyer, K. (Eds.). (2010). *Feminist Technology*. University of Ilinois Press.

Levine, F., & Heimerl, C. (2008). *Handmade Nation: The Rise of DIY, Art, Craft, and Design*. New York: Princeton Architectural Press.

Lewis, A., & Lin, F. (2008). *SwitchCraft: Battery-Powered Crafts to make and Sew*. New York: Crown Publishing Group.

Lindsay, E. (2013). The space between us: Electronic music + modern dance + e-textiles. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), *Textile Messages: Dispatches from the World of E-Textiles and Education*.

Maloney, J., Peppler, K., Kafai, Y. B., Resnick, M., & Rusk, N. (2008). *Programming by choice: Urban youth learning programming with scratch. Published in the*. Portland, OR: Proceedings by the ACM Special Interest Group on Computer Science Education. doi:10.1145/1352135.1352260

Marcu, G., Kaufman, S. J., Lee, J. K., Black, R. W., Dourish, P., Hayes, G. R., & Richardson, D. J. (2010, March). Design and evaluation of a computer science and engineering course for middle school girls. In *Proceedings of the 41st ACM technical symposium on computer science education* (pp. 234–238). New York, NY: ACM. doi:10.1145/1734263.1734344

Marculescu, D., Marculescu, R., Zamora, N., Stanley-Marbell, P., Kholsa, P., Park, S., ... (2003). Electronic textiles: A platform for pervasive computing. *Proceedings of the IEEE*. citeseer.ist.psu.edu/marculescu03electronic.html

Margolis, J., & Fisher, A. (2001). *Unlocking the Clubhouse: Women in Computing*. Boston, MA: MIT press.

Marvin, C. (1990). *When Old Technologies Were New: Thinking About Electric Communication in the Late Nineteenth Century*. New York: Oxford University Press.

McGaw, J. (2003/1996). Reconceiving technology: Why feminine technologies matter. *Gender and Archaeology*, 52–75.

National Research Council of the National Academies. (2011). *A Framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Ngai, G., Chan, S., & Ng, V. (2013). Designing i*CATch: A multipurpose, education-friendly construction kit for physical and wearable computing. AC Trans. *Computers & Education*, *13*(2). doi:10.1145/2483710.2483712

Ngai, G., Chan, S., Ng, V., Cheung, J., Choy, S., Lau, W., & Tse, J. (2010) I*CATch: A scalable plug-n-play wearable computing framework for novices and children. In *Proceedings of the 28th International Conference on Human Factors in Computing Systems* (pp. 443-452). Atlanta, GA: ACM.

Orth, M. (2013). Adventures in electronic textiles. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), Textile Messages: Dispatches from the World of E-Textiles and Education. Academic Press.

Orth, M., Post, R., & Cooper, E. (1998). Fabric computing interfaces. In Proceedings of CHI 98 Conference Summary on Human Factors in Computing Systems (pp. 331-332). New York: ACM. doi:10.1145/286498.286800

Osborne, R. (1981). Children's ideas about electric current. *New Zealand Science Teacher*, *29*, 12–19.

Osborne, R. (1983). Towards modifying children's ideas about electric current. *Research in Science & Technological Education*, *1*(1), 73–82. doi:10.1080/0263514830010108

Osborne, R., Tasker, R., & Schollum, B. (1981). *Video: Electric current*, working paper no. 51, *Learning in Science Projects*. Hamilton, New Zealand: SERA, University of Waikato.

Pacelli, M., Loriga, G., Taccini, N., & Paradiso, R. (2006). Sensing fabrics for monitoring physiological and biomechanical variables: E-textile solutions. In *Proceedings of the 3rd IEEE EMBS Intl Summer School and Symposium on Medical Devices and Biosensors*. Boston, MA: ACM. doi:10.1109/ISSMDBS.2006.360082

Paechter, C. (2003). Masculinities and femininities as communities of practice. *Women's Studies International Forum*, *26*(1), 69–77. doi:10.1016/S0277-5395(02)00356-4

Pakhchyan, S. (2008). *Fashioning Technology: A DIY Intro to Smart Crafting*. Cambridge, MA: O'Reilly Media.

Papadopoulos, D. (2007). Wearable technologies, portable architectures and the vicissitudes of the space between. *Architectural Design*, *77*(4), 62–67. doi:10.1002/ad.488

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.

Peppler, K. (2010). The new fundamentals: Introducing computation into arts education. In E. Clapp & M. J. Bellino (Eds.), 20Under40: Reinventing the Arts and Arts Education for the 21st Century. Bloomington, IN: AuthorHouse.

Peppler, K. (2013). STEAM-powered computing education: Using e-textiles to integrate the arts and STEM. *IEEE Computer*, *46*(9), 38–43. doi:10.1109/MC.2013.257

Peppler, K. (2014). *New Creativity Paradigms: Arts Learning in the Digital Age*. New York, NY: Peter Lang Publishing.

Peppler, K., & Bender, S. (2013). Maker movement spreads innovation one project at a time. *Phi Delta Kappan*, *95*(3), 22–27. doi:10.1177/003172171309500306

Peppler, K., & Danish, J. (2013). E-textiles for educators: Participatory simulations with e-puppetry. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), *Textile Messages: Dispatches from the World of E-Textiles and Education* (pp. 133–141). New York, NY: Peter Lang Publishing.

Peppler, K., & Glosson, D. (2013a). Stitching circuits: Learning about circuitry through e-textile materials. *Journal of Science Education and Technology*, *22*(5), 751–763. doi:10.1007/s10956-012-9428-2

Peppler, K., & Glosson, D. (2013b). Learning about circuitry with e-textiles. In M. Knobel & C. Lankshear (Eds.), *The New Literacies Reader*. New York, NY: Peter Lang Publishing.

Peppler, K., Gresalfi, M., Salen Tekinbaş, K., & Santo, R. (2014). *Soft Circuits: Crafting E-Fashion with DIY Electronics*. Cambridge, MA: MIT Press.

Peppler, K., Sharpe, L., & Glosson, D. (2013). E-textiles and the new fundamentals of fine arts. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), *Textile Messages: Dispatches from the World of E-Textiles and Education* (pp. 107–117). New York, NY: Peter Lang Publishing.

Peppler, K., Tan, V., Thompson, N., & Bender, S. (2015). *New tools for circuitry learning: evaluating the efficacy of circuitry construction kits.* Paper Presentation at the 2015 American Educational Research Association Conference.

Perner-Wilson, H., & Buechley, L. (2013). Handcrafting textile sensors. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), *Textile Messages: Dispatches from the World of E-Textiles and Education*.

Post, R., & Orth, M. (1997). Smart fabric, or "wearable clothing." In *Proceedings of the IEEE International Symposium on Wearable Computers (ISWC)* (pp. 167-168). IEEE.

Post, R., Orth, M., Russo, P., & Gershenfeld, N. (2000). E-broidery: Design and fabrication of textile-based computing. *IBM Systems Journal*, *39*(3-4), 840–860. doi:10.1147/sj.393.0840

Reichel, M., Schel, H., and Gruter, T. (2006). Smart fashion and learning about digital culture. *Current Developments in Technology-Assisted Education*, 1-5.

Schelhowe, H., Katterfeldt, E. S., Dittert, N., & Reichel, M. (2013). EduWear: E-textiles in youth sports and theater. In L. Buechley, K. Peppler, M. Eisenberg, & Y. Kafai (Eds.), Textile Messages: Dispatches from the World of E-Textiles and Education. Academic Press.

Scollon, R. (2001). *Mediated Discourse: The Nexus of Practice*. London: Routledge. doi:10.4324/9780203420065

Shepardson, D. P., & Moje, E. B. (1994). The nature of fourth graders' understandings of electric circuits. *Science Education*, *78*(5), 489–514. doi:10.1002/sce.3730780505

Shipstone, D. (1984). A study of children's understanding of electricity in simple DC circuits. *European Journal of Science Education*, *6*(2), 185–198. doi:10.1080/0140528840060208

Smith, P. (1968). *Body Covering*. *Museum of Contemporary Crafts*. New York: The American Craft Council.

Starner, T. (2002). Wearable computers: No longer science fiction. *IEEE Pervasive Computing / IEEE Computer Society [and] IEEE Communications Society*, *1*(1), 86–88. doi:10.1109/MPRV.2002.993148

Stepulevage, L. (2001). Gender/technology relations: Complicating the gender binary. *Gender and Education*, *13*(3), 325–338. doi:10.1080/09540250120082525

Thiberghien, A., & Delacote, G. (1976). Manipulations et representations de circuits electriques simples chez des enfants de 7 a 12 ans. *Revue Française de Pédagogie*, *34*(1), 32–44. doi:10.3406/rfp.1976.1613

Turkle, S., & Papert, S. (1992). Epistemological pluralism and the revaluation of the concrete. *The Journal of Mathematical Behavior*, *11*(1), 3–33.

Weaver, A. C. A., & Prey, J. C. (2013). Fostering gender diversity in computing. *Computer*, *46*(3), 22–23.

Weinberger, C. J. (2004). Just ask! Why surveyed women did not pursue IT courses or careers. *Technology and Society Magazine, IEEE*, *23*(2), 28–35. doi:10.1109/MTAS.2004.1304399

ADDITIONAL READING

Buechley, L., Peppler, K., Eisenberg, M., & Kafai, Y. (Eds.), *Textile Messages: Dispatches from the World of E-Textiles and Education*. New York, NY: Peter Lang Publishing.

Peppler, K. (2014). *New Creativity Paradigms: Arts Learning in the Digital Age*. New York, NY: Peter Lang Publishing.

Peppler, K., Gresalfi, M., Salen Tekinbaş, K., & Santo, R. (2014). *Soft Circuits: Crafting E-Fashion with DIY Electronics*. Cambridge, MA: MIT Press.

Peppler, K., Salen Tekinbaş, K., Gresalfi, M., & Santo, R. (2014). *Short Circuits: Crafting E-Puppets with DIY Electronics*. Cambridge, MA: MIT Press.

KEY TERMS AND DEFINITIONS

Arduino: A microcontroller board with pins that connect to electronics or computers, using text-based coding environments to sense and control something in the physical world. In the chapter we discuss LilyPad Arduinos, simple boards that can be sewn into fabric and control lights, sounds, and movements of the textiles.

Coding: Also known as *computer programming*. Creating a language that describes the instructions or program used in software; in this chapter, coding ranges from complex codes performed by technicians to the e-textiles codes related to Modkit or LilyPad Arduinos.

DIY: Also known as do-it-yourself. The method of building, modifying, or repairing something without the aid of experts or professionals. DIY has been closely aligned with the Maker Movement.

E-Textiles: Also known as *electric textiles* or *smart textiles*. Everyday textiles and clothes that have electric components embedded in them;

Maker Movement: The name given to the increasing number of people employing DIY techniques and processes to develop unique technology products. Educators use this to engage the natural inclinations of children and the power of learning by doing. *See also DIY.*

STEM: The curricular disciplines of science, technology, engineering, and math, fields where women and minorities are often underrepresented.