# STEAM-Powered Computing Education: Using E-Textiles to Integrate the Arts and STEM

Kylie Peppler, *Indiana University Bloomington*

**Incorporating novel, cross-disciplinary technologies such as e-textiles in computing education can broaden participation, particularly by women, and improve learning outcomes.**

The persistently lopsided gender makeup of computer and information science programs in US universities and colleges—only 18 percent of engineering school undergraduates in 2009 were women, for instance—suggests that the gender gap in computing education is still obstinately wide. Yet, despite several national initiatives to diversify participation in science, technology, engineering, and mathematics (STEM) fields, the underlying culture of computing education remains relatively stagnant, with a curriculum that continues to emphasize areas historically aligned more closely with male interests than women's, such as robotics, computer programming, and physics.[1]

Fortunately, contemporary computing is rife with new tools and materials that are spurring shifts in the ways we interact with technology. One example that has gained international prominence over the past five years is electronic textiles: fabric artifacts that include embedded computers and other electronics. Instead of focusing on practices such as soldering and desoldering, this computing genre involves sewing, quilting, crocheting, knitting, and other techniques that have traditionally been the domain of seamstresses, knitters, and crafters. Perhaps because of these ties, women make up a resounding majority (65 percent) of this burgeoning informal community.[2]

Our efforts at Indiana University to broaden STEM participation in youth communities leverage e-textiles as an alternative approach to computing education. Recent findings indicate that introducing such novel, cross-disciplinary technologies can broaden participation, particularly by women. This STEAM (STEM + arts)-powered approach also improves learning outcomes and thus has ramifications that extend beyond the issue of gender in computing.[3]

## WHAT ARE E-TEXTILES?

High-profile public displays of e-textiles have increased in recent years, ranging from the costumes in Super Bowl XLV's halftime show to Lady Gaga's "Living Dress" to Old Navy's hoodies with embedded speakers. In each of these

 Published by the IEEE Computer Society 

examples, textile garments are infused with electronics to produce unique aesthetic effects.

At the forefront of e-textiles production, new conductive materials—including thread, yarn, paint, and fabrics woven from copper, silver, or other highly conductive fibers—are replacing insulated wire and soldering to engender new forms of wearable computing. Although the electronic components produced for e-textiles might look radically different than those used in robotics, they share much of the same foundational infrastructure.

Several designers have developed novice-friendly toolkits suitable for adoption in computing education, including LilyPad Arduino (http://lilypadarduino.org), i*CATch,[4] fabrikit (www.fabrick.it), and Aniomagic (www.aniomagic.com). These toolkits have been deployed to cultivate various aspects of physical computing in a range of educational applications, including in-school, out-of-school, and higher education environments.

For example, thousands of people around the world use LilyPad Arduino, released commercially in 2007, to build interactive garments, sculptures, and other textile-based interactive artifacts. More than 100,000 LilyPad pieces have been sold to date, and large numbers are being used in educational settings.[3] The toolkit consists of a set of sewable electronic parts, including a microcontroller; an assortment of sensors, switches, lights, and speakers; and a spool of conductive thread. As Figure 1 shows, users sew modules onto cloth with the thread, which provides both the physical and electrical connections between the pieces.

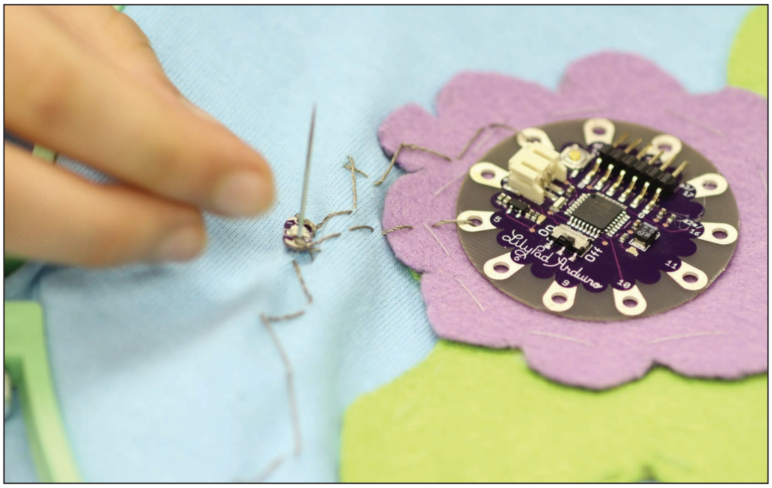

**Figure 1. With conductive thread, a user sews connections between a LilyPad Arduino microcontroller and an LED.**

The LilyPad microcontroller can be programmed using either the open source Arduino platform (www.arduino.cc) or a visual blocks-based language called Modkit,[5] based on Scratch.[6] Modkit enables designers to graphically configure LilyPad Arduino and to create programs that include basic computational concepts.

## E-TEXTILE DESIGN

Despite sharing common roots in electronics, material science, and computer programming with robotic constructions, whose appearance is secondary—if considered at all—to their ability to execute a task, e-textile artifacts are conceived primarily as aesthetic products with enhanced capabilities. This has nontrivial ramifications for e-textile design, which places a greater emphasis on artistic expression and creativity than on "making it work."

### Creative coding

As a backbone to any project at the intersection of physical and digital media, computer programming is essential to e-textile design.[7] However, the e-textile designer is less concerned with coding efficiency—having as few lines of code as possible—than with achieving 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?

### Artistic envisioning of material science

When e-textile designers create new works, they must make educated guesses about what material to use with digital media. In general, novices to e-textiles do not fully understand the energy-transfer capabilities of physical objects and have difficulty distinguishing conductive from insulating materials. Designers 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 might unintentionally create shorts in the circuitry.

### Inventive electronics

Creating e-textiles requires a firm understanding of electronics, yet even simple circuits can pose a challenge to new designers. Balancing the number of LEDs that can be lit by a 3-V 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 constructions. New materials also offer unique possibilities in electronic designs—for example, the natural resistance of conductive thread can be used in place of a commercially available potentiometer: the longer the thread, the greater the resistance in the circuit, and the shorter the thread, the less resistance in the circuit. 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.

## BROADENING COMPUTING EDUCATION THROUGH E-TEXTILES

The creative problem solving, flexible thinking, and risk taking integral to e-textile design are ideal byproducts of a STEAM-powered approach to education, which aims to balance technical expertise with artistic vision. By appealing especially to young girls and women, e-textiles offer a compelling medium to broaden participation in computing.

**E-textiles are not only effective tools for broadening participation in computing but might also offer greater transparency into STEM disciplinary content.**

The capacity for e-textiles to diversify participation was first documented by Leah Buechley and Benjamin Mako Hill,[2] who discovered that while men created the majority of traditional Arduino projects posted on Vimeo, YouTube, Flickr, and other sites (85 percent), women created most of the LilyPad Arduino projects (65 percent). What is striking about this comparison is that both types of projects share the same microprocessor and are programmed in the same language. The researchers suggested that the gender discrepancy could be due to some combination of the tools and materials used (insulated wire versus conductive thread to make connections between components), the construction practices employed (soldering versus sewing), and the nature of the products (robots versus interactive quilts).

To understand whether changing these factors could significantly alter classroom culture in a similar way, we implemented a series of e-textile experiments in middle school settings where we closely observed how gender dynamics played out. From videotaped observations of subjects working in mixed-gender pairs, we 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. The projects were positioned in front of the girls 81 percent of the time; the girls also spent 58 percent of the time directing activity, troubleshooting, and deciding next steps and made only 39 percent of the requests for help from teachers and peers. We found that this early leadership was predictive of having more sophisticated command of the technology in subsequent projects, requiring less troubleshooting and assistance from others.

Taken together, these studies suggest e-textiles can impact the computing culture in both the wild and the classroom. We attribute this largely to the STEAM nature of e-textile design and construction: the tools, materials, practices, and products are "coded" for girls, encouraging them to engage in computing by engaging their creative interests.

## IMPACTING LEARNING OUTCOMES

E-textiles are not only effective tools for broadening participation in computing but might also offer greater transparency into STEM disciplinary content.[8] For instance, e-textiles are particularly suitable for exploring circuitry.[9]

Knowledge of circuits is usually assessed through circuit diagrams.[10] Students are tasked with diagraming a sample circuit with the materials used to create it—in most cases, this includes a 9-V battery, a small lightbulb, and wiring—and then indicate the direction of current flow. Because we work with e-textiles, we created new assessments incorporating sewable LEDs, battery holders, and switches, but found that even those students with prior experience constructing simple circuits could not translate this understanding to the new materials.

However, after creating simple computational circuits with e-textile materials, we found in a pilot study that students significantly increased their understanding of key circuitry concepts.[9] A paired-samples $t$-test, for example, showed that their ability to diagram a working circuit was considerably higher in postassessment (mean = 0.78, standard deviation = 0.43) than in preassessment (mean = 0.11, standard deviation = 0.32); $t(16) = 4.76$, $p < .001$ (two-tailed). In addition, the students significantly increased their knowledge of current flow ($p < .05$), circuit polarity or directionality ($p < .05$), and connectivity ($p < .05$)—concepts even college undergraduates in introductory physics and engineering courses have persistent misunderstandings about.[11]

Stitching circuits seems to demystify ideas that can be elusive to students using traditional electronics toolkits, such as the fact that some circuit components have an associated polarity, that current flows in a loop, and that current only flows when there is a solid connection between components. Our pilot study suggests that e-textile toolkits underscore basic circuitry principles in tangible ways as well as allow for novel aesthetic possibilities.

## E-TEXTILE PRACTICES AND PRODUCTS

E-textiles will do little to broaden computing education without the support of robust practices and products. For example, soldering a LilyPad Arduino into a small robot in place of a standard Arduino microcontroller (sometimes used due to its small size) is not as transformative as producing a novel form factor, such as a sewn circuit or piece of programmed jewelry. Engaging novice designers in sewing and other nonengineering practices is the key to cultivating interest in the activity and building a bridge between the arts and STEM.

In trying to realize e-textile practices and products that will resonate with girls as well as boys in computing education, my colleagues and I have spent considerable time developing prototypes of such projects. At our e-textile workshops, we have found that youth gravitate toward two general categories of projects: e-fashion and e-puppetry. Others working to envision a STEAM approach to e-textile design have developed themes around sports, superhero costume design, and theatre to emphasize the work's performance possibilities.

LilyPond (http://lilypond.media.mit.edu), the primary online hub for the global e-textile community, showcases the range of e-textile applications that appeal to youth. Young designers around the world post images of their projects to the site, along with a brief description of their process and the code they used. Users draw inspiration from, and often extend or customize, others' ideas. Created for both formal and informal settings, these projects are a collective example of how youth can integrate e-textiles into their personal, cultural, and digital identities.

## PRINCIPLES OF STEAM-POWERED COMPUTING EDUCATION

Drawing from our experience with e-textiles, we have developed a series of eight guiding principles of STEAM-powered computing education.

### Choose open-ended, personal, and aesthetic tools and materials

STEAM-powered tools and materials allow for open-ended exploration, a high degree of personal expression, and aesthetically compelling possibilities. With the LilyPad Arduino, for example, novices and experts alike can create projects such as a fabric harp, an interactive dance costume, a simple circuit quilt, or a solar-powered backpack. Mitchel Resnick and Brian Silverman describe tools and materials that allow for such a diverse range of projects as having "wide walls,"[12] enabling personally and culturally meaningful work to emerge.

However, there is also an inherent tension in working with physical rather than digital materials. For the most part, young students can easily access digital content such as images, sounds, songs, video, and other content from the Internet for their designs. In contrast, the facilitator has to obtain physical materials in advance for a project, which has radical implications for the design space—the choice of fabrics or T-shirt colors can reify or challenge existing cultural norms. Involving students in these decisions is one way to address this issue.

### Make design thinking central

Design thinking provides a common ground for both the arts and STEM, particularly engineering, and positions the learner an active agent in the creative process rather than as a passive recipient of materials.[13] Externalizing ideas and building on them throughout the design process creates two conditions that are ideal for learning.[14] First, explaining an idea, in words or through an artifact, requires reorganizing that idea into different formats. Second, creating a physical representation of an idea and reflecting on that design creates an opportunity for formative feedback. In apprehending why designs fail to reflect original intentions, and what changes are needed to achieve their goal, students can refine their understanding of the concept being modeled.

**STEAM-powered tools and materials allow for open-ended exploration, a high degree of personal expression, and aesthetically compelling possibilities.**

### Create authentic combinations of STEM and the arts

The inherent challenge in designing STEAM activities is that they must authentically engage participants in both STEM fields and the arts. This could take many forms but includes learning about physics, engineering, and material science as well as about visual and performing arts, crafts, and media. With e-textiles, this might mean requiring students to understand Ohm's law in the context of circuit design as well as the various stitching techniques in order to choose the most appropriate one, both technically and aesthetically. While a STEAM-based approach might require more up-front groundwork for practitioners, students garner expertise in several content areas as well as the skill sets to think across traditional disciplinary boundaries.

### Facilitate easy-entry, but challenging, designs

In advocating STEAM-based education, Resnick and Silverman have argued for both a "low floor" (emphasizing easy entry into complex disciplines) and a "high ceiling" (enabling users to dive deeply into a project).[12] Initially, only those with advanced degrees in engineering, computer science, and textile design created e-textiles. However, tools and materials accessible to a wider audience are emerging. For instance, several e-textile toolkits let users snap the circuitry together to promote learning about the computational elements of e-textiles while limiting the need to understand crafting or aesthetically envision designs. Moreover, new tools such as the LilyPad Arduino and Modkit Micro (www.modk.it) lower the barriers to engagement for do-it-yourself designers and even young children while still enabling them to grasp the underlying scientific concepts.[3]

### Purposefully contrast multiple media, tools, and materials

Developing lines of contrast between diverse materials, tools, and media forces learners to reexamine what they know in one context when they see the same phenomenon play out in a new context. For example, color mixing with paint and light are radically different, and highlighting the properties of pigment and light motivates students to ask about these differences. Similarly, moving between the digital and physical domains illuminates how computer code on the screen relates to the control of physical materials in our environment.

**Because STEAM education is inherently interdisciplinary, there is a wide range of opportunities to draw on each discipline's unique practices and community values to envision diverse products.**

Even smaller lines of contrast between near-equivalent materials can help young students think flexibly about their designs. For example, many students have trouble transferring what they know about lightbulbs to two-pronged LEDs and knowledge of these to sewable LilyPad LEDs, as each of these components looks very different while ostensibly doing similar things. Moving from insulated wire, soldering, and alligator clips to sewing a circuit with conductive thread is similarly challenging to students: common mistakes include sewing through components or using the conductive thread in decorative ways, causing multiple shorts in the circuit.

### Involve a range of disciplinary experts

Because STEAM education is inherently interdisciplinary, there is a wide range of opportunities to draw on each discipline's unique practices and community values to envision diverse products. In our work with e-textiles, we have engaged knitters, composers, dancers, biologists, and computer scientists toward very different ends. The knitters, for example, combined e-textiles tools and materials to create stretch sensors that conduct electricity well when pulled as well as bags that hold the knitting pattern for their owner, whereas the biologists helped us create wearable computing experiences for young children to learn about complexity in biological systems.

Such varied perspectives motivate innovative and compelling applications of computing technology. Moreover, disciplinary experts in STEM and the arts each value different aspects of the work, which is important for ensuring broad participation. In game design projects, our computer scientists valued those games that had the most sophisticated kinds of programming commands (such as variables, loops, and conditionals) as well as complex interaction design, even if this meant reproducing known videogames or genres. In contrast, artists looking at the same designs valued those projects that were aesthetically moving and broke with the expected use of the medium, which often had very simple code and hand-drawn images.

Including a diversity of content experts in curriculum design drives creativity when using such materials. Within K-12 settings, instructors should consider pulling from resources within the local community, including family members with deep knowledge of a particular craft or colleagues with various disciplinary training.

### Devise new assessments, pedagogy, and learning environments

Moving from activities rooted in a single discipline to interdisciplinary—and even antidisciplinary—ways of working, as well as employing novel and diverse tools and materials, inevitably raises questions about what students are learning. Consequently, new ways to assess and train teachers, mentors, and facilitators are needed.

In our work, we wanted to make sure that young students could demonstrate an understanding of e-textile tools and materials as well as those traditionally used to teach circuitry. We thus drew upon a wide variety of domains, including digital arts, physics, and crafting, in conceptualizing what and how to teach and in organizing the learning space.

Our approach generally embraces the rich studio traditions of the arts classroom. However, for some activities, such as prepping materials (for example, cutting strips of fabric) and managing them over time, we rely on common electronics and engineering practices. Students sort and label materials by their voltage, resistance, and other properties.

To successfully transform classroom and after-school learning environments, it is important to relay these types of insights to preservice teachers and informal educators as well as provide rich cross-disciplinary training.

### Document and showcase work

As students work with new tools and materials to render aesthetically compelling work with STEM content, it is important to document the process and products of creation, celebrating failures as well as successes as learning experiences.

In our own work, we leverage social media as well as seek to develop new online communities like LilyPond, which was the first to blend electronics and textile design. As young students document the steps involved in creating their projects—in the vein of sites such as Instructables (www.instructables.com)—they develop technical writing skills and learn the fundamentals of multimedia design, such as how to tie images and video to text. Describing how to do something also forces students to reflect on the production process. Publicly sharing their work provides students with opportunities for feedback during project iteration. Exhibiting projects at physical gatherings such as Maker Faires (http://makerfaire.com) or local gallery displays serves a similar purpose.

While e-textiles have compelling implications for broadening participation and learning in STEM disciplines, other types of toolkits and materials are entering the marketplace that blend computation and craft in increasingly imaginative means.

Leah Buechley and her colleagues at the MIT Media Lab have designed a paper computing kit that enables the designer to place a series of magnetic microcontrollers, sensors, lights, and other devices on magnetic paper or a surface coated in magnetic paint, upon which the designer can use conductive paint to literally paint the circuit. The toolkit blurs book making, visual arts, and circuits, and has been used to create electronic pop-up books and other interactive walls or surfaces,[15] among many other possibilities yet to be explored.

Squishy Circuits design tools and activities provide more intuitive and playful ways for kids of all ages to create circuits and explore electronics through the use of conductive and insulating dough.[16] In addition to being well aligned with children's play, this approach blurs the boundaries between sculptural materials and circuits, opening the door for exciting new possibilities in STEAM education.

Finally, new digital fabrication techniques are integrating computing technology into uniquely crafted jewelry, furniture, and other artistic designs that open yet another landscape to explore in STEAM education.

Taken together, emerging tools, materials, practices, and products at the intersection of the arts and the STEM disciplines could revolutionize computing education as well as have rippling impacts within each of these fields.

## Acknowledgments

This article is based upon work supported by the National Science Foundation under grant number 0855886, awarded to the author.

## References

1. J. Margolis and A. Fisher, *Unlocking the Clubhouse: Women in Computing*, MIT Press, 2003.
2. L. Buechley and B.M. Hill, "LilyPad in the Wild: How Hardware's Long Tail Is Supporting New Engineering and Design Communities," *Proc. 8th ACM Conf. Designing Interactive Systems* (DIS 10), ACM, 2010, pp. 199-207.
3. L. Buechley et al., eds., *Textile Messages: Dispatches from the World of E-Textiles and Education*, Peter Lang Publishing, 2013.
4. G. Ngai et al., "Designing i*CATch: A Multipurpose, Education-Friendly Construction Kit for Physical and Wearable Computing," *ACM Trans. Computing Education*, vol. 13, no. 2, 2013; doi:10.1145/2483710.2483712.
5. E. Baafi and A. Millner, "Modkit: A Toolkit for Tinkering with Tangibles & Connecting Communities," *Proc. 5th Int'l Conf. Tangible, Embedded, and Embodied Interaction* (TEI 11), ACM, 2011, pp. 349-352.
6. M. Resnick et al., "Scratch: Programming for All," *Comm. ACM*, vol. 52, no. 11, 2009, pp. 60-67.
7. K.A. Peppler, "Media Arts: Arts Education for a Digital Age," *Teachers College Record*, vol. 112, no. 8, 2011, pp. 2118-2153.
8. Y. Kafai and K. Peppler, "Rethinking Transparency in Critical Making with E-textiles," to appear in M. Boler and M. Ratto, eds., *DIY Citizenship*, MIT Press, 2013.
9. K. Peppler and D. Glosson, "Stitching Circuits: Learning about Circuitry through E-textile Materials," *J. Science and Educational Technology*, Nov. 2012; doi:10.1007/s10956-012-9428-2.
10. R. Osborne, "Towards Modifying Children's Ideas about Electric Current," *Research in Science and Technological Education*, vol. 1, no. 1, 1983, pp. 73-82.
11. N. Fredette and J. Lochhead, "Students' Conceptions of Simple Circuits," *The Physics Teacher*, vol. 18, no. 3, 1980, pp. 194-198.
12. M. Resnick and B. Silverman, "Some Reflections on Designing Construction Kits for Kids," *Proc. 2005 Conf. Interaction Design and Children* (IDC 05), ACM, 2005, pp. 117-122.
13. M. Carroll et al., "Destination, Imagination and the Fires Within: Design Thinking in a Middle School Classroom," *Int'l J. Art & Design Education*, vol. 29, no. 1, 2010, pp. 37-53.
14. S. Papert, *Mindstorms: Children, Computers, and Powerful Ideas*, Basic Books, 1980.
15. J. Qi and L. Buechley, "Electronic Popables: Exploring Paper-Based Computing through an Interactive Pop-up Book," *Proc. 4th Int'l Conf. Tangible, Embedded, and Embodied Interaction* (TEI 10), ACM, 2010, pp. 121-128.
16. S. Johnson and A.P. Thomas, "Squishy Circuits: A Tangible Medium for Electronics Education," *CHI '10 Extended Abstracts on Human Factors in Computing Systems* (CHI EA 10), 2010, ACM, pp. 4099-4104.

***Kylie Peppler** is an assistant professor of learning sciences in the School of Education at Indiana University Bloomington. An artist by training, she engages in research that focuses on the intersection of arts, media, new technologies, and informal learning. She is coeditor of* The Computer Clubhouse: Constructionism and Creativity in Youth Communities *(Teachers College Press, 2009) and* Textile Messages: Dispatches from the World of E-Textiles and Education *(Peter Lang Publishing, 2013). Peppler received a PhD in education from the University of California, Los Angeles. Contact her at kpeppler@indiana.edu.*