CHAPTER 13.

E-TEXTILES TO TEACH ELECTRICITY: AN EXPERIENTIAL, AESTHETIC, HANDCRAFTED APPROACH TO SCIENCE

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On a national level, one of the big challenges facing education is diversifying the kinds of students who pursue science, technology, engineering, and mathematics (STEM) (see Resources at the end of the chapter). Too many students do not see a place for themselves in STEM fields, and what may begin as an initial interest in these areas in elementary school frequently drops off in middle school. Often this is most true of students who do not represent the traditional STEM workforce, especially girls and other nondominant students who are more likely to bring expertise and language (discourse) practices not valued in traditional school classrooms or tests. While this may be a national trend, many of us feel this challenge on a local scale in our own schools and classrooms. How do we reach out to kids to help them see the relevance of science in their own lives? What can we do to interest more diverse students in STEM?

A science teacher with 12 years' experience, James Howell teaches middle school science at an economically diverse rural town in the western United States. In a town best known for its world-class skiing, James teaches a very divergent population of students with equally divergent needs. On the one side, he teaches students from affluent homes with high expectations and resources regarding learning and college preparation. On the other side are the students from significantly lower socioeconomic backgrounds, most often from homes where English is not the primary language spoken. These students require the additional supports needed for English language learners (ELLs). Notably, James has noticed that his ELL students are the ones who are hardest for him to reach in science class. The Latino population, from which many of the ELL students come, makes up approximately 30% of the middle school student body. The rest of the school's population consists of mainly affluent Caucasian students. With an increasing Latino population, expectations are that the middle school will shortly exceed a 50% Latino population, making the issues facing teachers more robust. Thus the need to break down boundaries between students and science is felt at classroom, school, and national levels.

Enter e-textiles. Electronic textiles (aka e-textiles) are part of a growing group of "Maker" activities for learning that are part of an increasingly popular do-it-yourself (DIY) movement around the world.

The Maker movement has encompassed everything from woodworking and auto repair to cooking and knitting, but the most celebrated projects generally feature computational tools that have become increasingly affordable and accessible to the general public (see Resources). While being part of this larger DIY Maker movement, e-textiles also challenge it by using "soft" textile materials that are sewn and embroidered with conductive thread, integrating tiny computers (microcontrollers) and lights (LEDs) with traditional crafts, typically seen with women as the creators.

Some readers may be interested in why we chose e-textiles for a science unit and what they have to offer. We turn here to some earlier research by Deborah Fields and colleagues that points to what e-textiles have to offer in terms of learning.[1] First, uninsulated wiring: Using uninsulated copper tape or conductive thread in projects allows students to come face-to-face with short circuits in ways that insulated wiring does not. If they misconnect things or leave sloppy threads in the back of their project, these touching leads connect positively and negatively charged lines, shorting their project (i.e., it doesn't work!). Second, polarity of LEDs on a laid-out circuit: Unlike traditional light bulbs, LEDs (i.e., light-emitting diodes) have specific positive and negative ends. If one mixes up the two ends, the lights will not come on. We've found that this encourages discussion of electron flow and careful planning of circuits. Third, conductive connections: Because thread is not quite as conductive as wire, students have to learn to sew each electrical component quite thoroughly ("three times through" is a common motto for this). Often new sewers don't think to do this and have LEDs and snaps hanging loosely off their projects. They soon discover that these work only when the circuits are held just right, and they have to go back and resew them more thoroughly, leading to very solid remembering of what makes an electrical connection.

These are just a few ways that e-textiles offer unique opportunities to think about and experience electricity. Perhaps most important, throughout their projects students constantly troubleshoot and debug their work, as they inevitably make mistakes while they learn in this new area of design. But as we will share below, this seemed only to increase the level of ownership they felt in their designs and they learned a lot in the process. Further, some prior studies with e-textiles have shown that because of the integration of crafting into circuitry and computing, they indeed disrupt boundaries for students with technology and engineering, especially girls. We wanted to see whether they could break down barriers to interest in science as well.

THE ORIGINS OF OUR E-TEXTILES PROJECT

In the summer of 2013 James' school district provided a weeklong Science Engineering Technology and Math (STEM) conference for any interested teachers in the county. As part of this workshop, James met Dr. Deborah Fields as she led a small group of teachers in an intense mini-workshop (10 hours) learning to design with e-textiles. Beginning by creating a light-up bracelet, teachers were introduced to the basics of e-textiles: how to sew, how to design circuits, how to integrate sewable computers to make the lights on their clothes blink. As part of the workshop, James remade an existing university hoodie by adding several lights that blinked and twinkled more and more intensely the harder he squeezed two patches in the pockets—which became a silent signal to his students that they needed to pay attention (see Figure 1). James' hoodie is an example of the personal expressiveness

1. For more resources on what students learn by using e-textiles, see these articles: Peppler and Glosson (2013); Kafai, Fields, and Searle (2012); Kafai, Fields, and Searle (2014); Kafai et al. (2014).

and the challenging science and engineering work that can take place together in e-textiles projects. James was very excited by his creation and immediately began to discuss with Deborah the ways in which this work was directly applicable to what he taught in eighth-grade physical science.

Figure 1. James Howell's programmable human sensor hoodie.

Putting Together a Team

James' initial interest in using e-textiles in his eighth-grade science classes led to a discussion with Deborah and other members of Utah State University (USU) about developing a specific curriculum and set of projects designed to meet the curricular and motivational needs of his diverse students. E-textiles had never been applied in a formal science class, so there were no existing models on how to accomplish this. Deborah had mostly led e-textiles projects in elective courses or workshops and did not have a background in formal science education. How could we justify doing these crafty projects in science class? What standards would they meet? Where could we get the money for supplies? How would we know if the unit "worked" compared to more traditional instruction?

To move the project forward we got together a team of people with different expertise, with James as the teacher at the core. Deborah sought out help from two colleagues at Utah State University. Dr. Colby Tofel-Grehl was a science teacher and new assistant professor focusing on science education. She would help create the science units, making sure they met standards and that the appropriate science content was integrated into the units. Dr. David Feldon, the new STEM director at USU, helped us think about how to design the circuitry units and how to measure whether e-textiles actually helped students learn concepts about electricity as well as whether the project made a difference in their attitudes toward science. Of course this project couldn't happen without the support of the middle school administration—James approached his principal and after a couple of team meetings we had the go-ahead to move forward. Not only that, but the principal earmarked $5,000 for supplies for the project, seeking funding from a local foundation for the special money needed.

In discussions as a team, we realized that we had an opportunity to teach eight full science classes—the entire eighth grade of the school. James and the other eighth-grade science teacher switched classes toward the end of every school year, allowing him to teach electricity to his four eighth-grade classes as well as to the other teacher's four eighth-grade classes. This allowed us to explore the potential benefits of the e-textiles approach compared to other approaches. We decided as a team that James would teach half of the classes the way he had always done, using alligator clips and lightbulbs, and the other half of the classes using e-textile–based projects. To ensure that all students were exposed to the same content material, Colby constructed specific content lessons that would ensure that all students were taught the same information while leaving the differences in materials separate. David developed assessment materials to best explore the learning outcomes of students. James, Deborah, and graduate student Gabriella Ducamp chose the specific e-textiles projects, using resources developed for Deborah's class by some of her former students and samples created by a current student (Janell Amely).

Creating an E-Textiles Unit for Science Class

All classes had approximately 20 days for the electricity unit. For all eight of the classes, regardless of whether they were offered e-textile or traditional projects, James taught content lessons at the beginning of the unit as overviews and throughout as standard mini-lessons. On the first two days of the unit all classes explored energy, electron transfer, and conductivity. James taught additional lessons on circuits, types of circuits, and what causes short circuits throughout the units. As this information was introduced to the students, so were different projects and activities. Both groups participated in the same activities for the first two weeks of the unit. Tasks during the first week included using balloons to model charge, making use of the periodic table and digital multimeters to predict the conductivity of various materials, drawing simple and parallel circuits with appropriate schematic symbols, and assembling circuits using bulbs, 9V batteries, and alligator clips. During the second week, students in both groups completed one project using nontraditional materials—paper circuits—in which students adhered copper tape to card stock and added LEDs and a battery to complete series and parallel circuits in a decorative fashion.[2] Moving forward, while the traditional classes used alligator clips and lightbulbs to explore how to make circuits, the e-textiles students used conductive thread and LED lights to sew circuitry-based jewelry and fashion items.

The e-textiles classes constructed three designs using e-textiles materials while the control group performed activities covering the same content using traditional materials. During the third week, e-textiles students designed a light-up bracelet using felt, LEDs, and coin-cell batteries while the traditional students researched batteries, tested the voltage of batteries using multimeters, and practiced assembling various circuit configurations with alligator clips, lightbulbs, and 9V batteries. During the final week of the unit, students in the e-textiles classes created wearable technology by sewing circuits using a LilyTiny—a preprogrammed mini-computer (i.e., a microcontroller) that has different outputs for blink, fade, twinkle, and "heartbeat" lighting effects.[3] Meanwhile, the students in the traditional classes troubleshot short circuits and continued to practice assembling circuits made of traditional materials. See Table 1 for an outline of the e-textiles activities and the kinds of concepts they were intended to teach. To show the range of personal styles and expressiveness students showed in their e-textiles work, even with identical design challenges, we include pictures of some of their projects (see Figures 2, 3, and 4).

Table 1. **Outline of the e-textiles activities.**

Project	Targeted Skills and Knowledge
Paper circuit (see Figure 2)	*Electricity*: Conductivity, simple circuits, polarization *Conductive Materials:* Copper tape, LEDs *Crafting*: Taping, cutting, folding
Bracelet (see Figure 3)	*Electricity*: Parallel circuits, switches, polarization, short circuits *Conductive Materials:* Conductive thread, metal snaps *Crafting*: Basic sewing, running stitch, knots
LilyTiny project	*Electricity:* Computational circuits, resistance, common ground *Programming:* Preprogrammed microcontroller supports knowledge of the capabilities of computing

2. We strongly recommend starting with paper circuits. They are relatively simple and the resources are cheap (paper clip for a battery holder!). Then you can move on to soft circuits that use simple or parallel circuits, and finally to computational circuits (something we did not tackle in this project but have elsewhere) that use sewable microcontrollers to make lights blink, twinkle, and fade. You could add sensors to these projects so that squeezing some conductive aluminum foil patches make the lights change brightness or using a light sensor to make lights turn on when it gets dark. Some of the resources we've used are listed below

3. The LilyTiny microcontroller is available on Sparkfun.com for about $4. It has four preprogrammed outputs: fade, blink, heartbeat, twinkle. The LilyTwinkle is nearly identical—it has four different preprogrammed twinkling effects. If you want to program your own lights, try the LilyPad Arduino (Sparkfun.com) or the Adafruit Flora (adafruit.com) or the Adafruit Gemma (adafruit.com).

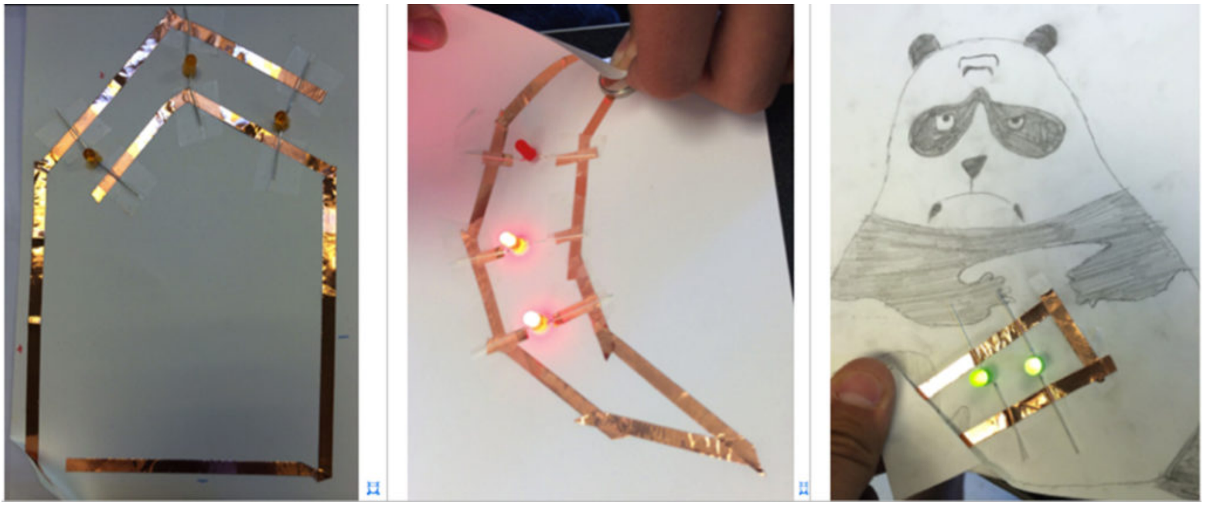

Figure 2. Examples of students' paper circuits.

Figure 3. Examples of students' bracelet projects.

Figure 4. Examples of students' LilyTiny projects.

HOW IT WENT

If you would have taught this way the whole year, I would have been way more interested in science.~Phillip

Overall, everyone learned regardless of which class students were in. We noted improvements across all classes in their understanding of how electricity works and how circuits function. Yet almost immediately, James reported seeing a difference in the attitude of his e-textile class students, particularly his ELL students. Students such as Phillip, who noted his new interests in the sentence above, turned in completed assignments for the first time all year long. Noting their eagerness to work and take projects home over the weekends for additional time, James found himself eager to understand what this new engagement signified and why it was so different from normal: "Quite frankly, the change was beyond my predictions!" He reported that for the first time all year he got completed work from nearly an entire class of ELL students. While these students may not have gained *more* than other groups in terms of learning, for the first time that year they kept pace with the other classes.

In the next sections we share some stories of individual students and some themes of *why* we think e-textiles made a difference to students, especially ELL students. Where we can we refer to some other research that has been done on e-textiles, especially as it helps us understand this particular set of classroom experiences. The stories, though, are unique to this first integration of e-textiles into a science classroom.

Connecting Across Boundaries

One thing we found encouraging was that e-textiles allowed students to draw on a range of different kinds of expertise, and that some of this expertise came from families who before this unit had not been framed as helpful for science. Others have noted that e-textiles are a special combination of circuitry, computing, and crafting.[4] The crafting component in particular disrupts what people think about science, especially because it is intricately related to all of the other aspects of a successful e-textile design. Sewing circuits is very different from creating them with alligator clips. Notably,

4. Kafai, Y. B., Fields, D. A., & Searle, K. A. (2012). Making learning visible: Connecting crafts, circuitry & coding in e-textile designs. In J. van Aalst, K. Thompson, M. J. Jacobson, & P. Reimann (Eds.), The Future of Learning: Proceedings of the 10th International Conference of the Learning Sciences (ICLS 2012), Vol. 1, Full Papers (pp. 188-195). International Society of the Learning Sciences: Sydney, NSW, Australia.

working with one's hands, something often not recognized as a legitimate form of expertise in schools though it is cognitively sophisticated (see Mike Rose's book, *The Mind at Work: Valuing the Intelligence of the American Worker*),[5] becomes relevant in the context of e-textiles. Many of James' ELL (and other) students have parents and relatives who are expert sewers and expert sewing teachers.

A prime example of this trend is Jose, a young man who failed science consistently in eighth grade before the e-textiles unit. A nonnative English speaker, Jose gravitated toward art to express his ideas, avoiding academic engagement, perhaps in part because his family members do not have a lot of academic, school-based expertise. When it came to the first e-textiles project, Jose had a design idea for his bracelet that he could draw, but he didn't know how to sew, so he sat with his grandmother (a seamstress at a local dry cleaner) nightly as she suggested and demonstrated sewing techniques. Though his bracelet was not functional, it looked great. Before long, friends came to Jose for advice—offering to explain science concepts or help with his circuit design in exchange for recommendations as to how to improve their sewing techniques. Jose's LilyTiny hanging was one of the most balanced final pieces in terms of circuit and sewing design as well as functionality (see Figure 5). Like Jose, for the first time in their academic careers many of James' ELL students received instruction and help with their homework from their parents or family members. E-textiles helped generate interest in students' schoolwork because family expertise was finally framed as relevant to science education, breaking down some boundaries between home and school.

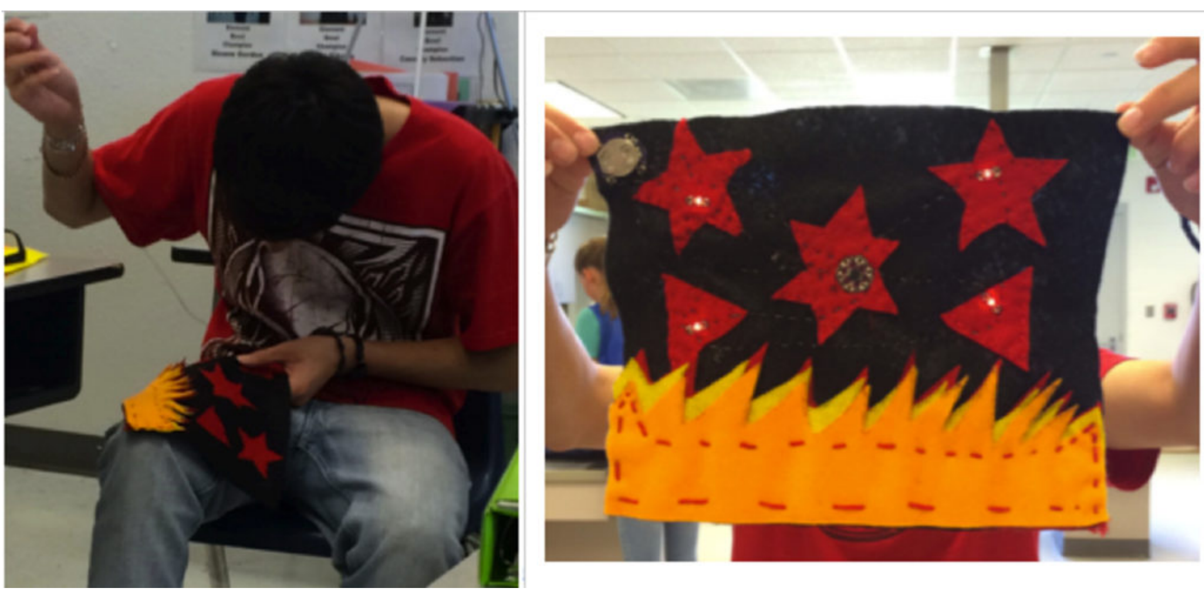

Figure 5. Jose working on his project (left) and Jose's finished project, complete with decorative sewing of the flames.

Personal Ownership

Another thing we found important in the e-textiles unit is the idea of ownership. Since the completion of the e-textiles unit, several students have asked James for more batteries to power their projects, pointing to the continued ownership they have over their projects. They continue to wear, display, and use their e-textile projects! Maria, a studious bilingual student with a strong work ethic encouraged by her parents, took her LilyTiny project to the library after school every afternoon

5. Rose, M. (2005). The mind at work: Valuing the intelligence of the American worker. New York, NY: Penguin.

until her parents came home from work. Using her "nerdy" skills, she upgraded her worn high-tops into something more fashionable (see Figure 6). This actually helped her connect with her classmates and gain social status as she answered their questions about the unique project. Her project simultaneously displayed her knowledge of science while also being a cool fashionable item that could connect her with friends. Notably, e-textiles are generally transportable, easily displayed in many places. This promotes a wide audience for viewing and asking about e-textiles, allowing them to act as boundary-crossing objects that are relevant to friends and family as well as to science teachers. Actually taking something home and being proud of a creation was a significant factor in students' success in e-textiles.

Figure 6. Maria's project from planning stages (left) to circuit diagrams (middle) to final completion (right).

Persevering Through Struggle

Students need to struggle and learn from mistakes; it's one big part of how people learn. James, like many teachers, often has to remind paraprofessionals and aides in his classroom not to give students answers. One of the lessons we learned from this unit was to allow *more* time for students to make mistakes and troubleshoot their projects. Recommendation: If you decide to infuse e-textiles into your electricity unit, set a project completion date and save two days after that completion date for troubleshooting! As James put it, "I underestimated the value of this troubleshooting period with our first study group. Letting students struggle solidified learning and allowed students to teach others based on their new understanding."

In the context of the e-textiles class, student struggle often became a collaborative event, encouraging peers to teach each other. Consider Sofia, who possessed a strong presence among her mostly male group of Latino friends, often clarifying meaning as they code-switched between English and Spanish, helping each other understand instructions and content. While making her bracelet, she struggled to understand how snapping the bracelet would close the circuit (i.e., creating a switch), but after examining the *Bracelet Guide* with Mr. Howell, she understood the concept and passed this understanding along to her friends. Allowing the time for students to struggle and overcome the bugs in their projects created a new dynamic in which they could also share their expertise (and their trials) with each other in getting things to light up.

Choice and Personal Aesthetics

Allowing the students to decorate, choose, and design their e-textiles awakened that sense of ownership that normally does not come up in science for all students. Art and aesthetic suddenly become relevant to science, allowing for students to connect with science in ways they may not have before. Like those of most other students, each of Annie's designs was personal (see Figure 7). In her paper circuit, she used a basic schematic drawing to envision making a complex paper circuit maze, which she was able to use to explain electron flow. This went far beyond the basic instructions for completing the paper circuit, encouraging her deeper learning about circuitry. For her bracelet, she made the aesthetic design choice to show something that naturally lights up—stars. With her final project she made a T-shirt depicting a planet with glowing rings to match the bracelet, taking the extra step of sewing a pocket into it and hiding the LilyTiny microcontroller, so that her image would be the focus of her project rather than the tools used to make it. Annie thought that she grasped electrical concepts at a deeper level when crafting e-textiles than she was able to express during the traditional lessons and worksheets in the unit. Something about drawing out and constructing the design so carefully helped her to get inside of it.

Figure 7. Annie's three e-textile projects from left to right: paper circuit (maze), starry bracelet, and glowing planet with hidden microcontroller (lower left of picture).

Many of the extra steps taken to personalize a project can actually lead students to revise their circuit diagrams in sophisticated ways, providing the double bonus of learning alongside motivation.[6] What makes e-textiles special is that the science of electricity and circuits becomes interwoven with the style of the person designing them. The science aspects aren't just slapped on top of an otherwise purely decorative project. Sewing the circuits actually promotes learning about short circuits, electrical polarity, and conductivity. The physical structure of the very personalized circuits ensures that each student had his or her own particular challenges in keeping the positive and negatives sides from touching, discovering the relevance of a "common ground," and so on.

Beyond that, the act of sewing e-textiles led to a calm and concentrated classroom atmosphere. As James commented,

> *Take a room of 25 middle school students and put a needle and thread in their hand, and the only sound you will hear is that of utter concentration. I can't explain it, but during this sewing time my students had higher levels of concentration and focus than many of the other hands-on activities in my classroom.*

The tactility, individuality, and displayability of the e-textiles really lent themselves to hard, concentrated work. In addition, students knew they would be able to keep their projects, and we think this encouraged deeper effort and ownership.

6. Kafai, Y. B., Fields, D. A., & Searle, K. A. (2012).

FINAL THOUGHTS

Do you need to partner with university researchers to implement e-textiles into your electricity unit? Absolutely not. However, we found a wonderful synergy between a science teacher (Howell) eager to reach out to students not engaged in his science classes, a former science teacher-now-researcher (Tofel-Grehl) willing to dig in and figure out the science behind e-textiles, and a researcher-crafter (Fields) who had a lot of expertise in teaching e-textiles in school workshops, clubs, and even computing classes (but notably not science!). Add to this a school administration willing to try something new as well as to find and commit funding for supplies, some undergraduate and graduate students who helped to design some instructional guides and sample projects (former students of Fields), and a graduate student willing to regularly observe the class (Ducamp). Parallel to the ways that e-textiles bridge many forms of expertise across school, family, and friends, we too brought different expertise and were all willing to work across our normal boundaries to make this project work. It was unique and atypical for each of us.

What were the key things that made this project a success? First, James actually became engaged with e-textiles through his own intensive designs. We cannot emphasize enough how important it is to *make something yourself* before figuring out how you might teach it to students. Second, we saw the potential in e-textiles to connect to science education. All of the elements that worked about the units—perseverance, ownership, choice, and aesthetics—worked because they were also part and parcel of constructing scientific objects. Third, we were able to do everything a second time through tag-team leadership structure of this electricity unit. Like the students doing their e-textiles, we had the chance to debug the unit a bit. For instance, James set aside more time for construction and troubleshooting projects in the second round.

Where can we find resources for doing this? We have listed some resources we have used at the end of the chapter, including the e-textile guides that we developed for this unit (see Resources for Getting Started with E-Textiles). Many resources are online, and if you're looking for a place to start we recommend Jie Qi's paper circuit activities (also in Resources). Additional project ideas can be found on sparkfun.com (our main go-to supplier)—check the LilyPad e-textile tutorials developed by Leah Buechley: https://learn.sparkfun.com/tutorials/introducing-the-lilypad-design-kit; also apply for an educational discount). Adafruit (another of our main suppliers) has some other e-textile tutorials using some different sewable hardware, mainly the Flora and the Gemma. Ecrafting.org and Instructables.com also have ideas for projects. Just search for "LilyPad," "e-textiles," or "Flora." Most important, consider the social resources available to you. Many students and parents have crafting experience and others may have Maker, science, or technological expertise. It was through combining our own expertise and resources that we were able to make this unit happen. One of the great things about e-textiles and similar craft-based technology projects is that parents and students can bring their own expertise from home into school. We think this is one of the areas where we could grow: finding ways to better draw on and leverage family expertise.

These materials are expensive. Are e-textiles worth the cost? Absolutely! Depending on what components and specific subprojects are included, e-textiles curricula can range from modest to very expensive. For the projects selected in James' room, the materials cost approximately $50 per student. As Mr. Howell said, "Expensive? Yes, but well worth it." However, you could complete this project inexpensively by collecting and reusing materials or putting students in pairs. To keep costs down, students in Mr. Howell's class reused materials when they could across projects, such as batteries, and had their design plans approved before making their projects to prevent waste. Everything from expensive sports-team shirts to materials found in the lost-and-found bin at school were incorporated in students' e-textiles. In an example of the latter, Ben was so enamored of the hat he found in the school's lost-and-found bin, which reminded him of a favorite cartoon character, that he took his work home and completed it using wires, since he did not have conductive thread there. He paraded into class the next day wearing it. Reusing materials or using alternative materials doesn't seem to deter student ownership. Plus, using and adapting found or alternative materials such as Ben's wires can encourage innovation and learning!

RESOURCES

Resources on Engaging Students in Science and Engineering

Atwater, M., Wiggins, J., & Gardner, C. (1995). A study of urban middle school students with high and low attitudes toward science. *Journal of Research in Science Teaching, 32,* 665-677.

Barton, A., Tan, E., & Rivet, A. (2008). Creating hybrid spaces for engaging school science: How urban girls position themselves with authority by merging their social worlds with the world of school science. *American Education Research Journal*, *45*(1), 68-103.

Brickhouse, N. W. (2001). Embodying science: A feminist perspective on learning. *Journal of Research in Science Teaching, 38*(3), 282-295.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*, 474-496. doi:10.1002/tea.20347

Nasir, N. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning, and identity in basketball and classroom mathematics. *Journal of the Learning Sciences*, *17*(1), 143-179.

President's Council of Advisors on Science and Technology. (2011). *Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future*. Washington, DC: Office of Science and Technology Policy, Executive Office of the President.

Swarat, S., Ortony, A., & Revelle, W. (2012). Activity matters: Understanding student interest in school science. *Journal of Research in Science Teaching, 49,* 515-537. doi:10.1002/tea.21010

U.S. Government Accountability Office. (2005). *Higher education: Federal science, technology, engineering, and mathematics programs and related trends* [Report to the Chairman, Committee on Rules, House of Representatives (GAO-06-114)]. Washington, DC: Government Accountability Office.

Resources on Research on the Maker Movement and E-Textiles

Buechley, L., & Hill, B. M. (2010, August). LilyPad in the wild: How hardware's long tail is supporting new engineering and design communities. *Proceedings of the Conference on Designing Interactive Systems (DIS)* (pp. 199-207). Denmark: Aarhus.

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Gauntlett, D. (2011). *Making is connecting*. Cambridge, England: Polity Press.

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Kafai, Y. B., Fields, D. A., & Searle, K. A. (2012). Making learning visible: Connecting crafts, circuitry & coding in e-textile designs. In J. van Aalst, K. Thompson, M. J. Jacobson, & P. Reimann (Eds.), *The Future of Learning: Proceedings of the 10th International Conference of the Learning Sciences (ICLS 2012), Vol. 1, Full Papers* (pp. 188-195). International Society of the Learning Sciences: Sydney, NSW, Australia.

Kafai, Y. B., Fields, D. A., & Searle, K. A. (2014). Electronic textiles as disruptive designs in schools: Supporting and challenging maker activities for learning. *Harvard Educational Review, 84*(4), 532-556.

Kafai, Y. B., Lee, E., Searle, K. S., Fields, D. A., Kaplan, E., & Lui, D. (2014). A crafts-oriented approach to computing in high school. *ACM Transactions of Computing Education, 14*(1). 1-20.

Peppler, K., & Glosson, D. (2013). Stitching circuits: Learning about circuitry through e-textile materials. *Journal of Science Education and Technology, 22*(5), 751-763.

Resources for Getting Started With E-Textiles

- Our own guides are available freely online.
- o Bracelet project:

http://itls.usu.edu/files/projects/ETextiles_Bracelet_Guide.pdf

- o LilyTiny project:

http://itls.usu.edu/files/projects/ETextiles_LilyTiny_Guide.pdf

- Jie Qi developed the basic projects we used for paper circuits: http://technolojie.com/circuit-sticker-sketchbook/. Note: She has developed circuit stickers to use (peel and stick LEDs with conductive adhesive) but you can also use normal LEDs. Just bend the wires out horizonally and use tape to connect metal to metal (i.e., LED leads to the copper tape).
- o She also hosts a Google group for educators working on new versions of paper circuits: https://plus.google.com/u/0/communities/106297899247135466221
- Leah Buechley (developer of the LilyPad Arduino) has created tutorials in several venues:
- o Sparkfun tutorial on soft circuits: https://learn.sparkfun.com/tutorials/introducing-the-lilypad-design-kit.

- o *Sew Electric* book by Leah Buechly (excellent resource for learning to compute with e-textiles). Available on Amazon. Plus several sections are available free online: http://sewelectric.org.
- Instructables.com has tutorials on everything under the sun, including e-textiles! Just search for "LilyPad" or "e-textiles" and you will find projects and instructions created by users.
- Ecrafting.org is another resource for specifically educational e-textiles projects. At the time of this writing the site was relatively new, but it regularly puts up design challenges used by schools and libraries around the United States.