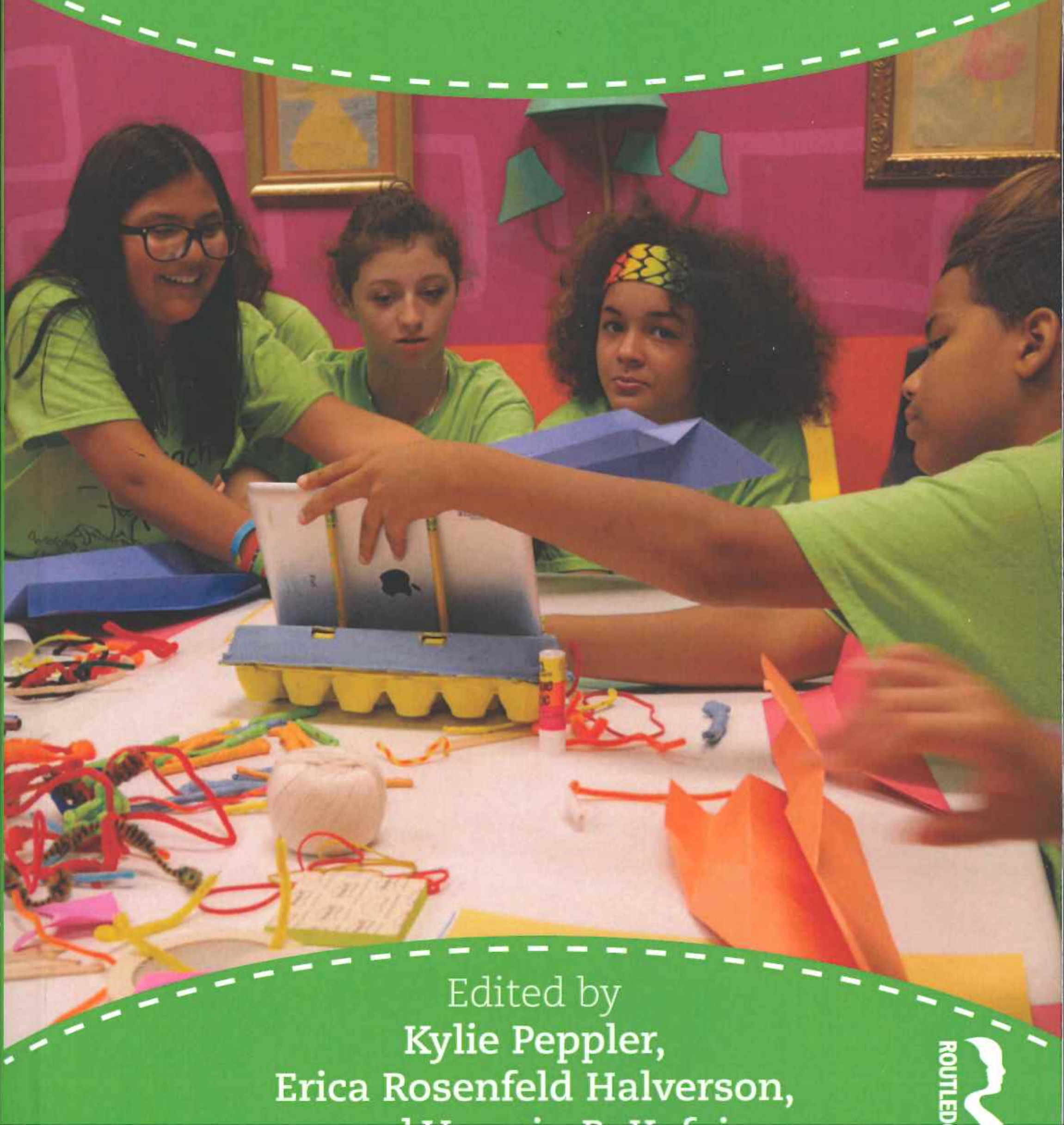
VOLUME 2

Makeology

Makers as Learners



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CHAPTER 13

ReMaking Arts Education Through Physical Computing

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Introduction

The Maker Movement is an amalgam of low-tech and high-tech traditions, though it is the invention and incorporation of new technology that propels its current attention and reach. Similarly, there has been increasing attention paid to the role of new technologies in visual and performing arts education, reflected in the creation of new "media arts" national standards (www.mediaartseducation.org). Though both spheres evaluate technology for its functional and expressive purposes, media art places a greater emphasis on visual culture and linear media, whereas computational media factors more prominently into the broader Maker Movement. Given that computation is taking a more central place in the palette of many of today's professional artists, it is worth investigating whether a greater conversation between arts education and Maker Culture could better prepare youth for entrance into the professional discourse of today's contemporary art.

Over the last two decades, professional artists have mastered computation alongside the visual and aesthetic thinking necessary to the arts (Maeda, 2004; Reas, 2006). Artists approach code as though it were a type of material, like clay or paint, with distinct characteristics, affordances, and limitations. Through an intimate familiarity with the material and a variety of cultivated techniques, artists shape computer code to envision new forms, interfaces, and applications. Because code is so central to expression in new media, a number of scholars, educators, and artists have argued for the inclusion of computation as one of the "new fundamentals" of media art, necessitating the adoption of new computational tools that enable users to engage the computer as a new medium (Maeda, 2004; Peppler, 2010a, 2010b; Reas, 2006) and further arguing that new tools make it possible for even the youngest of artists to engage in computational creativity (Peppler, 2010a; Peppler & Warschauer, 2012).

This chapter takes a closer look at what a maker approach to arts education might look like, one that enhances traditional arts instruction with approaches for producing art that interacts with its environment, facilitates expressive modalities of wearable technology, and takes advantage of the latest breakthroughs in art, technology, and science. Creative production like this can be seen in array of art venues from the colloquial to the curated, including Do-It-Yourself (DIY) creative practices (Kafai & Peppler, 2011), showcased in venues like Maker Faires, as well as the work of professional artists like Cory Arcangel or in the tech-enhanced fashion designs of Hussein Chalayan exhibited in the world's premier art museums. Because of the centrality of "physical computing"—new forms of computational creativity to control and respond to our physical environment—to artistic expression, this chapter argues that we must expand our vision for the arts in education by adding physical computing, a quintessential maker method of production, to the K–16 arts curriculum.

Seeking to address the feasibility of narrowing the gap between arts education and maker practice, this chapter explores the extent to which youth are able to engage in authentic and creative forms of physical computing. Data is pulled from a two-week e-textiles summer workshop with nondominant Chicago Public School students (Buechley, Peppler, Eisenberg, & Kafai, 2013). E-textiles blend computation, craft, and electronics and involve the sewing of wearable computers, sensors, LEDs, and small motors into cloth using conductive thread. The e-textile can then be programmed using novice-friendly software like Modkit (Baafi & Millner, 2011) and uploaded to the wearable computer. Examples of middle school youth engaging in the creative production of e-textiles are presented in this chapter to illustrate how youth can easily be introduced to the basics of physical computing, which encompass a range of techniques and processes, including (1) learning about electronic construction and theory, (2) learning to code creatively, and (3) learning traditional and high-tech craftsmanship. This chapter concludes with a discussion surrounding the implications that physical computing represents for 21st-century K–16 arts education.

Background

Maker Practice, Physical Computing, and Media Arts

The arts reflect the current historical moment. As such, it should come as no surprise that new technologies are being used ubiquitously as creative tools in the arts. This emergent domain of art involving new technologies is an expansive and somewhat amorphous area, commonly referred to as "media arts," "new media," "digital art," or "interactive art" (Nalven & Jarvis, 2005; Paul, 2003). Although the terms have a good deal of overlap, the term "media arts" is used here to "encompass all forms of creative practice involving or referring to art that makes use of electronic equipment, computation, and new communication technologies" (Peppler, 2010a, p. 2119). Media arts encourage designing, creating, and interacting with technology in new ways, which are being widely explored in contemporary art practice.

This mix of tools, materials, techniques, and concepts brings contemporary artists in touch with a number of traditional design and technology domains, including fashion design, product design, arts, crafts, textile design, game design, media design, interaction design, architecture, and interior design, as well as a number of traditional technology domains, including digital technology, wearable technology, material science, electrical engineering, wireless technology, and nanotechnology, among others. In fact, many contemporary media art is created by artists that have either cross-disciplinary training or by teams of collaborators that each specializes in different areas.

Undergirding the work of these artists and many others in contemporary art is the leveraging of software and hardware to sense and control the physical world. Physical computing, in the broadest sense, means building physical systems, sculptures, or environments that are interactive through the use of hardware and software that can communicate with people by using sensors and output devices controlled by small computers, called "microcontrollers." Generally, physical computing can be viewed as a way of describing the relationship we have with the digital world.

Existing Toolkits and Educational Approaches to Support Physical Computing

Currently, there is a larger national push to include technology in the schooling curriculum and new momentum to include new technologies in the arts education curriculum (Arts Education Partnership, 2004), as evidenced by the adoption of media arts curriculum in large schooling districts like Los Angeles Unified (e.g., LAUSD Arts Branch, 2005). However, new media arts programs are often limited by their exclusive adoption of software that emphasize image manipulation (e.g., Adobe Photoshop) as opposed to tools that allow youth to explore the medium of the computer through learning to creatively code (Peppler, 2010b). Those few academic programs that have provided entryways into these areas have taken place almost exclusively in elite higher education institutions steeped in Fine Arts traditions. However, designers over the past several years have created and marketed novice-friendly toolkits with varying degrees of creative potential that would be suitable for adoption in arts education.

First, there is a body of artistic work that has emerged around robotics kits for artists that employs simple gears, pulleys, levers, and microcomputers to sense and control lights, sounds, motors, and other output devices. For example, the commercially available LEGO Mindstorms NXT construction kit allows designers to create robots using unique combinations of microcomputer LEGO bricks, programmed using a visual building block language to take inputs from touch, color, and/or ultrasonic sensors. Other, more advanced robotics toolkits include the Arduino Platform—the toolkit of choice for most artists, designers, and DIY hobbyists—which includes a small microcontroller and accompanying software that can be used to control any number of input and output devices (Banzi, 2008). Although robotics toolkits like these are typically associated with science and technology courses, courses on robotics have also been taught in Fine Arts programs at the undergraduate level (Turbak & Berg, 2002).

A second approach to physical computing toolkits involves a body of work that has emerged around soft circuits or e-textiles. E-textiles are fabric artifacts that include embedded computers and other electronics (Berzowska, 2005; Buechley et al., 2013; Marculescu et al., 2003; chapter 8 of this volume). Instead of focusing on practices like soldering and desoldering, this genre of physical computing involves learning about sewing, quilting, crocheting, knitting, or other techniques that have historically been the domain of seamstresses and crafters. In this tradition, new materials like conductive thread, conductive fabrics woven from copper, silver, or other highly conductive fibers, conductive yarn, and conductive paints are engendering new genres of work that look and feel different from traditional circuits soldered together with insulated wire. There is a range of internationally available toolkits to support e-textile production, including the LilyPad Arduino, i*CATch, fabrickit, and Aniomagic. 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 (Buechley et al., 2013; Fields & Lee, 2016, in volume 1 of this series; Kafai, Fields, & Searle, 2014; chapter 5 of this volume).

This chapter takes a qualitative approach to examining youth in the process of art making involving physical computing with e-textiles in order to address the extent to which e-textile production facilitates opportunities for youth to engage in authentic and creative forms of physical computing. More specifically, we were interested in the extent to which e-textile production facilitates opportunities for youth to engage in (a) electronic construction and theory, (b) creative computing, as well as (c) traditional and high-tech craftsmanship. The development of these skills puts youth in a place where they can combine new technologies and traditional materials in artistically expressive ways.

The E-Textiles Summer Workshop

While many educational approaches have been developed to support physical computing and a wide range of hands-on activities, our two-week summer workshop centered on youth designing with e-textiles for their natural connections to interests in fashion, design, arts, crafts, and new technologies, as well as their ability to engage traditionally marginalized youth (Peppler, Salen, Gresalfi, & Santo, 2014), especially young women (Buechley, Eisenberg, Catchen, & Crockett, 2008; Kuznetsov & Paulos, 2010).

The summer workshop was taught by four professional K–12 teachers at a university facility in Chicago over a period of two weeks, meeting an average of four hours per day, Monday through Friday. The teachers, all newcomers to the world of e-textiles, taught in teams of two in two separate classrooms equipped with interactive whiteboards, large project tables, and one laptop per child. A concerted effort was made to keep didactic modes of instruction to a minimum; the majority of youths' learning would come from playful exploration with the materials and observations of each other's projects and processes. This workshop concentrated on the development of the youths' individual sensibilities within the structure of specific thematic assignments (Rusk, Resnick, Berg, & Pezalla-Granlund, 2008). Emphasis was placed on independent investigations and creative problem solving.

The workshop was offered freely to middle-school-aged youth in the public schools and attracted 53 participants—57% of whom were African American, 15% Caucasian, 9% Latina/o, 9% Biracial, and 19% declined to state. The group included nearly equal numbers of female ($N = 27$) and male youth ($N = 26$). The youth were rising 6th- and 7th-grade students and more than 80% were from low-income communities.

Over the course of the workshop, we collected extensive videotaped observations of classroom interactions, youths' sketchbooks, and informal interviews with youth. Two cameras with wireless microphones were used to capture the workshop events and dialogue. These cameras were consistently focused on eight of the workshop participants who wore the wireless microphones over the course of the workshop. Randomly selected but representative of the diversity of the youth participating, youth recorded their notes and ideas for their projects in a personal sketchbook throughout the workshop. The sketchbooks contained all of the participants' notes, as well as their circuit diagrams, initial designs, and finished project sketches. At the end of the workshop, these notebooks were collected to aid in our data interpretation process, since they provided insights into the youths' design process and contained information that was difficult, if not impossible, to capture through video alone.

The 200+ hours of videotaped observations were first logged according to the focus and the current workshop activity and were subject to further analyses. The observations were then tagged for recurrent practices involving physical computing, e-textile production, and art making. We then chose a selection of these vignettes that were both representative of the dataset yet were illustrative of what physical computing can look like with middle-school-aged youth.

YOUTHS' MEDIA ART AND PHYSICAL COMPUTING

These data sources offer us a closer look how youth create media art via physical computing, informing us about the new materials, processes, and tools required for meaning-making and creative expression with new media. Each aspect of physical computing is presented in greater depth below with attention paid to the extent that youth are able to engage aesthetically and creatively in these introductions beyond merely meeting technical requirements.

Electronic Construction and Theory

The following vignette is of two youth working to construct their first e-textile circuit, after having participated in introductory activities using electronics (see Table 13.1). Amber, a White 7th grader in a well-worn purple T-shirt printed with peace signs, is partnered with Antoine, an African-American 6th grader in basketball shorts and whose height makes him look a little older than his age. The two are working on a project that involves two sock puppets that will complete a circuit when they make contact.

One of the hand puppets was intended to be "reddit robot," who is the "mascot" of reddit.com. In a storyboard that Amber and Antoine created around their puppets, reddit robot sets out to "make people lazyer" [sic] by adding the music to the Nyan Cat Internet meme that rose to prominence at the time of the workshop.

In the sock puppet version of reddit robot, the youth employed their electronics domain knowledge to advance this narrative; the LED on the robot's antenna illuminated when it touched that of the second puppet (equipped with the battery and the other half of the circuit), which represented the content that reddit robot was uploading to the Internet. Having successfully sketched the circuit design earlier, the following vignette depicts the two in the process of making their circuit operational before stitching into the puppets. The youth designed and created their own custom battery holder that sandwiched a 3V battery between two pieces of insulating felt with a small hole cut in the top and bottom sides to create an access point for conductive fabric to touch the battery. The youth ensured a tight connection on either side of the case by affixing a rubber band around it, crossing

Table 13.1 Video transcript of Amber and Antoine troubleshooting the circuitry on their e-textiles project

Video transcript	*Gesture*	*Interpretation*
1. **Amber:** Hold that there. Nah, that ain't going to work—there's not enough pressure . . . It's the rubber band [holding the battery case together] that might not work.	Amber *and* Antoine *place both strips of conductive fabric to the top of the battery holder. The LED fails to illuminate.*	After a first attempt to connect the conductive fabric between the battery and the LED, Amber offers a troubleshooting hypothesis: maybe the connection isn't secure between the battery and its case.
2. **Antoine:** Excuse me, Ms. B—it's not working.		
3. **Amber:** We're testing it with the LED 'cause they [need] more volts, but it's not working.	Ms. B *approaches and places her hands on the project.*	Amber uses domain-appropriate terminology, like LED and volts, to describe the problem.
4. **Ms. B:** Do you think maybe you might have those on the wrong side?	Ms. B *flips the battery holder over, moving both strips of conductive fabric to the underside of the case.*	Ms. B checks to see if the youths applied their knowledge of electrical polarity to their circuit to make sure that the battery is positioned in the right direction respective to the LED.
5. **Antoine:** We tried switching 'em around.		Antoine indicates that they have already tried turning the battery over in a prior attempt—a second hypothesis for why the project might not be working.
6. **Amber:** And they're not touching on the inside [which would cause a short].	*Points to conductive pads on the opposite sides of the battery holder.*	Amber realizes that the next appropriate step to debug the project would be to see if they made the battery holder correctly. She verifies that they have not inadvertently created a battery holder that would cause a short circuit, referencing another domain-appropriate concept—a third hypothesis for why the project isn't working.
7. **Ms. B:** OK, they're not touching . . .	Ms. B *opens the battery case to check.*	
8. **Amber:** Our battery might be dead?		Amber considers a fourth hypothesis: their battery is dead.
9. **Ms. B:** We need to problem shoot again.	Ms. B *applies pressure to the ends of the conductive fabric on the LED prongs. Nothing changes. Then she slides one of the legs of the LED to the backside to connect with the negative side of the battery holder and leaves one of the legs on the positive side of the battery holder. The LED lights up for the first time!*	
10. **Amber:** Huh! She fixed it!	Amber's *face lights up and her speech gets excited.* Antoine *punches his fist in the air.*	
11. **Ms. B:** Nah, I didn't fix it—y'all just weren't holding 'em right. So you *do* have a good connection.		Ms. B verifies that their circuit design was good; the problem lay in the way they were holding the various pieces of their circuit together.
12. **Amber:** Yeah! Perfect! . . . OK, so we figured out how we're going to do it.	Antoine *and* Amber *head back to their table excitedly.*	

over the middle of the conductive fabric on either side of the battery holder. Moments before the start of this vignette, Amber and Antoine confirmed that the battery holder worked with a multimeter. The pair is holding the electronic components of their puppets together to check whether their homemade battery holder on one puppet is capable of lighting a traditional two-leg LED that will be positioned on the other.

While the youth took initial pains to align what they saw as the negative side of the battery with the negative prong of the LED and vice versa, they didn't realize that both of the connecting fabric strands were resting on the top (positive side) of the battery only. They ultimately, with the help of the instructor, realized that one of the conductive fabric strands would have to reach beneath the battery case to make a complete circuit. By identifying the error and making the corresponding changes to their puppets, the youth were afforded a more robust understanding of how electronic theory works than had they limited their activities to pen and paper explorations.

This mirrors the material exploration of traditional arts instruction, which encourages students to explore a wide range of media, particularly drawing attention to the movement between two- and three-dimensional expressions of ideas. This is used to develop artists' conceptualization of space and its representation, an aspect often proven to be difficult for students.

Once the pair returned to their table, a nearby researcher engaged them in an informal interview about their project. Immediately, the youths' language around the puppet shifted from specific technical qualities as exemplified above, toward incorporating the electronics into their creative vision for the project.

Amber: Our puppets are going to be antennae firing.

Antoine: Yeah, like both have an antenna, and when their antennae touch, her antenna is gonna light up.

Amber: 'Cause mine's a robot. (Points to the peace signs printed on the sock. The pattern is similar to the one on her T-shirt.) A very *peaceful* robot.

Antoine: The battery . . . it's like a switch. If *that* isn't touching *that*, then the circuit is open and energy can't flow through.

Amber and Antoine incorporated the functionality of the circuit into how they described their project—it was no longer just about a functional circuit, it became more about creating an action through electronics that enhanced how viewers saw their puppets' character (see Figure 13.1). Yet, even though the circuitry is in service of a narrative they created for their puppets, their description of how the puppets interconnect were rich with a remarkable amount of domain-specific language, naming not only the physical components of their electronic constructions (e.g., LED, battery) but also the unseen ones (e.g., volts), as well as the ways they work together (e.g., switch, energy, open circuit). A grasp of electronic theory transmitted through the act of working with e-textiles is not only evidenced by the way they incorporated a functional circuit formation into their puppets, but also in their ability to think flexibly in the act of troubleshooting; the youth, after all, came up with three alternative hypotheses to test when their LEDs initially failed to light.

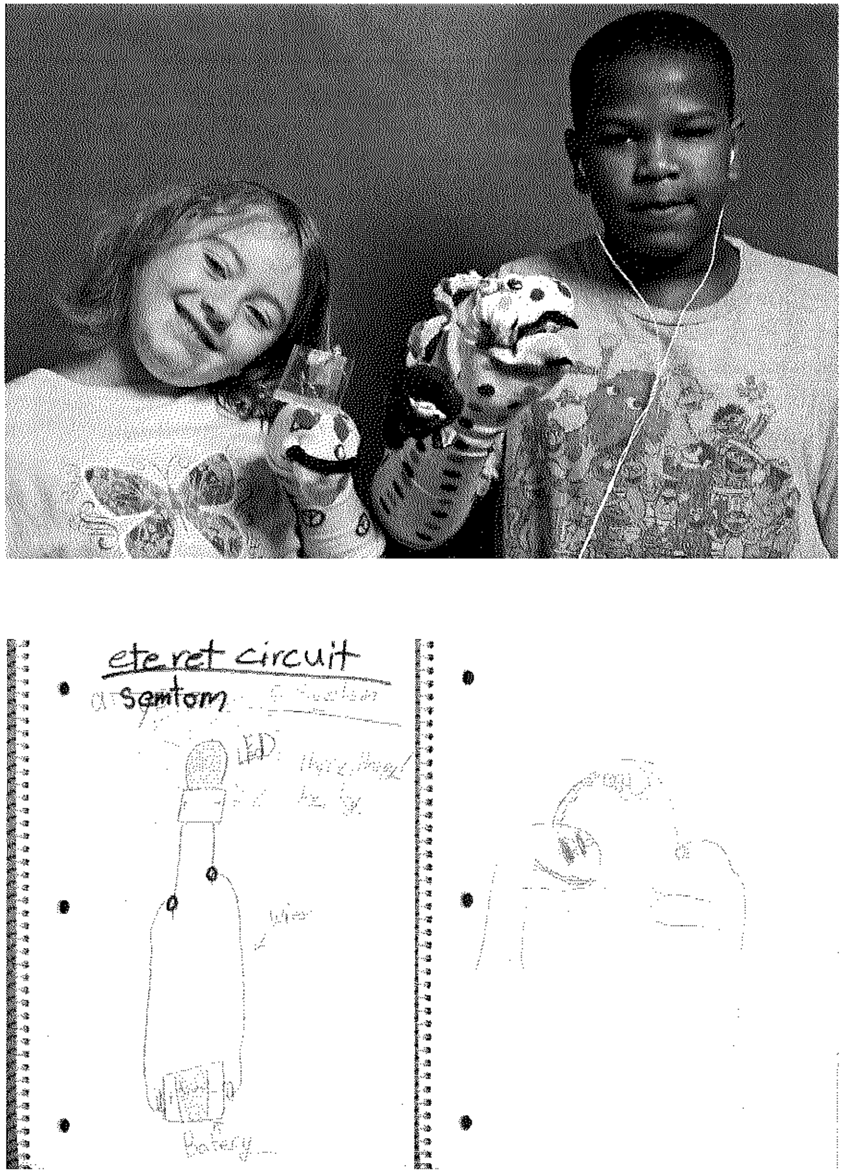


Figure 13.1 Top: Portrait of Amber and Antoine displaying their sock puppets. Bottom left: Planning diagram for the electric circuit in their sock puppet. Bottom right: Planning diagram for the puppet interaction to light the LED.

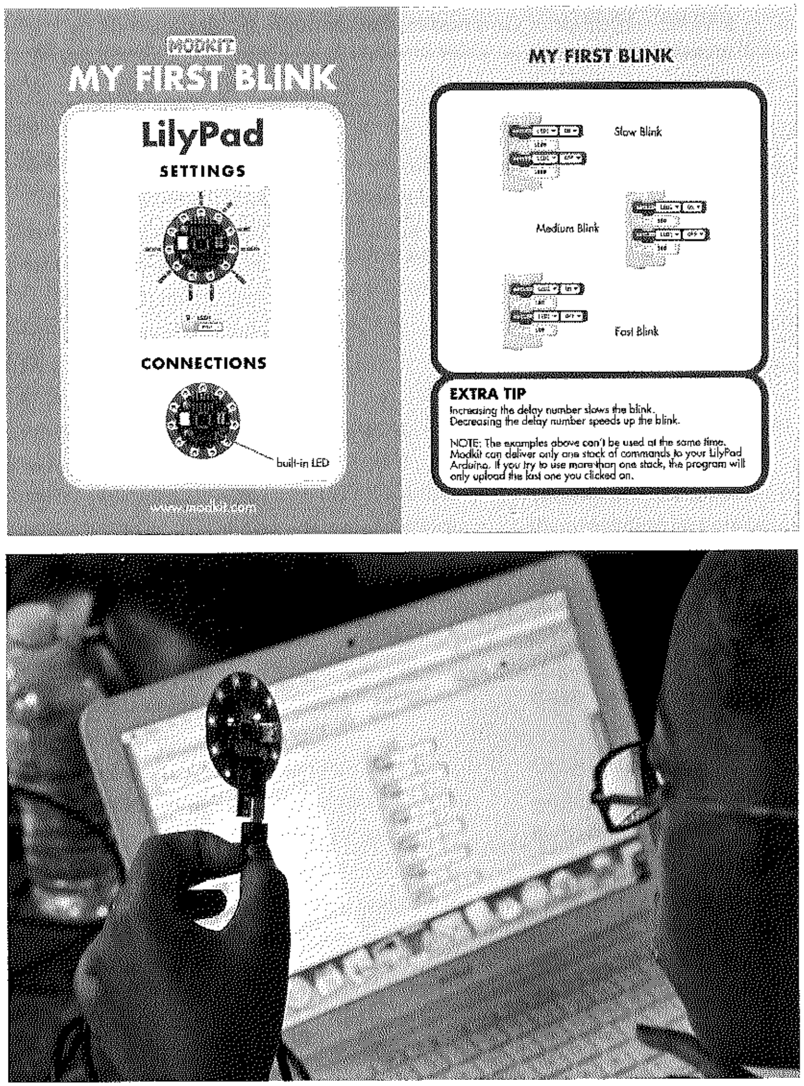
Creative Computing

As a backbone to arts projects sitting at the intersection of physical and digital media, learning to expressively and creatively approach computing is an essential skill. While overlapping with goals of computer science, the goals of creative computing is less about the efficiency (as few lines of codes as possible) of the code and more about the functionality and aesthetic possibilities of the code. Typically, in courses on digital arts and physical computing in higher education, students explore text-based languages like Arduino in combination with physical computing, as well as experiences with Pure Data (PD), Adobe Flash, C, and Python (Peppler, Sharpe, & Glosson, 2013). Our workshop utilized a new user-friendly alternative to text-based languages like Arduino, called Modkit Alpha.

After the first foray to basic electronic theory and circuit construction with e-textile materials, youth were introduced to microcontrollers and how they could be programmed to control lights, sound, and several other types of output. To assist youth with independently learning the basics of creative computing with Modkit Alpha, youth were provided with a series of cards depicting how to configure the LilyPad using the Hardware settings in Modkit, as well as sample blocks of code and additional tips (Figure 13.2).

"My First Blink" kinds of programming activities can act as initial starting points for youth to envision possibilities for creative computing. By way of illustration, the following vignette is taken from a 7th-grade African-American youth, Omarion, working on his "My First Blink" and then extending his discoveries to imagined possibilities for physical computing (see Table 13.2). Omarion sits at a long table surrounded by six of his peers. Prior to this vignette, Omarion had successfully uploaded his first program to the LilyPad—the "slow blink"—and was in the process of executing a program for a faster blink rate.

Despite the aspects of recreating code from initial "instructions," Omarion and his peers saw the real potential in transposing digital commands into physical behaviors. Omarion, in particular, anticipated the "meta-medium" features of producing media art (Peppler, 2010a) in the connections he made to many different types of artistic practices, all departing from the variations of an indicator light's blink rate. Across these unique connections, Omarion imagined how digital signals could be translated to audio, visual, and movement. Each of these visions incorporates a multimodal "story" of some kind, involving sound and motion. As a foundation for what it means to creatively code, much of the practice of computer programming in the context of the arts begins with an intention (be it visual, audio, gestural, or interactional) which leads to seeking out commands or groups of commands that help to realize this idea, often letting the two coevolve. In his final act in which he uses the Modkit cards to create a program in order to make his abstract "saw" go faster, Omarion enacts the central definition of how artists creatively code: the utilization of programming in order to realize a higher aesthetic aim.



EXTRA TIP
Increasing the delay number slows the blink.
Decreasing the delay number speeds up the blink.

NOTE: The examples above can't be used at the same time. Modkit can deliver only one stack of commands to your LilyPad Arduino. If you try to use more than one stack, the program will only upload the last one you clicked on.

Figure 13.2 Top: Modkit card to assist with "My First Blink" programming activities. Bottom: Youth engaging in physical computing via manipulating code and physical materials.

Table 13.2 Video transcript of Omarion experimenting with ModKit code

Video transcript	*Gesture*	*Interpretation*
1. **Omarion:** *(singing)* "Get up, get down, put your hands up to the sound. Get up, get down, put your hands up to the sound . . ."	*His singing trails off as he consults with the Modkit card and makes modifications to his code.*	Omarion sings in time with the flashing of his LilyPad LED, likening the steady blink of the indicator light to a musical pulse. In this connection, Omarion connects a programmed light to his prior media experiences and is envisioning how programming could be put to use to recreate the beat of one of his favorite songs.
2. *(to a neighbor)* Hey, what about 1 [as a delay signal value]?	*Omarion consults with peers on the opposite side of the table with delight as they show off the varying rates their LilyPads blink.*	Omarion and his peers draw inspiration from each other's programs, specifically in the interaction between their programs and the effect on the physical object. The exploration is social and motivates the youth to try out new combinations of code.
3. **Jake:** *(to peers at table)* I'm doing 5.	Jake *holds up his LilyPad to show off the blink.*	Jake shows others how a 5-millisecond delay produces a very quick blink.
4. **Omarion:** Wait-wait! Give it to me, give it to me . . . Let me see 1, let me see 1 . . . Oh my God, dude!	*Omarion walks around the table to closer inspect Jake's program. He and peers go back to showing off what different programs look like on their LilyPads. Omarion returns to his chair and resumes programming his LilyPad. He uploads a new program to the LilyPad and observes the "uploading program" blink default.*	Jake's project appears to inspire Omarion, who replicates Jake's code in his own program as a departure point for a new idea.
5. *[in a high voice, like a sonar. Starts slow and increases in speed and pitch, climaxing in an explosion sound]* Boop . . . boop . . . boop . . . Boop. Boop. Boop. Boop . . . Boopboop boopboopboop . . . *Buggsssschhhh!*	*The rapid "upload blink" ceases and the LilyPad light starts blinking at steady and moderate pace, as per Omarion's uploaded program.* *Omarion gazes at the blinking light, then holds up the LilyPad and rotates it slowly in a spiral.*	Like before, Omarion connects the blinking light to an external reference—a sonar or a time bomb. This time, he is inspired by the changing rate of the blinking light that confirms that a program has been uploaded to the LilyPad; first moderate (from the previous uploaded program), then more rapid (the faster, "uploading blink.")
6. *(to anyone who'll listen)* This is a saw. *Zzzzzzsch!* The faster this goes, the faster the revolution of the saw is. So it goes like this: *Zzzsch-Zzsch! Zzzzzzsch Zzzzzzsch Zzzzzzsch!*	*Omarion circles the circumference of the LilyPad with his pointer finger—fast and clockwise at first, then more slowly and counterclockwise. He maintains this moderate speed, still humming melodically, for about 20 seconds.*	The new rate of the blinking light gives Omarion a new vision: a saw. He envisions how the code could be translated into motors and gears. This connection also seems to incorporate the physical design of the LilyPad: its circular shape and reflective metal.
7. I'm about to make it go faster!	*Omarion puts down the LilyPad and stops humming. He looks down at the support materials and begins to make small modifications to the code, toggling between typing and looking at the support materials.*	Omarion switches gears; while his prior visions took flight from something that the LilyPad reminded him of, he now leverages support materials to realize an idea that begins in his mind, moves through the programming environment, and is fully realized on the physical object.

Traditional and High-Tech Craftsmanship

Craftsmanship skills required in physical computing vary depending on the form of materials being used. In the summer workshop, youth learned to thread a needle, tie knots, and sew a basic running stitch—all basic staples of traditional sewing practices that, though foreign to today's younger generations, are cultivated through creating e-textiles. And yet, e-textile craftsmanship differs from its more traditional counterpart in that it necessitates exploring fabrics and decorative materials beyond their look and durability. E-textile creation requires that attention be paid to the physical properties of the materials (e.g., whether something is elastic, conductive, or insulating), as well as to the alignment between the materials used and the goals of the circuit (e.g., a zipper can become a switch in an e-textiles project). Furthermore, the conductive thread must make specific and well-stitched connections between the microcontroller and the components in order to accurately bring the programmed elements of the project to life, bringing new meaning to the quality of youth's sewing techniques. What results is a hybrid approach to traditional craft that infuses electronic theory into the choices youth make when sewing their circuits into their projects.

The following vignette illustrates how youth move flexibly between traditional and high-tech crafting traditions in the production of e-textiles, merging what they know about electronic construction and theory to realize their designs with both traditional and novel crafting materials (see Table 13.3). This vignette features Darryl, a 6th-grade African-American male, as he meticulously stitches a programmed LilyPad and LEDs into a T-shirt. Darryl previously decorated the T-shirt using fabric paint to look "spray painted," creating a large, eight-pointed star-like shape in its center. At this stage in the project, Darryl is sewing his LilyPad to the center of the star, in addition to four LEDs to the radiating points of the star, each of which were programmed with a unique behavior so as to augment the exploding gesture painted on the shirt (see Figure 13.3). To get started, Darryl works with an embroidery hoop to create a flat surface for stitching, and begins stitching with conductive thread through the sew holes of one of the LilyPad's petals. Throughout the process, Darryl issues himself verbal reminders of best practices for sewing as well as circuitry requirements (recalled from his previous work stitching LEDs in parallel into an electronic bracelet) while in the process of stitching his electronic components into the T-shirt design.

From here, Darryl moves through the remaining holes on the LilyPad with equal precision, gaining accuracy and speed. Throughout, Darryl leverages an arsenal of crafting techniques to independently fix emerging problems, including quickly threading and rethreading his needle; consistently toggling between the front and the back of the T-shirt design to check whether his thread has any loose or hanging loops that could be later tangled or knotted; performing a series of methodical checks to the sewing; and sewing an even running stitch (particularly for a novice) to his LEDs. He is also notably slow to rip everything out and start over—something most novices are prone to do. Instead, he works with the mistake and creatively problem-solves.

Table 13.3 Video transcript of Darryl stitching a LilyPad and LEDs into his "ElectriciTee"

Video transcript	*Gesture*	*Interpretation*
1. **Darryl** (talking quietly to himself): And then, so . . . and go back through because I have to make the negative tight, so I'm gonna have to keep going through . . .	Darryl *pulls the needle through a sew hole on the LilyPad from beneath the fabric, turns the needle over, and pushes the needle back through the shirt. This starts to secure the LilyPad to the fabric and ensure the conductive thread will transmit a signal to another component along the circuit.*	Darryl begins his stitching with aesthetic and functional goals simultaneously in mind: starting with the knot on the underside of the shirt ensures that the tail of the knot won't short the circuit. Aesthetically, hiding the knot beneath the fabric also ensures a cleaner look, even though it is harder to execute.
2. I move the LEDs out of my way . . .	*Still holding the needle partially protruding through the fabric,* Darryl *picks two LEDs off the top of the hoop and places them on the table.*	Darryl pays meticulous attention to organization—a key crafting practice. Having placed the LEDs on the T-shirt as part of his planning process, he moves them to the side so as not to lose them.
3. Then, I'm gonna pull this through, like that . . .	Darryl *pulls the thread taut from beneath the embroidery hoop.*	Darryl is mindful of moving slowly and methodically.
4. And gonna . . . straight . . . gonna have to go back through here . . .	*He lifts up the shirt, reaches in through the neck, turns the needle around, and pushes it back up through the same sew hole on the LilyPad. He struggles to get the needle all the way back through the fabric. He pulls the needle harder and the thread pulls out of the needle.*	Darryl starts to sew back through a second time for the secure connection. But, because the needle is single-threaded (Darryl prefers to use a single-threaded needle, leaving a 3″ tail on the one side, instead of a double-threaded one taught in the workshop), the needle becomes unthreaded.
5. *Tsk.* Oh, man.	*He grabs the short amount of thread that made it through on the last push and tries to pull it all the way taut.*	Darryl works within the constraints of the problem. Instead of starting over, he starts to investigate what went wrong and continue from the successful parts of the previous gesture.

(*Continued*)

Table 13.3 (Continued)

Video transcript	*Gesture*	*Interpretation*
6. So, I just made a *big mistake*. I'm gonna put the needle in here . . .	*He cleans up the thread and pins the needle into a nearby pincushion. He turns the hoop over to inspect the problem. He discovers that the shirt and the thread have become entangled.*	He is still investigating what went wrong, treating it like a 3D problem. He toggles between front and back, he traces the whole thread line—these are critical to discovering the root of the problem.
7. Oh, *that's* what it was. Okay.	*He uses his fingers to methodically undo the knot and separate the threads.*	Darryl talks himself through the problem, feeling confident that he can deal with the setback.
8. That was okay. Yeah, that's okay.		
9. Now I'm gonna have to somehow pull this out 'cuz I just made a mistake.	Darryl *pulls the thread back into a straight line and reaches it over to the pin in the pincushion.*	This is a traditional crafting technique: reorganizing and resuming. Darryl remains confident in his ability to problem-solve. He does this without skipping a beat, all motions are fluid and intentional.
10. I'm gonna have to connect this back on . . .	*He snaps the thread back into the self-threading needle.*	
11. Okay. Now. I'm gonna go back through here. And then I'm gonna sew . . . through . . .	*He picks up where he left off, trying to make a firm connection with the sew hole of the LilyPad. This will be the second loop through the same sew hole.*	Darryl ensures a strong connection between the microcontroller and the conductive thread that will connect the LilyPad to the LED.

The vignettes featured here illustrate how youths' work in e-textiles seems to lend itself to both authentic and creative forms of physical computing, well aligned to professional practice. At the heart of youths' creative production with physical computing is the ability for youth to forge connections between multiple domains in compelling new ways beyond the screen. This form of expression ties together multiple strands of domain knowledge—many, if not all, of which are being introduced to this age group for the

Figure 13.3 Detail of Darryl's ElectriciTee. The LilyPad is placed in the center of the design and the four LEDs are placed on the four larger points of the star. Meticulous running stitches complete a path for electricity to flow throughout the design.

first time (e.g., electronic construction and theory, computational creativity, and traditional and high-tech craftsmanship), yet these findings suggest that e-textile production presented advantageous opportunities for youth to not only engage in authentic technical practices of each specific domain, but also provided a flexibility for youth to build upon each domain toward a specific, accumulating vision. This is a noteworthy accomplishment given the high level of technical expertise that physical computing presents, which can bring to mind didactic, step-by-step forms of instruction. Examples like the ones presented here not only represent model ways in which these tools present novel opportunities to tinker, explore, and create, but also how classrooms can be set up to accommodate playful forms of self- and peer-directed learning with ideas that resonate with youth interests.

In sum, the central tenets of physical computing present us with a new vision of what a maker frame to arts education can look like in today's classrooms—not an abandonment of time-honored tools, but an opportunity to think and express across physical and digital forms. Such an effort situates new technologies within the landscape of historical traditions and practice. In a time where pervasive digital technology is changing our relationship to images and artworks, hard-and-fast distinctions between genre, place, and form are becoming increasingly blurred, thus expanding the possibilities for experimentation and innovation in contemporary art. Capitalizing on these multimodal trends, a 21st-century arts classroom should be just as open to new technologies and responsive to new media as an increasing amount of subject areas in K–16 education. This vision—arts education "ReMade"—situates art making with new technologies alongside traditional materials, embracing new media as a material in which to be sculpted for artistic expression.

REFERENCES

Arts Education Partnership. (2004). *The arts and education: New opportunities for research.* Washington, DC: Arts Education Partnership (AEP).

Baafi, E. & Millner, A. (2011). A toolkit for tinkering with tangibles & connecting communities. In *Proceedings of Tangible, Embedded, and Embodied Interaction (TEI)* (pp. 349–352). Funchal, Portugal.

Banzi, M. (2008). *Getting started with Arduino* (1st ed.). San Francisco, CA: O'Reilly Publishing.

Berzowska, J. (2005). Electronic textiles: Wearable computers, reactive fashion, and soft computation. *Textile, 3*(1), 2–19.

Buechley, L., Eisenberg, M., Catchen, J. & Crockett, A. (2008). The LilyPad Arduino: Using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. In *Proceedings of the Special Interest Group on Computer–Human Interaction (SIGCHI) Conference on Human Factors in Computing Systems (CHI)* (pp. 423–432).

Buechley, L., Peppler, K., Eisenberg, M., & Kafai, Y. (Eds.). (2013). *Textile messages: Dispatches from the world for e-textiles and education.* New York, NY: Peter Lang Publishing.

Fields, D. A., & Lee, V. R. (2016). Craft technologies 101: Bringing making to higher education. In K. Peppler, E. Halverson, & Y. Kafai (Eds.), *Makeology: Makerspaces as learning environments* (Volume 1) (pp. 121–137). New York, NY: Routledge.

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

Kafai, Y. B. & Peppler, K. (2011). Youth, technology, and DIY: Developing participatory competencies in creative media production. In V. L. Gadsden, S. Wortham, & R. Lukose (Eds.), *Youth Cultures, Language and Literacy: Review of Research in Education, 35*(1), 89–119.

Kuznetsov, S. & Paulos, E. (2010). Rise of the expert amateur: DIY projects, communities, and cultures. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction (NordiCHI): Extending Boundaries* (pp. 295–304). Reykjavik, Iceland.

LAUSD Arts Branch. (2005). *Media arts study group report.* Los Angeles, CA: Los Angeles Unified School District (LAUSD) Arts Branch. Retrieved August 31, 2007 from artseducation.lausd.net/portal.php?id=MEDI

Maeda, J. (2004). *Creative code.* New York: Thames & Hudson Inc.

Marculescu, D., Marculescu, R., Zamora, N., Stanley-Marbell, P., Khosla, P., Park, S., . . . Nakad, Z. (2003). Electronic textiles: A platform for pervasive computing. *Proceedings of the IEEE, 91*(12), 1995–2018.

Nalven, J. & Jarvis, J. (2005). *Going digital: The practice and vision of digital artists.* Boston, MA: Thomson Course Technology.

Paul, C. (2003). *Digital art.* New York, NY: Thames & Hudson.

Peppler, K. (2010a). Media arts: Arts education for a digital age. *Teachers College Record, 112*(8), 2118–2153.

Peppler, K. (2010b). The new fundamentals: Introducing computation into arts education. In E. P. Clapp & M. J. Bellino (Eds.), *20Under40: Reinventing the arts and arts education for the 21st century* (Ch. 19, pp. 294–309). Bloomington, IN: AuthorHouse.

Peppler, K., Salen, K., Gresalfi, M., & Santo, R. (2014). *Short circuits: Crafting with DIY technologies.* 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* (Ch 8, pp. 107–117). New York, NY: Peter Lang Publishing.

Peppler, K. A. & Warschauer, M. (2012). Uncovering literacies, disrupting stereotypes: Examining the (dis)abilities of a child learning to computer program and read. *International Journal of Learning and Media, 3*(3), 15–41.

Reas, C. (2006). Media literacy: Twenty-first century arts education. *AI & Society, 20*(4), 444–445.

Rusk, N., Resnick, M., Berg, R., & Pezalla-Granlund, M. (2008). New pathways into robotics: Strategies for broadening participation. *Journal of Science Education and Technology, 17*(1), 59–69.

Turbak, F. & Berg, R. (2002). Robotic design studio: Exploring the big ideas of engineering in a liberal arts environment. *Journal of Science Education and Technology, 11*(3), 237–253.

"*Makeology* is the first broad and comprehensive examination of the Maker Movement as a catalytic force for young people's learning. Practitioners and scholars interested in implementing and studying making as a force for creative expression and student-centered learning will find in this two-volume collection a wealth of thoughtful and significant information."
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"This second volume offers a window into the biggest promise of the Maker Movement—to give children agency and meaning in their own learning. As a potentially transformative practice and field of scholarship, Makeology has the opportunity to catalyze the attention of researchers, teachers, school administrators, parents, curriculum developers, and policy makers because the authors offer insights into the ways one can begin to study, model, and understand these phenomena of learning."
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—**Mitchel Resnick, LEGO Papert Professor of Learning Research and head of the Lifelong Kindergarten group at the Media Laboratory at Massachusetts Institute of Technology, USA, from Volume 2**

Makeology introduces the emerging landscape of the Maker Movement and its connection to interest-driven learning. While the movement is fueled in part by new tools, technologies, and online communities available to today's makers, its simultaneous emphasis on engaging the world through design and sharing with others harkens back to early educational predecessors including Froebel, Dewey, Montessori, and Papert. *Makers as Learners (Volume 2)* highlights leading researchers and practitioners as they discuss and share current perspectives on the Maker movement and research on educational outcomes in makerspaces. Each chapter closes with a set of practical takeaways for educators, researchers, and parents.

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