Bringing the Maker Movement to School

Fourth-grade students create projects to illustrate the transfer and transformation of energy.

By Wendy Smith and Brian C. Smith

Our school's fourth-grade Maker Showcase, now in its second year, is a celebration of student projects that epitomize the intersections of science, technology, engineering, and creativity (see Internet Resources). To illustrate how electrical energy can transfer and transform, these young makers fill the school with over 90 projects, ranging from light-up, three-dimensional paper cityscapes to a hand-crafted robotic bird that interacts with passersby. Parents, students from other grades in our school, and the high school robotics class are invited to the showcase, where they can interact and play with the projects while having informal conversations with the makers to learn about the inspiration for the ideas, the iterative design process, and our students' understanding of electrical energy.

The Maker Movement has emerged over the past decade due to a surge in cultural do-it-yourself (DIY) mindsets, growth in online and offline (Maker Faire) community connectedness, and increasingly affordable technology. In schools, the Maker Movement is a natural fit, as integration is already the norm—the convergence of subject areas and the blending of skills and concepts results in the construction of knowledge through personally meaningful experiences.

The Maker Movement allows students to strengthen humanistic values through projects and experiences that require the use of their heads, hearts, and hands. Students are introduced to creative technologies that bridge the digital and physical worlds. Through whimsical projects, students take an interest in the concepts and ideas that might normally be offered through a textbook or worksheet. The Maker Movement also emphasizes the necessity of problem-finding, problem-solving, and the power of social learning through sharing and collaborative work to solve issues small and large. To learn more about the Maker Movement in education, visit the Maker Education Initiative website and other links listed in the Internet Resources section.

PHOTOS COURTESY OF THE AUTHORS

Students use copper tape, LEDs, and coin batteries to build their own circuits to light up greeting cards.

Tinkering, the unstructured process of testing ideas that come to mind, is integral to the Maker Movement. When children are tinkering and playing, they are engaging with a

FIGURE 1.

Materials:

- basic electricity kits (batteries, bulbs, wires, battery holders)
- coin batteries
- LEDs
- motors
- buzzers
- wires with alligator clips
- copper tape
- conductive thread
- sewable coin battery holders
- large-eye sewing needles
- sewing machine
- craft materials (e.g., felt, paint, feathers, pipe cleaners, construction paper)
- MaKey MaKey kits
- Hummingbird Robotics Kits

Unfamiliar Materials:

- Paper circuits: Instead of using wires, paper circuits are made with copper tape.
- Sewable electronics: These "soft circuits" can easily be made using conductive thread, a sewable coin-battery holder, LEDs, and fabric or felt. Remove the coin battery, and the circuit can be safely washed.
- MaKey MaKey: With a MaKey MaKey circuit board, USB cable, a few alligator clips, and conductive materials, you can create objects to control your computer.
- Hummingbird Robotics Kit (*www.hummingbirdkit.com*): Combine the kit with Scratch or Snap programming and craft materials, and students can create robots, kinetic sculptures, and animatronics.

TABLE 1.

Circuit materials and challenges.

Circuit Materials	Challenges
Batteries, bulbs, wires	• Make the bulb light. • Make the bulb light with the fewest number of wires. • Find a way to turn the bulb on and off. • Make two bulbs light.
Coin batteries, LEDs	• Make the LED light. • Discover how many LEDs can light from one coin battery.
Coin batteries, buzzers, motors, LEDs	• Make the buzzer buzz. • Make the motor spin. • Make the motor spin in the opposite direction. • Use more than one type of load in the circuit.
Coin batteries, copper tape, LEDs, construction paper, markers	• Make the LED light. • Make a light-up greeting card. • Make a light-up greeting card that turns on and off.
Conductive thread, coin batteries, sewable coin battery holders, LEDs, felt	• Make the LED light (no sewing). • Sew a circuit to make the LED light on a felt keychain tag.
MaKey MaKey kits, laptop, Scratch website, variety of both conductive and insulating materials	• Make a circuit that uses physical objects to play one of the instruments on the Scratch websites. • Try using your MaKey MaKey circuit to interact with a program that you create in Scratch.
Hummingbird Robotics Kits, laptop, Scratch website	• Make a green LED light. • Make a green light blink on and off. • Make a green, yellow, and red light blink in order. • Make one of the LEDs turn on when someone gets close.

blend of objects, concepts, ideas, environments, and people. Tinkering allows the time and context for ideas to collide.

The dog is programmed to wave its paw and blink the lights on its collar when someone comes near.

Creativity often occurs at these collision points. Providing experiences for students to tinker allows them to think with objects—whether they are toys, tools, or materials to use. Martinez and Stager (2013, p. 36) state, "When we allow children to experiment, take risks, and play with their own ideas, we give them permission to trust themselves. They begin to see themselves as learners who have good ideas and can transform their own ideas into reality."

By connecting this type of maker-centered learning experience with our fourth-grade science unit on electrical energy, the Maker Showcase project was launched.

Blending Inquiry and Fabrication

As students explore electrical energy through the construction of various circuits, they develop the understanding that energy can be transferred and converted from one form to another. Constructing a circuit using batteries, bulbs, and wires is a common experience in elementary science classrooms, but what if that experience was changed to include LEDs, coin batteries, buzzers, motors, conductive thread, or other uncommon conductive materials? What about programming the LED to interact with its surroundings? Classic circuit activities become entirely new experiences when students question and deepen their understanding of circuits as they work with unfamiliar materials (Figure 1, p. 31).

According to Bevan, Petrich, and Wilkinson (2015), classrooms may need to alternate between step-by-step *fabrication*, or assembly tasks, and tinkering. Fabrication activities can be useful for familiarizing learners with tools or properties of materials and helping them develop skills that can later serve more complex and creative tinkering endeavors. We developed foundational experiences to build student familiarity with circuits and new materials. The goal of the step-by-step fabrication tasks was to explore a variety of materials to develop an understanding of a circuit. Although the product was the same for all, the process allowed for student inquiry into basic concepts through the exploration of materials. Later, during the project phase, students would tinker with a variety of kits, materials, and ideas.

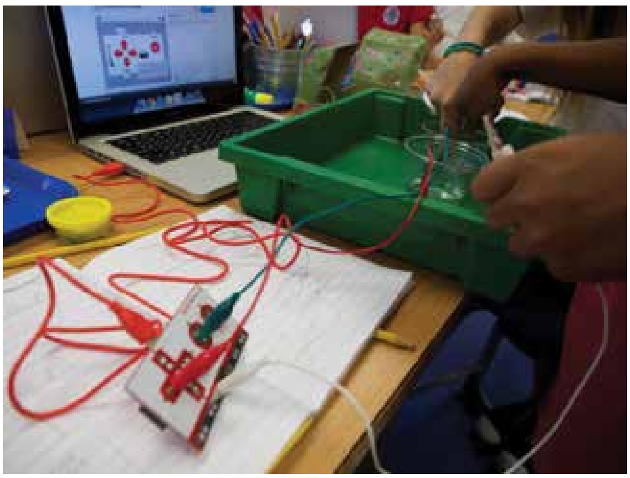
Table 1 shows how experiences with circuits were ordered and scaffolded to blend fabrication and inquiry. These exploratory lessons were taught to the whole class in the science, technology, engineering, and math (STEM) lab, and additional time to continue to work with the materials took place in the classroom. Although some basic skills—including how to thread a needle and connect wires to a circuit board—were directly taught, the experiences with developing the circuits were open-ended to allow for student discovery. These experiences were conducted over a four-week period by the STEM specialist, technology coach, and classroom teachers.

Materials for the project were purchased using our school's science budget (see Figure 1 and Internet Resources). The first-year cost was substantial due to the purchase of nonconsumable materials, including the MaKey MaKey and Hummingbird Robotics Kits. The Hummingbird kit includes a microcontroller device that can be programmed to read inputs (i.e., light, sound, infrared and temperature sensors) and control outputs (i.e., LEDs, buzzers, and various motors). The MaKey MaKey kit is another microcontroller that includes wires to clip to a variety of materials in order to control the mouse and keyboard of a computer. Once the microcontroller is purchased, materials, sensors, and actuators (motors, and so on) can be acquired at many electronics websites (see Internet Resources) and electronics or hardware stores. In the following years, the only materials that will need to be purchased are the consumable supplies such as LEDs, coin batteries, conductive thread, copper tape, and a variety of craft materials. Schools with limited budgets may want to consider applying for grants and contacting their parent-school organizations to help fund the materials.

Whimsical Ideas of Children

After the foundational circuitry experiences, students were challenged to create a project for the Maker Showcase to show the transfer and transformation of energy. Paper circuits, wearable circuits, MaKey MaKey kits, Hummingbird Robotics Kits, or a combination of materials could be used. The novel, playful, and sometimes whimsical ideas of children show how creativity can flourish when given the chance. Some of the clever project ideas included:

- Light-Up headband: Sparkle and shine with LEDs in this wearable circuit.
- Red carpet: Walk down the red carpet like a celebrity and have your picture automatically taken when you touch a star on the ground.
- Shy turtle: When you get too close, the turtle hides in his shell.
- Pinball game: Launch the ball and watch the LEDs light up when it lands in the hole.
- Light-up drinking cups: These cups work best when watching a movie in the dark.
- Twin robots: Twin girls with LED eyes sing karaoke.
- Model helicopter: A miniature version with a rotating propeller and lights.
- Cow-culator: Press spots on the cow to get the answer to multiplication problems.



Students explore conductors and insulators using Scratch programming with the MaKey MaKey.

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013):

4-PS3 Energy • *www.nextgenscience.org/4ps3-energy*
The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Performance Expectations	**Connections to Classroom Activity** *Students:*
4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents. 4-PS3-4. Apply scientific ideas to design, test, and refine a device that converts another.	• observe how energy is transferred in electric circuits. • create projects to illustrate how electrical energy can be transferred and transformed using creative materials and modern technologies.
Science and Engineering Practices	
Planning and Carrying Out Investigations	• program a computer to interact with an object in the physical world and identify causal relationships be-tween the script (code) and the results. • create and write algorithms using Scratch software to run a program that interacts with a physical object. • make predictions about what would happen if a variable in the circuit design were changed. • apply scientific core ideas about the transfer of energy when designing and creating the circuit of the project.
Developing and Using Models	• develop a physical prototype or diagram of the circuit used in the project.
Obtaining, Evaluating, and Communicating Information	• communicate scientific understandings of electrical energy and technical information of the design and construction of the project during the Maker Showcase.
Disciplinary Core Ideas	
PS3.A Definitions of Energy • Energy can be moved from place to place by moving objects or through sound, light, or electric currents. PS3.B Conservation of Energy and Energy Transfer • Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. ETS1.A: Defining Engineering Problems • Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account.	• construct and explore electrical circuits using a variety of creative materials and modern technologies. • make closed circuits. • create circuits that use sensors that change electric cur-rent to activate a motor. • label drawings to identify the source of energy, input (beginning form of energy), load (what uses the energy), and output (new form of energy). • use the engineering design process to develop their Maker Showcase project. • compare and evaluate multiple design solutions to meet the project criteria. • work within the constraints of time and availability of materials.
Crosscutting Concepts	
Energy and Matter	• construct and test various electrical circuits using multiple components, conductors, and insulators and identify causal relationships among materials and their structure.
Cause and Effect	• program a computer to interact with an object in the physical world and identify causal relationships between the script (code) and the results

- Choreographed Christmas tree: Watch and listen as the lights are choreographed to a Christmas carol.
- Wacky clock: Try and figure out the time as the hands on the clock spin in different directions.

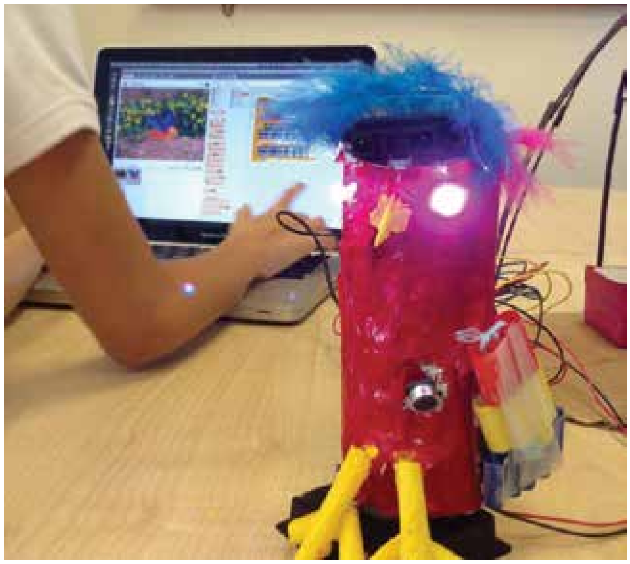
Students were encouraged to develop projects around areas of personal interest. Music, fashion, animals, games, and sports were common themes throughout the projects developed in the nine classrooms. Students with similar interests joined together while some students chose to work independently. For students who struggled with developing project ideas, further conversations about personal interests were supplemented with inspirational projects found on various maker websites, including Instructables and Sylvia's Super-Awesome Mini-Maker Show (see Internet Resources). It is important to note that these sites were shared to inspire project ideas but not intended to be used as step-by-step guides for fabrication.

Facilitation of Projects

Tinkering can be thought of as creative, improvisational problem-solving (Bevan, Petrich, and Wilkinson 2015), and this is exactly what students did as they worked on their projects over three weeks. Their efforts became messy, hard fun. When groups encountered a problem, open-ended questions and comments were used to help guide their learning. These prompts included:

- What do you know about … ?
- I wonder what will happen if … ?
- Why do you think that is happening?
- What do you notice about … ?
- How can we find out about … ?
- What other way can you try?
- How can you solve the problem?
- Tell me more about ...
- How can we change that?
- What happened when you did that?
- Show me what you've accomplished so far.
- How can you troubleshoot … ?
- What do you want to do next?
- How can you make this more interesting?

As students worked through problems with their project, some decided to go in a new direction or modify an initial idea based on what they discovered. Often, students switched between tinkering and fabrication. If there was something they needed to learn to move forward with their project, mini-lessons were offered on such topics as programming with sensors, exploring gear ratios, and constructing parallel circuits. Because the classroom teacher had the support of the STEM specialist and technology coach, each teacher could offer timely, responsive support to either individuals or small groups. Project time was essentially workshop time; students learned from each other, shared coding tips, provided possible solutions to design problems, and asked questions of each other to help push thinking. Throughout the entire unit, students used their notebooks to document their work following the engineering design process. Some teachers required their students to document their work and learning each day, whereas others had their students document at intervals throughout the unit.



The bird uses distance and sound sensors for a fun interactive experience.

Students were given three weeks to complete their projects. The timeframe each week varied from teacher to teacher. Some chose to schedule project time each day for 45–50 minutes, whereas others worked on projects every other day for 90 or more minutes.

The Maker Showcase

The literacy coach worked with a small group of interested students to advertise the event. To educate and invite parents, teachers, and principals, students wrote an email and a school newsletter article, created a sign for the office and posters to hang throughout the school, and made a slideshow presentation to inform younger students about the Maker Showcase.

Connecting to the *Common Core State Standards* (NGAC and CCSSO 2010):

- W.4.2 Write informative/explanatory texts to examine a topic and convey ideas and information clearly.
- SL4.4 Report on a topic or text, tell a story, or recount an experience in an organized manner, using appropriate facts and relevant, descriptive details to support main ideas or themes; speak clearly at an understandable pace.
- SL.4.5 Add audio recordings and visual displays to presentations when appropriate to enhance the development of main ideas or themes.

On the day of the event, students manned their creation stations, organized their projects, and shared documentation of their process. Some chose to have their science notebooks available to view, while others created more formal slideshows to have running during the Showcase. A few groups also chose to have "hands-on" stations where visitors could try out some of the materials and make their own circuits. Visitors could provide feedback via 5 in. × 7 in. cards to comment on what they learned, what they were wondering, and what they liked about a project.

During the Showcase, the school was filled with children and adults exploring imaginative, playful projects, all showing the transfer and transformation of electrical energy. Although on the whole the event was a grand success, there were a few glitches along the way. Power became a bit of an issue because older laptop batteries that needed to be recharged and the Hummingbird Robotics Kits needed outlets for motors. Some younger visitors were not always careful when playing with projects, and students needed to do some quick fixes. Problem solving was never-ending for these young engineers.

Students use conductive thread, LEDs, and coin batteries to stitch their own light-up key chains.

Assessing Student Learning

Student learning was assessed in multiple ways. At the beginning of the unit, students were given "agree-disagree" statements (Keeley 2015) related to energy and energy transfer (see NSTA Connection). This formative measure allowed teachers to uncover common misconceptions related to the unit and hear student ideas about energy. Throughout the unit, statements were revisited and new understandings shared. At the end of the unit, students responded to the statements again, this time as a summative measure of learning.

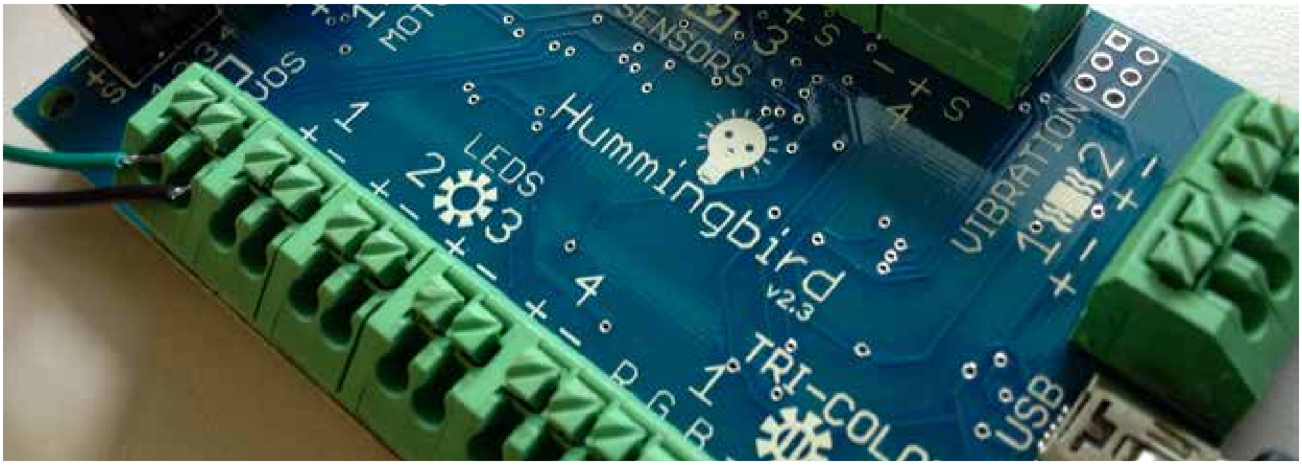
Students also completed a checklist as a self-reflection on how well they felt they met the goals of the project (see NSTA Connection). As students reflected on their project experience, they gained insight as they processed, linked, and constructed meaning. Some teachers on the team opted to turn the checklist into a rubric to assess student learning.

Additionally, students completed a mini project poster to display during the Maker Showcase (see NSTA Connection for a template). On the poster, students drew a model of their circuit and labeled how energy was transferred and transformed. They also provided personal responses to the essential questions of the unit.

- How and why do things in our world change?
- How do scientists investigate how the world works?
- How do engineers develop solutions for problems in the world?

Reflection

Working with unfamiliar materials in novel ways provides authentic experiences for students to deepen their understanding of energy and energy transfer. This became evident during rich, informal conversations with children about their learning. Based on student learning and feedback from both students and teachers, the Maker Showcase project continues to grow and develop. Additional teacher workshops to develop confidence and proficiency with the materials will be offered as well as more classroom time for students to tinker with programming and physical computing before and during the development of student projects. Ideas for meaningful connections to literacy are being shared and planned including nonfiction reading



Using the Hummingbird Robotics Kits, young students can quickly learn to use inputs and outputs to control a circuit.

and writing of feature articles. What is encouraging are the conversations taking place about bringing more authentic, maker-centered learning into the formal curriculum. ■

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The Lead Project. 2013. *Super scratch programming adventure! Learn to program by making cool games*. San Francisco, CA: No Starch Press.

Wilkinson, K., and M. Petrich. 2014. *The art of tinkering*. San Francisco, CA: Weldon Owen.

Internet Resources

Hummingbird Robotics Kit
www.hummingbirdkit.com

Instructables
www.instructables.com

Invent to Learn
www.inventtolearn.com K–12 Fab Labs and Makerspaces
https://groups.google.com/forum/#!forum/k-12-fablabs

Make
www.makezine.com

Maker Education Initiative
www.makered.org

Maker Showcase video (2014)
https://youtu.be/NRKoha2In0k

Maker Showcase video (2015)
https://youtu.be/8xYR4zwBYQg

MaKey MaKey
www.makeymakey.com

MaKey MaKey Piano Remix
http://scratch.mit.edu/projects/2543877

MaKey MaKey Drum Machine
http://scratch.mit.edu/projects/2728243

Scratch
https://scratch.mit.edu

Scratch Offline Editor
https://scratch.mit.edu/scratch2download

Sylvia's Super-Awesome Maker Show
http://sylviashow.com

NSTA Connection

Download the assessment worksheets and showcase template at *www.nsta.org/SC1609*.