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Innovative youth: An engineering and literacy integrated approach

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When we asked middle school students whether they had the ability to invent things, they balked. They exclaimed that adults are the ones who invent and that everything that could possibly be invented had already been created. Yet history abounds with stories of young people solving problems and creating new technologies, and new innovations are surfacing every day. We wanted our students to realize that they were capable of creating the future, and that science literacy and engineering skills would help them become the innovators and inventors of tomorrow.

We set out to help students develop literacy and engineering skills while fostering an identity as individuals who are capable of changing society. Our focus on literacy within this project is a direct response to the abilities and needs of our participating students, whose first language is Spanish and who vary in their reading ability (third- to sixth-grade level). As such, all texts and materials used during our sessions were selected and adapted accordingly. The participating children visited our university every week during their after-school program, which is hosted at the local community center. Although this setting allowed for flexibility that may be limited in a more traditional classroom context, teachers who incorporate collaborative practices during instruction could easily replicate the activities described in this article. For example, as teachers create more opportunities for students to engage in cooperative, small-group activities (Cohen and Lotan 2014), teachers could follow our experiences with as many small groups as resources allow.

Engineering design, maker education, and literacy

The *Next Generation Science Standards* (NGSS Lead States 2013) include engineering as both a practice and disciplinary core idea, requiring that students not only *do* engineering but also learn *about* engineering as a way of applying scientific knowledge to creating new technologies that improve lives. We addressed this dual requirement by coupling engineering activities that involve the application of scientific conceptual knowledge with reading and discussing adapted biographies of

CONTENT AREA

Literacy, science, and makerspace (engineering) education

GRADE LEVEL

6–8

BIG IDEA/UNIT

Scientific innovations and electricity

ESSENTIAL PRE-EXISTING KNOWLEDGE

None

TIME REQUIRED

8–10 hours

COST

$75–$250 (depending on available resources and number of stations needed)

FIGURE 1: Overview of the activities

Activity	Reading materials	Materials used	Alternatives
Activity 1: Illuminating Inventions	Louis Braille: Invention of the Braille Alphabet; Becky Schroeder: Reading in the Dark	Three objects of similar size: a small ball, dog figurine, and glow-in-the-dark mouse figurine	Any three portable objects of similar size and coloring, with only one that glows in the dark.
Activity 2: Simple Circuits	None	AA batteries, battery holders, wires, light bulb, and basic circuit kit	3V cell batteries ($5 for 10, available online), copper tape or aluminum foil, light-emitting diode (LED) lights ($5 for 100, available online)
Activity 3: Volta's Circuit	Alessandro Volta: Lightning and the Invention of the Electric Circuit	Students can revisit the equipment used during the electric circuit activities and associated diagrams to connect key points to the text about Volta.	N/A
Activity 4: Circuits Everywhere	None	Makey Makey circuit boards with USB cable connectors and alligator clips, OLPC XO laptops, Scratch programming software (see Resources)	Makey Makey Go (a smaller version that is available for $25; see Resources), computers in the school lab or library with the browser-based free Scratch program (see Resources)
Activity 5: A Sensing Sock	Kenneth Shinozuka: Invention of the Sensing Sock for Patients With Alzheimer's	Science in Action Award video about Shinozuka's invention (see Resources)	N/A
Activity 6: Making a Pressure Sensor	None	Video news story about Shinozuka's invention (see Resources), demo switch made from cotton balls and aluminum foil, modeling clay, aluminum foil, cotton balls, LED lights, tape, straws, light bulbs, wire, AA batteries, battery holders, Scratch software (see Resources), Makey Makey circuit board (see Resources)	Homemade conductive and insulating dough (see Resources)
Activity 7: Sharing Maker Projects	None	Modeling clay, cotton balls, aluminum foil, LED lights, tape, light bulbs, alligator clips, Scratch software (see Resources), Makey Makey circuit board (see Resources)	N/A

Adapting Innovation Stories

1. Map the original versions of the text (ensuring the inclusion of key concepts and ideas).
2. Draft initial adaptations. The drafts should not compromise scientific accuracy.
3. Ask colleagues with expertise in science and literacy to review the drafts.
4. Ask a few students who have demonstrated less advanced reading levels to review the drafts for understanding.
5. Revise the drafts to ensure clarity and scientific accuracy for readers.

children who invented something that solves a problem.

Our integrated approach aligns with the general movement schools have made toward integrating making into classroom learning. *Making* is the act of creating physical artifacts—using knowledge and skills from science, technology, engineering, art, and mathematics (STEAM)—for the purpose of sharing creations with the world. Since the inception of the very first Maker magazine in 2005 and the first Maker Faire in 2006, makerspace learning continues to increase its relevance and presence in our school communities. Maker spaces, also characterized as Tinkering Spaces, HackerSpaces, or Fab(rication) Labs, have sprouted rapidly in U.S. schools as one of multiple approaches to meeting the new, practices-oriented science education standards (Kelly 2016).

Our approach

We created a series of activities divided into two complementary types of sessions: four 60-minute sessions focused on making and three 60-minute sessions emphasizing literacy. Both session types contribute to students' understanding of engineering.

We first reviewed simple circuits by having students look at images depicting different arrangements of a battery, bulb, and wire and predicting which would light the bulb. They then tested these arrangements and came to a consensus about the criteria for a complete circuit. We then introduced the circuit board and Scratch programs to students to increase technological complexity and foster creative products. By the end of the activity series, which consisted of seven hour-long meetings, our students were able to employ their understanding of how to create a complete circuit and coding to create a final project of their choosing. In addition to gaining insights about how early scientists created and used electric circuits, our participants also learned how the fundamental circuit can be applied to create more complex systems with the Scratch programming tools (see Figure 1 for activity overviews and materials lists, along with low-cost alternatives).

Language and literacy played a central role in transforming our students' perspectives about and perceived roles in innovation. We developed "Innovation Stories," which followed the general model of a Science Discovery Narrative (SDN), highlighting the process that led to the discovery. An *SDN* is a story or telling of how a scientist came to discover or learn something new, as it actually happened, including the mishaps and the trials and errors. These SDNs are crafted from the scientists' perspective, thus providing a more intimate view of how new knowledge was created. Discovery narratives have been found to significantly support students' sustained understanding of conceptual information (Arya and Maul 2012). Our Innovation Stories (introduced and discussed during our literacy sessions) are adapted versions of journalistic accounts or biographies that describe the backgrounds, problems, and efforts of certain inventors, all of whom began their explorations during their youth and whose experiences have some relevant connection to making projects involving electric circuits and computer programming. We used a process (see sidebar) that is supported by literacy experts (e.g., Fisher, Frey, and Lapp 2012) to adapt our stories from their original sources in a way that supports accessibility and understanding of key concepts. We could then reference the readings during making activities and ensure that they were grade-level appropriate, interesting to middle school students, and aligned with the *Common Core State Standards*, in English language arts (CCSS ELA; NGAC and CCSSO 2010), and the *NGSS*. All texts used in this unit were vetted by a panel of reviewers that included two middle school students, a science educator, a literacy specialist, and three graduate students with a background in science and literacy instruction. Such vetting involved separate meeting discussions, during which the reviewer thought aloud any confusion in wording or described process. The panel members reviewed and confirmed their approval on all edited versions.

The adaptation process began with a general search for stories about young people who have invented new technologies that made a contribution to society. Such stories were then checked for authenticity and accuracy during a further search for multiple reliable sources. For example, we checked the Wikipedia entry about Louis Braille against other sources available in university or public libraries, and while information about Braille differed according to the interests of the authoring source, we found no conflicting information presented across these sources. We selected textual sources based on established credibility (e.g., preferring widely recognized, national news sources over lesser known local outlets, and attending to those sources that have been reviewed and commented on by other experts) and modified them in terms of text length and readability. The length of an individual text was determined by the extent to which the text (along with other associated texts targeted for a particular reading and discussion session) could be read and discussed by most participants in less than 50 minutes within a *collaborative context* (in which students are encouraged to help one another during discussions, with support from teachers as requested or needed). As a result, all of our texts were no longer than two pages (approximately 600 words). Key information in any text (including data, figures, and tables) should be understandable to all participants within collaborative contexts.

Overview of activities

Activity 1: Illuminating inventions

We begin by showing students three objects of similar size—a small rubber ball, a dog figurine, and a plastic, phosphorescent toy mouse—and ask them to predict which would glow in the dark. They test their ideas by closing their hands around each object while the lights in the classroom are off. This challenge of "seeing in the dark" serves as a primer for two Innovation Stories readings. The first reading describes Louis Braille's invention of the Braille alphabet and introduces the idea of finding a problem (reading while blind), coming up with an idea to solve the problem (raised bumps on paper that could be detected by the fingertips), and creating a prototype of the idea (a system of bumps on thick paper). The second reading introduces Becky Schroeder, who had a similar problem: Unlike Braille, Becky Schroeder could see, but she wanted to be able to read in the dark. Schroeder used phosphorescent paint to create a clipboard that illuminated printed text.

Both readings introduce the ideas of multiple prototypes and learning through failure, along with new words such as "patent." Students contrasted the stories using evidence from the text. In contrasting these stories, students noted that both inventors were young, had original ideas, and created things that helped others. Students also discussed what they would like to invent.

Activity 2: Simple circuits

Students explore (or review) simple circuits. Students look at images depicting different arrangements of a battery, bulb, and wire and predict which will light the bulb. They then test these arrangements and came to a consensus about the criteria for a complete circuit. They should be instructed to let go of any circuit that feels like it is getting warm. Precautionary measures to ensure safety for all students include (a) wearing safety goggles (to prevent eye contact with stray hot wires) and (b) explicit warnings against conducting such experiments outside of class. Using batteries, wires, and bulbs, students then collectively experiment and develop criteria for producing light. This experience provides background knowledge for subsequent readings and for projects described in activities 4–7.

Activity 3: Volta's circuit

Students review circuits through their discussion of a quick problem set that asks which of a series of circuit diagrams would result in lighting a bulb; this activity is common to electricity unit materials. Teachers facilitate and encourage students to try out their hypotheses with the available materials (bulbs, wires, and batteries). After this 20-minute activity, the participants read about Alessandro Volta, who lived during the 1700s. His pursuits in understanding lightning began in his youth and led to his invention of the electric circuit. Our students were surprised about his use of animal parts (e.g., frog legs) during this time, thus leading to discussions about available resources and animal rights during the 1700s. Through a guided, whole-group discussion, students are asked to draw comparisons between their previous making activity and Volta's multiple trials, which eventually led to the first successful circuit.

Activity 4: Circuits everywhere

The making sessions provide hands-on opportunities for students to use science and engineering. We use a device called a Makey Makey, composed of a circuit board and a USB cable that allows everyday objects (e.g., bananas, aluminum foil) to be converted into the equivalent of keyboard signals, which can then be used to control computer programs written by students. For example, students may connect pieces of fruit to the device and write a short program so that touching the pieces of fruit results in playing a song. We combined the device with Scratch Programming (see Resources), software that allows students to create complex computer programs without worrying about the syntax required in more traditional, text-based programming languages (see Hansen et al. 2015 for an example).

Students further explore electrical circuitry using circuit boards and the block-based computer programming language of Scratch. Following brief introductions to the materials, students are asked to use their knowledge about circuits, Scratch programming, and the Makey Makey circuit board to create animations that can be activated using a "spacebar," an arrow key, or a mouse click. That is, by connecting the board to the computer and creating a program with Scratch, students can then connect conductive objects (e.g., modeling clay, aluminum foil, fruit) to the Makey Makey. When that object is then touched by another person, completing a circuit, the Makey Makey sends a signal to the computer indicating that the key has been pressed, thereby activating the program written by the student. Students' programs included a shark eating a fish, a cat chasing a dog, and a person singing.

Activity 5: A sensing sock

During this literacy-based session, students read about Kenneth Shinozuka, who invented a sock with a pressure sensor that would detect when his grandfather, who suffered from Alzheimer's disease, was walking around at night, and then text caregivers to alert them. The class begins with an observation activity: Students are shown a video and asked to record what they observe (i.e., behaviors of an elderly man with Alzheimer's). The contents of this video highlight the problem that Shinozuka experienced and serve as a foundation for learning new vocabulary through the Innovation Story. Following a group discussion of the reading, students review all the Innovation Stories introduced to this point and place these events in order on a timeline.

Activity 6: Making a pressure sensor

The following day, students devise their own switch that responds to being pressed. This class begins with a video-recorded news story and discussion of Shinozuka's invention. Students are asked to recall information from the previous day's reading. After a demonstration of a simple pressure-activated switch constructed from cotton balls and aluminum foil, students begin making their own sensors using materials such as modeling clay and cotton balls (see Figure 2). Students then connect their pressure-sensor systems to their computer programs.

Activity 7: Sharing maker projects

After a brief review using students' notes, videos, and a discussion, students continue working on the projects they started during Activity 4. Some of our students focused almost exclusively on perfecting their Scratch program, whereas others reworked the physical objects that would work as a "spacebar" or switch. Our students' final projects included a clay model of a bus driver that laughed when touched, a tree key that caused a cartoon shark to eat a fish, and a replica aluminum foil keyboard that prompted a *sprite* (an animation of a person) to rotate as if breakdancing. Each student or pair had the opportunity to share the creations with the group.

FIGURE 2: Students working on a pressure-activated switch

Implementing the activities

Each of the activities described above lasts less than one hour and involves a wide range of tools and materials. To implement the activities in a classroom of 30 students, students should first be organized into smaller cooperative groups of four to six. Whole-class discussions prior to and following the activities help make visible the ideas and discoveries that each group experiences. Further, several collaborative reading approaches can guide teachers in facilitating group reading sessions (in four-member groups). Each student in the group can take on a particular role to support comprehension of the Innovation Stories. Collaborative Strategic Reading is one such approach that has been found to boost reading comprehension for elementary and secondary students (Boardman et al. 2015). Descriptions, instructions, and all materials are freely available (see Resources).

Conclusion

Throughout this program, we observed and recorded our students' works-in-progress as prototypes were created. These collected records showed us student gains in new knowledge and a general understanding of the innovation process. For example, several of our students noted that they had no idea that phosphorescence was a natural phenomenon. Such integration of knowledge from textual sources is a key *CCSS ELA* standard (e.g., CCSS.ELA-LITERACY.RI.6.7; NGAC and CCSSO 2010). Further, our students demonstrated their ability to quickly navigate the Scratch programming tool, taking less time than anticipated to set up and execute a variety of coded actions.

We view the inclusion of the Innovation Stories as a form of culturally responsive instruction, in that students are able to share personal experiences that relate to the characters in the stories. All texts were developed to reflect a diversity of innovators based on age, gender, cultural background, and ability (Au 2009). We would often ask our students what they were passionate about and ideas that they would like to develop, which was a way to adapt texts to make the content more meaningful and less abstract for students. Most of all, this showed our students that they could be innovators, no matter their ages or abilities. The nature of the tasks and the number of hands-on tools and technologies also make this program accessible to students of varying levels of abilities and skills.

The collaborative nature of this program allows for a diverse population of students to help one another and apply or reference what they learned from previous lessons during their exchanges with one another. One of the greatest surprises from this project was that even though students had materials, understandings, purposes, and workspace in common, they created vastly different products. For example, one student used her knowledge of the sock sensor to create a miniature Eiffel Tower that would light up, whereas another student created a "cushy keyboard" that would move a sprite derived from the Scratch program.

Our students developed their knowledge about and interest in science and engineering through these activities, as evidenced in their eagerness to engage in every activity and their successful completion of final projects. Given enough time, space, and materials, students can engage in, investigate, and create new knowledge and innovations. Such an experience fosters a sense of ownership, confidence, and adaptive expertise, giving students the problem-solving skills needed for solving new problems in unfamiliar contexts (Martin, Dixon, and Hagood 2014; Petrich, Wilkinson, and Bevan 2013). Through the deliberate integration of making and literacy activities, we are beginning to foster such adaptive problem solving, a required skill for successful engagement in 21st-century studies and careers. What we found to be important was not the specific technology used but the coordinated stories of innovation coupled with engineering or making tasks that used similar content while being flexible enough to allow students to use their own creativity to construct novel innovations. ●

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RESOURCES

Materials

We used the Makey Makey: An invention kit for everyone (approximately $50) available through MakerShed.com, Amazon.com, Adafruit.com and other online retailers. A simpler version, Makey Makey Go (approximately $25), is available at shop.makeymakey.com. Scratch programming can also be connected to physical objects through robotic kits such as the Lego Wedo robots (approximately $140, available at shop.education.lego.com), and the arduino-based robotic kit mBot (approximately $75 available at *www.makeblock.cc*).

Online

Invent to Learn—*http://inventtolearn.com*

Making conductive dough—*http://bit.ly/2IBlrv1*

Science in Action video—*www.youtube.com/watch?v=xXi4WiMdNEA*

Science Discovery Narratives—*http://tinyurl.com/klzn7mw*

Scratch programming software—*https://scratch.mit.edu*

Shinozuka news story—*www.youtube.com/watch?v=bpHgUVyLDIM*

Using Collaborative Strategic Reading—*http://bit.ly/2nG8bBT*