Community Outreach with Play-Doh® Electronics

Tom Bensky, California Polytechnic State University, Department of Physics, San Luis Obispo, CA
William Bensky, Mission College Preparatory Catholic High School, San Luis Obispo, CA

It never fails: you're in your office and the phone rings. Your department head says, "Hi! Fifty kids are coming to campus in 30 minutes. Can you meet with them and give them a one-hour hands-on activity that will make them excited about physics?" Likely you'll run to your demonstration room and grab anything that'll generate a bright light or cause something to explode or levitate, right? In recent years, we've taken a more systematic approach to hosting visitors by developing a ready-to-go hands-on activity that provides opportunities for learning about DC electric circuits.

Our approach involves using commercially available Play-Doh® (PD hereafter) as a conduit for building simple DC electric circuits. We first learned of this approach by watching a TED talk on "Squishy Circuits,"[1] where we learned that PD sufficiently conducts electricity to be used directly as a connection medium between electronic components. In use, one literally pushes leads from batteries, LEDs, and motors directly into pieces of PD to interconnect electronic components, eliminating the need for a breadboard or wires. We've used such circuits many times over the past few years for campus visitors ranging from third grade to high school. It is the intent of this paper to describe our approach to "Play-Doh electronics," including an outline for an hour-long activity.

Why Play-Doh?

In the original "Squishy Circuits" plan,[2] one is to make his or her own PD, using household ingredients, with the ability to make both conducting (with salt) and nonconducting (with sugar) PD. The recipes work very well, but we found this step too time consuming. We thus simply buy commercial PD[3] that has a slightly salty taste, which, combined with its inherent moisture, undoubtedly plays a role in its conductive properties. We do without nonconducting PD in our lessons.

We encourage the instructor to investigate PD's conductive properties, but warn that physically satisfying observations require careful and systematic measurements.[4,5] For our purposes, the most compelling feature of PD circuits is the ability to light LEDs using batteries with a voltage of around 6 V or more. This has proven to be a creative activity for young students, allowing them to make cars and animals with PD, embedding LEDs as "headlights" and "eyes," for example. From our own experience, however, we know that an LED would instantly blow out if connected directly to six or more volts. As an interconnect, the PD is obviously behaving like a series resistor, protecting the LED. In an informal visual test, a 9V battery with two 0.5-in balls of PD is lighting an LED as shown in Fig. 1. Again from our experience with electronics, the LED seems to glow with about the same brightness as the 9V battery running the LED through a resistor in the 100s-of-ohms range.

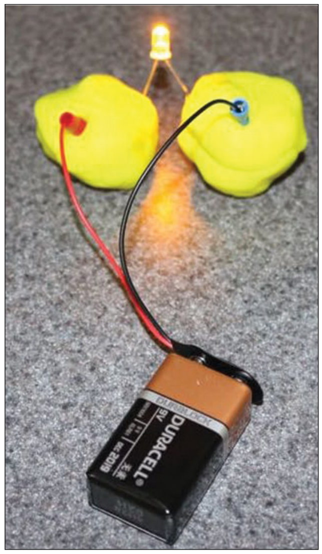

Fig. 1. An LED in a sample Play-Doh electric circuit.

We confirm this by measuring the current in the circuit in Fig. 1 to be about 20 mA. Recasting the PD as a resistor, we obtain the circuit in Fig. 2. Measuring the voltage drop across the yellow LED to be 2.1 V, we conclude that the PD is behaving like a 345-Ω resistor, loosely confirming our brightness observation. Students all seem to be aware of PD's salty taste and seem to know that salt (perhaps as in salt water) can be associated with conduction. There is typically little surprise to them that PD conducts electricity.

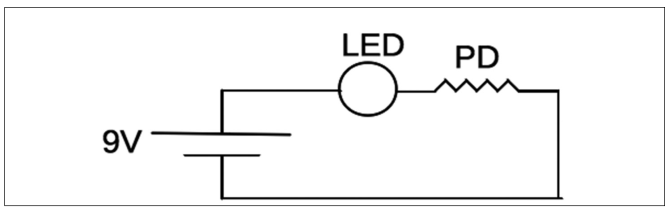

Fig 2. The equivalent circuit of that in Fig. 1. Here, PD means "Play-Doh."

Building a Play-Doh electronics kit

In this section, we make our recommendations for how to assemble a PD electronics kit for use in your own outreach efforts. Naturally, one must get a suitable quantity of Play-Doh, which can be purchased from a variety of sources. We have successfully used the name brand product as well as off brands found at dollar and department stores.

Next we discuss the electronic components. Visiting teachers often ask about how they might go about acquiring their own PD electronics kits, and we notice they are typically unaware of how to purchase electronic components. Do they need to work directly with an overseas supplier? Do they need to order in large bulk quantities? Are the parts very expensive? The answer to these questions is "no," so we thus introduce the reader to the world of purchasing (surplus) electronics. Our favorite retailer is Allelectronics.com, but others are available[6] that make acquiring electronic components a

typical online shopping experience. We'll provide an example here by quoting part numbers and costs from Allelectronics.com.

The first critical component is a power connection to a battery. We've settled on 9V batteries for our kits, as we find their single unit, rectangular form factor to be convenient. An easy connection to the PD is achieved using a 9V battery clip (BST-3, 4/$1.00).

Next, we move to the LEDs, a core component here, which we point out extend in capabilities well beyond the simple red indicator domes we are mostly familiar with. LEDs come in many colors of the spectrum (Red: MLED-7, 10/$1.00, Yellow: MLE-3, 10/$1.25, Green: MLED-2, 10/$1.25, Blue: LED-59, $0.60/each, and White: LED-83, $0.95/each), and can also exhibit various effects without any additional electronics (red flashing: LED-4, 2/$0.90; fluttering red-green-blue: LED-232, $0.65 each; red-green-blue color changing: LED-158/$0.75 each). We note that the flashing LEDs can serve as drivers, causing everything connected in series with them to "flash" as well. There are also bi-color LEDs (LED-202, 3/$1.00) that emit one color when inserted into the circuit one way, and another color when reversed in the circuit. High brightness LEDs are also available (LED-273, 5/$1.00) that will always elicit an excited response from the students. Infrared LEDs may also be purchased (ILED-8, 3/$1.00) whose emission students can only "see" using the cameras on their mobile phones.

With the parts in hand, some work needs to be done on them prior to including them in a kit. An LED that will arrive in the mail will appear as shown in Fig. 3(a), and we note that the two leads are extremely fragile. With PD circuits, the leads need to be drastically separated for insertion into the PD and, if deployed as is, will result in leads being broken clean off (within minutes). Thus, all LEDs need to be made "student proof," and here is our suggestion on doing so.

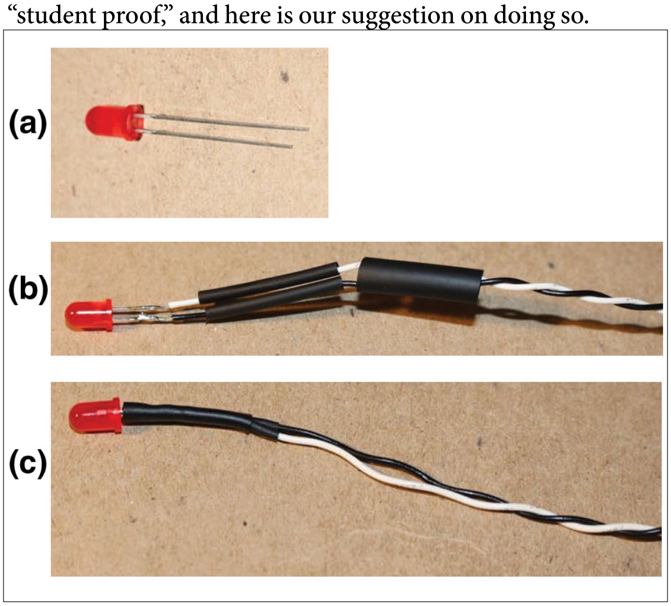

Fig. 3. "Student proof" assembly of an LED, (a) as it would arrive from a parts supplier, (b) showing soldering and placement of heat-shrink tubing, (c) final assembly.

First, obtain some "twin-lead" wires (WRB-24, 10 ft/$1.30). Alternatives are thin speaker wire from a local hardware store, or product #173164 from Jameco.com ($9.95/100 ft). Next, clip the LED leads down to about 0.25 in and solder the twin-lead wire onto them, as shown in Fig. 3(b). Obtain "heat shrink tubing" (HS-4901, $11.95) and slip appropriate sizes onto the twin-lead wire, also as shown. After soldering, slide the tubing in place and melt it with a heat gun, including a larger piece to cover the smaller pair, for a final assembly shown in Fig. 3(c). We have found this to be an extremely durable, long lasting configuration. The heat shrink tubing provides for mechanical stability and there is almost no student focus on the fragile LED leads. For the other end of the wires, simply stripping off insulation won't mate well with the PD, so we attach male style "crimp-on" connectors (2225 or 2125, 50/$3.25) as shown in Fig. 4. Our final LED assembly is shown in Fig. 5, and that for our battery connector is shown in Fig. 6.

This completes the core ideas for assembling a "production level" PD electronics kit. We note that the durable assembly steps are time consuming, but it is worth the initial investment, as the devices will last and can be used over and over again. The crimp-on connectors will always be needed for the PD end of any electronic component you choose to use. In Fig. 7, we show an outfitted switch, motor, and potentiometer.

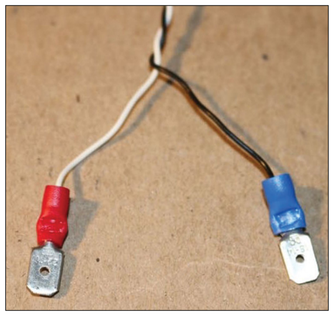

Fig. 4. Play-Doh end for an electrical component, showing crimp-on connectors for good mating with the Play-Doh itself.

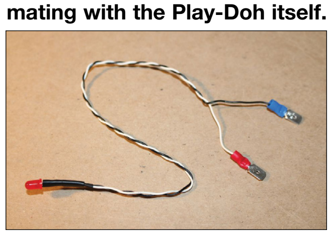

Fig. 5. Final "student-proof" LED assembly.

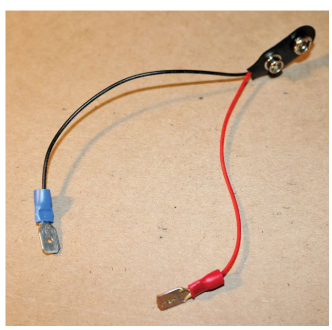

Fig. 6. Final 9V battery connector assembly.

Lastly, as you determine your goals with the PD electronics, we encourage you to browse through Allelectronics.com for other electronic components that might be interest. Potentiometers such as (NATP-10K, 2/$1.50) allow for LED dimmer circuits. A reed switch (RSW-35, $1.25/each) allows for using a magnet to control a circuit, as does heat with a thermal switch (THSW-167, $0.75) (we use carefully supervised BBQ click lighters). A few "sand" power resistors (100-30, $1.00, etc.) have a good form factor use with the PD, and motors (and their subsequent motion) should be considered, but the resistance of the PD will prevent most small DC motors from spinning up. We recommend DCM-272 for $1.25, which

Fig. 7. A switch, motor, and potentiometer, outfitted with twin-lead wire and crimp-on connectors.

is a small motor made to cause a cell phone to vibrate. CdS photocells (PRE-24, $1.25), whose resistance changes with light level, can be used to make an LED dimmer that works by moving one's hand or cell phone flashlight over the photocell (thereby changing light levels). A force sensor (Jameco.com, 2136471, $10.95) has a force dependent resistance that can be used to control the brightness of an LED based on the strength of a touch. High pitch buzzers such as SBZ-493, $0.85/each are always popular. The idea of current flow can be addressed by including an analog meter such as PMD-25MA for $12.00. Normally open and normally closed momentary switches (MPB-1, $0.85 and MPB-5R, $0.60) are nice elements for circuit control.

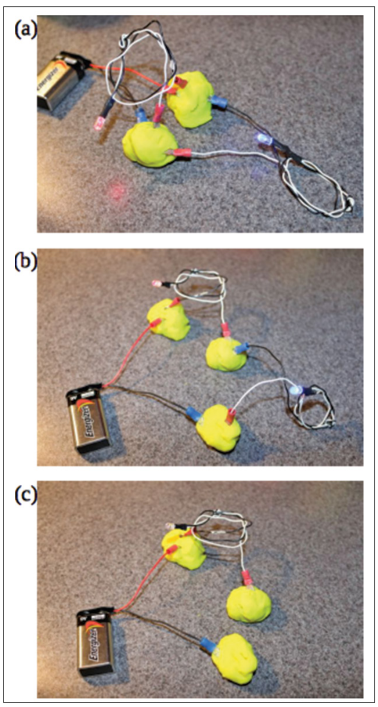

Fig. 9. Commonly seen expansions of the starting circuit shown in Fig. 10, where (a) students simply jam more LEDs into the same two lumps of Play-Doh, thus creating this parallel circuit, (b) a series circuit, and (c) a broken circuit (touching the lower two Play-Doh lumps will cause the LED to light, hence a simple switch has been constructed).

Lessons

Our lessons always begin around a simple series circuit, consisting of two lumps of PD, the 9V battery and connector, and an LED. We base our instruction around simple sketches such as that shown in Fig. 8. Even this starting circuit can occupy the uninitiated for some time, as they see the LED only lights when inserted in a particular orientation (polarity), and with the opportunity to try the other LEDs in their kit. As the lessons proceed,

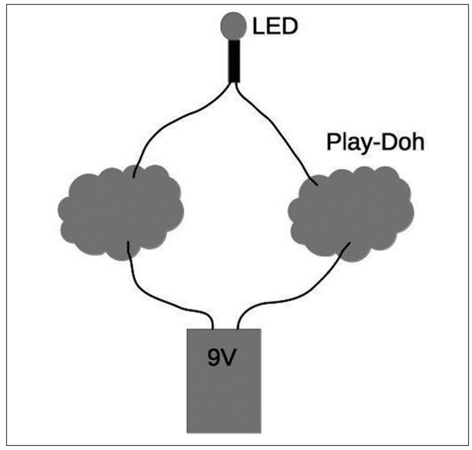

Fig. 8. Simple Play-Doh circuit sketch, used to motivate discussions with our students.

we typically see the circuits shown in Fig. 9. Figure 9(a) is the most common, where students simply "jam" more LEDs into the PD lumps, transforming the original series circuit into a parallel circuit. A proper series circuit as shown in Fig. 9(b) requires a third lump of PD, with an LED inserted with the wrong polarity preventing the entire circuit from working, while Fig. 9(c) represents just one example of an open circuit students will create, puzzled that the LED doesn't light (touching the lower two PD lumps, however, will light the LED, demonstrating a simple PD switch).

The students are encouraged to replace the LED with a buzzer or motor. We emphasize the idea of a "circuit" and point out the circular nature of the components in a *working* circuit, emphasizing how all components in their kit have two connectors, one for the electricity to go "in" and the other for it to go "out," and now is their chance to trying putting a switch (mechanical, reed, heat), photoresistor, force sensor, fixed resistor, or potentiometer into their circuit. It is not long after this that we begin to see circuits using several lumps of PD, holding multiple components.

We are pleased that the collection of materials in our kit allows for the construction of circuits that can serve a (simple) purpose, as older students might need more of a challenge. Here are some ideas we have used. This first group exploits the fact that components in series pass the same current.

Idea: Build a buzzer that pulses on and off.

Solution: Use a flashing LED in series with a buzzer.

Idea: Build a fire alarm.

Solution: Use a thermal switch in series with the buzzer.

Idea: Build a theft alarm for your book, phone, bag, etc.

Solution: Use the reed switch in series with the buzzer and a suitably placed magnet.

Idea: Build an AND gate.

Solution: Two switches in series with an LED and battery.

This second group requires components in parallel with focus on the circuit junction between the two parallel components.

Idea: Turn an LED on or off, using only two lumps of PD.

Solution: Place a switch *in parallel* with the LED, shunting current away from the LED at the junction when the switch is closed.

Idea: Build an OR gate.

Solution: One switch in series with a battery and LED, then a second switch added in parallel with the first.

Lastly, here are some ideas that will require some trial and error, typically generating discussion.

Idea: Build a conductivity tester circuit.

Solution: A three-lump circuit using an LED with a gap between two lumps across which various items can be placed (pencil, a student's own finger, washer, screw, nail, piece of plastic, rubber, glass, etc.).

Idea: As in hallway lighting at home, use two switches, either of which can turn an LED on or off.

Solution: This is not a trivial task, and we encourage the student to research "two-way switches" on the internet.

Finally, we note that any three-lump series circuit is a voltage divider. If made with a fixed resistor and a potentiometer (unbeknownst to the students), a smooth range of voltages from 0 to 9 V will appear at their center PD lump relative to ground as the potentiometer is changed. As a "grand finale" to our lesson, we instruct each group to build such and issue them a long (50-ft) twin-lead wire such as WRB-14 for $23.50, outfitted with crimp connectors. They are instructed to insert one of their end wires into their "center lump" and the other into the lump connected to the black wire of the battery (ground). The other end is routed across the classroom into a USB data acquisition device, in our case a LabJack U6[7] connected to a central computer, itself connected to the room's projection system (see Fig. 10 inset). We encourage the reader to consider (using some custom software) the possibilities of having a controllable voltage feed from each group of students. In our case, we have developed software that maps a given group's voltage into the position of "paddle" on the computer screen, allowing for a class-wide game of "Pong,"[8] as shown in Fig. 10 (10 "paddles" and the yellow ball at center). Students control their respective paddle by altering their potentiometer, thus allowing them to culminate the lesson by building a "Play-Doh video game controller."

Conclusions

The lessons described above have been developed as part of a structured outreach program called the "Learn by Doing Lab."[9] In addition to providing a "by reservation only" destination to campus visitors, college students investigating the possibility of becoming teachers earn course credit by actually running the lessons with the visitors (after being trained on them during the initial weeks of the term). Visitors come from local schools in our area, to the tune of 200 students per week. They are broken up into groups of 50 and sent through various one-hour lessons such as the one described here. Pictures of our lab in session are available.[10]

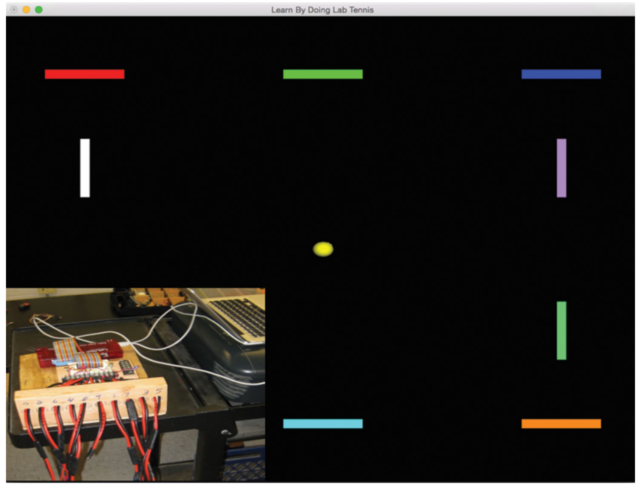

Fig. 10. A 10-paddle "Pong" game, where each paddle position is derived from a given group's voltage. The yellow dot is the (moving) bouncing ball. (Inset: Labjack computer interface box measuring simultaneous voltages coming from 10 student groups.)

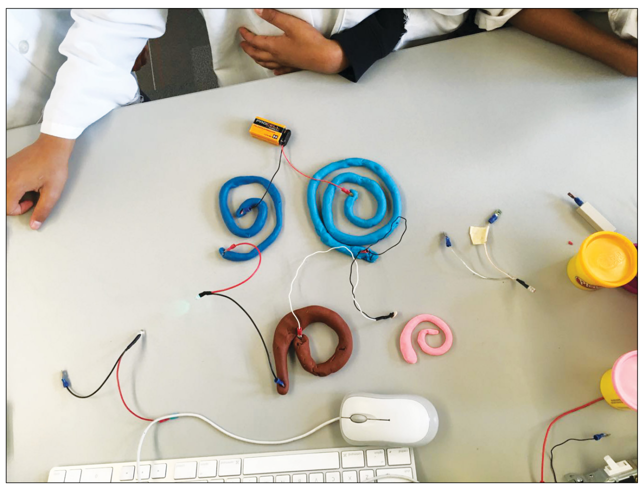

Fig. 11. More components of the Learn by Doing Lab using Play-Doh.®

In our lesson, we typically start with a 10-minute presentation on electricity using some pictures of things like a battery or power line, in an attempt to let the visiting students settle in and focus on the theme of our lesson. They are also shown a picture of a simple PD circuit and given a short description of what they'll be doing. We next get everyone into a big circle, with everyone holding hands, and show how an electrical device[11] can be turned on only when our "human circuit" is complete. We then break into small groups, with one college student mentoring each group, at which time the circuit building and experimentation beings, typically lasting for about 20 minutes. Then we call everyone's attention and discuss insulators and conductors, then build and use the

conductivity tester described above for another 10 minutes. We then systematically build and test the video game controller for about five minutes, then spend 10 minutes allowing all students in a group to play a class-wide game of "Pong," followed by a five-minute wrap-up.

We have found our PD electronics kits to be a robust and stimulating way of spending an hour with uninitiated campus visitors. The kits take only minutes to store and retrieve. The ability to implement our lessons to 50 students is possible only due to the mentorship of our student assistants. A small expert-to-student ratio is critical in productively managing the kits and ensuring a meaningful experience.

Acknowledgments

T. B. is indebted to J. Keller of the Cal Poly CESAME program[12] for his invitation to develop this lesson, including providing funding for the supplies. Thanks also to S. Bush, E. Himmelblau, and Jennifer Carroll for their wisdom and enthusiastic support on those busy Friday mornings when a bus of 100 eager and energetic kids arrived at our classroom door. Thanks also to K. Wakeman, T. Kwapnoski, and S. Hegg for managing the visitor schedules and for navigating our cryptic lists of electronics parts to order.

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7. See http://www.labjack.com, the U6 model ($299).
8. Contact tbensky@calpoly.edu if interested in obtaining the software.
9. See http://www.cesame.calpoly.edu/content/learn-by-doing-lab .
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Tom Bensky *is a physics professor interested in investigating the use of electronics at all levels of STEM education.*
tbensky@calpoly.edu

William Bensky *is a high school senior, is passionate about the use of technology in education, and is involved with multiple outreach projects. His other interests include astrophysics, astronomy, and computational mathematics. He hopes to pursue aerospace engineering in college.*

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Our esteemed column editor Diane Riendeau has indicated that she must relinquish her position as the *TPT* "For the New Teacher" column editor after three years of exceptional service. While her shoes will be difficult to fill, *TPT* is opening a search for applicants with a background in high school physics teaching, and who are interested in providing and/or soliciting manuscripts, materials, and resources for a *TPT* column largely devoted but not limited to issues of concern to those teaching introductory physics in secondary school. If you (or individuals you'd recommend) are suited for the role, please contact the editors at tpt@appstate.edu for more information.

DOI: 10.1119/1.4965262