AC 2011-1331: EXCHANGE: USING SQUISHY CIRCUIT TECHNOLOGY IN THE CLASSROOM

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Exchange: Using Squishy Circuit Technology in the Classroom

Abstract

This paper presents exercises utilizing squishy circuits as an educational tool. Squishy circuits are constructed with conductive and insulating play dough, allowing students to sculpt their own circuits. Students can be taught in a hands-on exercise, using batteries and basic electronic components (light emitting diodes, DC motors, etc.). This method may allow electronics and circuit building concepts to be presented at a much younger age than with traditional methods, as there is no need for soldering irons or proto-boards. Some of the fundamental concepts that are explored include: electrical resistance, series and parallel circuits, current flow in a circuit, diodes, and batteries. This paper will present recipes for both the conductive and nonconductive dough, as well as exercises that can be used in the classroom.

Introduction

Squishy circuits are a tangible medium designed to enhance students' understanding of basic electronics and circuit building. Furthermore, they allow these concepts to be introduced to students at a much younger age than other, traditional methods[4]. Like other tangible mediums, squishy circuits have the potential to be effective educational tool, because they employ visual and playful learning techniques[1,7].

As semisolid ionic substances, most commercial and homemade molding compounds are conductive[5,6]. However, the electrical resistance of commercial play dough is widespread and unpredictable. Using low voltage applications, the current flow through the compounds is minimal. Minimal current flow combined with a potentially high resistance from a commercial compound could cause the electric components in the circuit to function poorly, or not work at all. The conductive play dough explained later has both a predictable and stable electrical resistance[4].

The salt base of the conductive dough is what allows it to conduct electricity. Adversely, the insulating dough is sugar-based, which greatly reduces its conductivity. In simple circuit building, it isn't necessary to include the insulating dough. However, when making more complex shapes and structures to incorporate squishy circuits, insulating dough can be used to prevent short circuits[4]. This provides potential to develop more sophisticated designs that incorporate genuine creativity.

Making Squishy Circuits[3,8]

Recipes and instructions, which can be found on the project website, to make both conductive and insulating play dough are reproduced below:

Conductive Dough Ingredients:

- 1 cup Water
- 1 cup Flour
- ¼ cup Salt
- 3 Tbsp. Cream of Tartar
- 1 Tbsp. Vegetable Oil
- Food Coloring (optional)
- ½ cup Extra Flour

Making Conductive Dough

To make the conductive dough mix all of the ingredients, except for the ½ cup extra flour, in a medium sized pot. Cook this over medium heat, stirring constantly. Once the mixture starts boiling, it will start hardening. Keep stirring until it forms a ball in the center of the pot. After this, take the ball and place on a lightly floured surface. The ball will be very hot, so let it cool for a few minutes and knead on the floured surface. Slowly knead the extra flour into the dough until a desirable consistency is reached.

NOTE: ½ cup is an approximate measurement. More or less extra flour may be necessary to achieve a desired consistency.

Insulating Dough Ingredients:

- 1 cup Flour
- ½ cup Sugar
- 3 Tbsp. Vegetable Oil
- ½ cup Deionized Water (distilled water will also work)
- 1 tsp. Granulated Alum (optional)
- ½ cup Extra Flour

Making Insulating Dough

Unlike the conductive dough, making the insulating dough requires no cooking. To make the insulating dough, mix all of the ingredients, excluding the ½ cup deionized water and ½ cup extra flour, in a pot or large bowl. Add a small amount of deionized water (about 1 Tbsp.) and knead. Keep adding small amounts of deionized water until the mixture becomes moist and dough-like.

NOTE: ½ cup is an approximate measurement. More or less deionized water may be necessary. Additionally, insulating play dough made without granulated alum will have less elasticity and keep for a shorter time than its alum-included counterpart.

Once the mixture is moist and dough-like, place it on a lightly floured surface and knead. Continue to knead extra flour into the mixture until it obtains a firm consistency and loses most of its stickiness.

Both the conductive and insulating dough should be stored in an airtight container or plastic bag.

Gluten Free Variant

Additionally, in case of any wheat allergies, both recipes can be made with gluten-free flour. To do this, simply substitute gluten-free flour.

NOTE: Using gluten-free flour when making the conductive dough will require a longer cooking time and produce a slightly oilier compound.

Teaching with Squishy Circuits – Play & Create

LED circuit

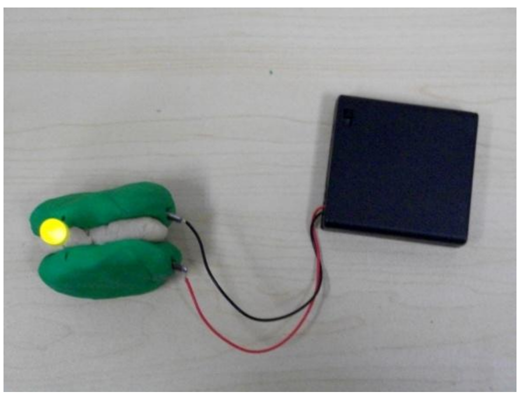

Figure 1

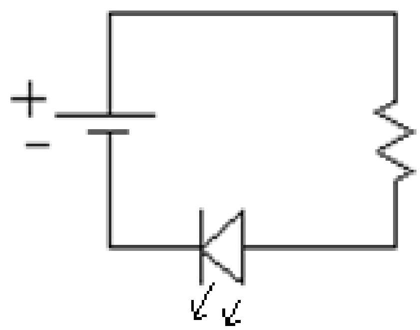

Figure 2

Figure 1 shows an example of a squishy circuit with a light emitting diode (LED). This circuit consists of two pieces of conductive dough (green) insulated by insulating dough (white), an LED, and a battery pack. The battery pack used in this circuit the other circuits described in this paper is six volts, containing four ‘AA’ batteries.

Figure 2 shows the circuit diagram for this circuit. In this diagram electric current is flowing clockwise. Since LEDs are diodes, they will only allow current to pass through in one direction. Thus, if wired improperly, the LED will not light. To wire the LED in the correct direction, place the cathode, typically indicated by having a short lead, with the negative (black) battery terminal and the anode, typically indicated by the long lead, with the positive (red) terminal.

Motor circuit

Figure 3 demonstrates a squishy circuit very similar to Figure 1 containing a DC motor instead of an LED. Unlike LEDs, DC motors allow current to flow in either direction. The direction of current flow will dictate the rotational direction of the motor shaft.

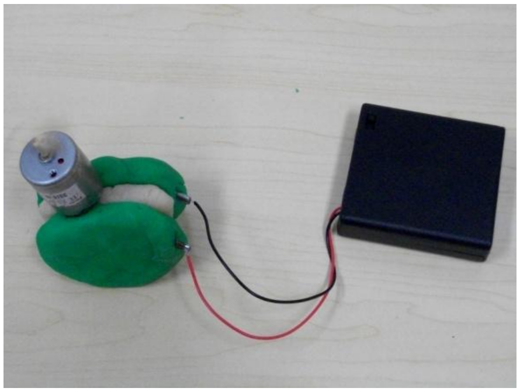

Figure 3

When using DC motors in conjunction with squishy circuits, it is necessary to crimp or solder larger leads to the end of your battery. This will increase the surface area of the dough in contact with the battery pack and allow for larger current to flow, turning the motor.

Short Circuits and Switches

Figure 4 shows the same circuit as Figure 1, but it has been shorted with a strip of conductive dough. In this short circuit the current returns to the negative battery terminal rather than traveling across the LED, preventing the LED from lighting.

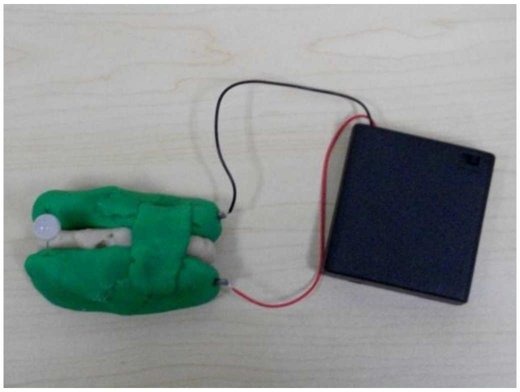

Figure 4

Using this concept, switches can be implemented in squishy circuit designs. Figure 5 shows an open circuit. There is an insulating barrier after both the right and left LED, preventing them to light. Figure 6 and Figure 7 demonstrate a switch. Placing a switch made of conductive dough across the current gap will allow the current to reach the negative battery terminal and light its corresponding LED.

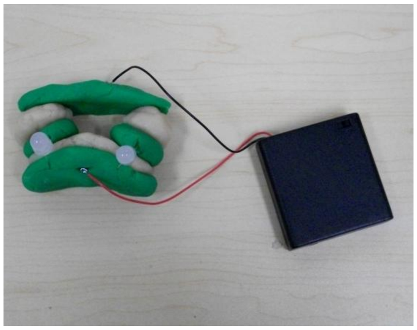

Figure 5

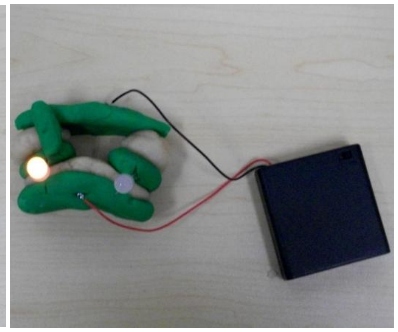

Figure 6

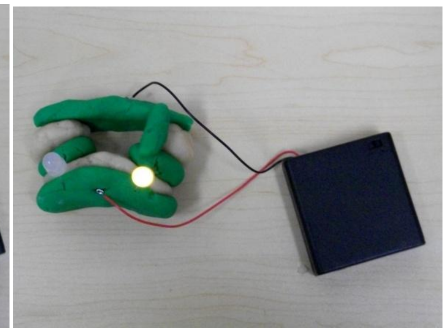

Figure 7

Series and parallel

Figure 8 and Figure 9 show examples of LEDs in parallel and in series, respectively. The LEDs appear dimmer in series because they are each receiving less voltage than their parallel counterparts. A six volt battery pack is being used. If the resistance of the dough is neglected, each LED in parallel is receiving six volts, where the two LEDs wired in series are only receiving three volts a piece. However, the actual voltage to each LED will be less than the previously mentioned values due to a voltage drop from the dough's electrical resistance.

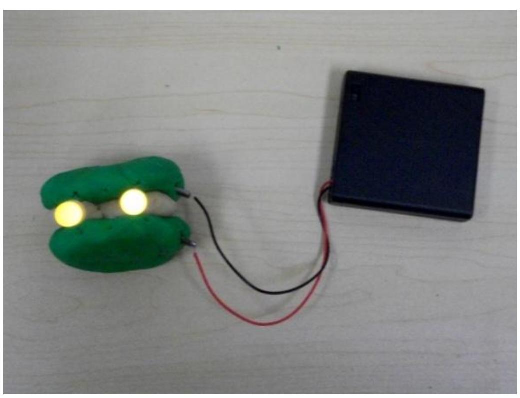

Figure 8

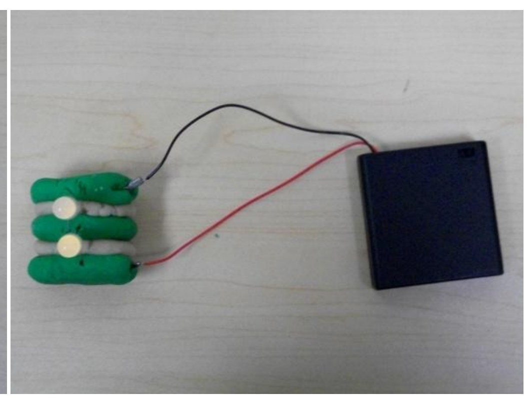

Figure 9

Resistance

The conductive dough serves as a wire with a built-in resistor. Because it is a semisolid, the resistance in the circuit increases as the length of the dough increases. The circuit demonstrated in Figure 10 is essentially the same as the circuit shown in Figure 1, but it uses longer pieces of dough as wires. Since the resistance of the dough "wire" increases with length, the voltage across the LED in figure 10 is lower than the voltage across the LED in Figure 1.

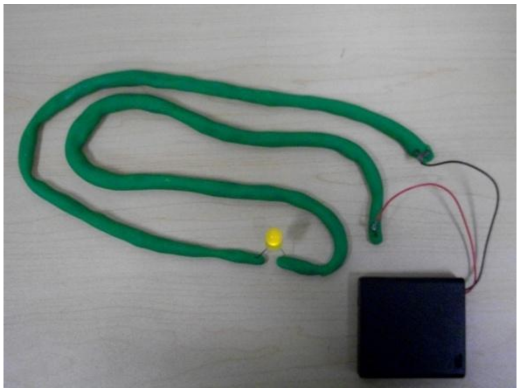

Figure 10

The exercises above present demonstrations of basic electronics and circuit building concepts. Using these in conjunction with each other and slight variations provide an excellent introduction to electronics and circuit building. We propose these exercises for implementation in late elementary and middle school curriculum. However, in our experience, by early elementary school students are able to process and comprehend the topics being presented.

Research is still underway to determine the most effective method for classroom assessment. Some suggestions include: a post-activity quiz, a questionnaire to be completed during the circuit building exercises, and classroom discussion. Additionally, students could be asked to create a unique circuit, on their own or in small groups, that incorporates various concepts from the exercises shown above. The successful implementation of these concepts will demonstrate the students' understanding of the material.

In-Field Testing of Squishy Circuits

This activity has been tested widely in a variety of situations. We have used this activity for a number of "try it" events, in which people were free to stop by a table where the squishy circuit materials were available for use. Additionally, one of the project developers was available to assist users. These events included an open-to-the-public "Make: Day" at the Science Museum of Minnesota, two E4 (Excellence in Elementary Engineering Education) conferences for teachers, and a science day for teachers and the public at an NSTA conference. In all of these settings, participants ranging from young children (typically age three or older) to grandparents were able to build simple LED and DC motor circuits. For the youngest children, supervision and one-on-one coaching is recommended. For elementary school aged users, and older, we found that once they were coached through the creation of a simple LED circuit (pictured in

Figure 1), they were typically quite eager to continue exploring the capabilities of the materials on their own.

We have tested a curriculum (available on the project website) with two groups of middle school aged summer camp students participating in a class on engineering and toy design. Pairs of these students were given packets containing squishy circuit materials, as well as written instructions that walked them through various activities (including building LED circuits and switches) to work on at their own pace. We have also used the curriculum in a setting where approximately 60 students, working in pairs, were led step-by-step through the activities by a presenter in a lesson approximately twenty minutes long. All students in of these three class/lecture settings were successful in getting their LED squishy circuits to work, and the enthusiasm in the rooms was very noticeable.

As we have posted the recipes and project instructions freely online, and have published the recipes in Make: magazine, it is reasonable to assume that this project, and others like it, are being conducted in homes, schools and museums. We have received many emails from museums, parents, and teachers about the use, or potential use, of squishy circuit technology. Museums have used it for family day activities as well as extracurricular classes. The squishy circuit project has also been included in teacher activity guides for the PBS SciGirls television series.

Safety

This activity was designed with safety at the forefront of our considerations. All ingredients for the dough recipes can be found in food stores. As the conductive dough recipe involves cooking, it may be easier to have the dough prepared in advance if this activity is being done with younger children.

We do not recommend using the dough with high voltage or current. We have tested these activities using four AA batteries, as well as a single 9 Volt battery.

In one of the public events mentioned above, an adult user bypassed the dough and attached the LED directly to the battery pack. This prompted the LED to pop, which posed a potential risk to the eyes of the user and those nearby. We have never witnessed this again, and it should be stressed that this occurred when the user *did not* use the dough or follow instructions. This could have been avoided by following the directions presented and implementing the dough in creating the circuit. Additionally, wearing safety glasses would have reduced the risk.

Benefit of Incorporating Squishy Circuits in Education

Previously used to teach electrical resistance and Ohm's Law in physics classes, the inclusion of play dough in electronics education is not an entirely new idea[5,6]. However, using play dough as a tool not only to teach but to *introduce* basic circuits and electronics to students is a recent development that is showing great promise. Because of their intuitive nature, electronics can be a difficult subject for people to learn. Presenting these topics through a familiar and fun medium is one of the most effective ways to teach students, especially younger students, the material and ensure that they are fully understanding it[1,7]

In addition to effectively teaching the material, squishy circuits can help students exercise genuine creativity. If it can be built with play dough, it can be used as a circuit. The possibilities are endless. Squishy circuits provide students with the opportunity to design, create, and invent truly original ideas. This is the best way to develop creative thinking capacities and one of the most effective ways to learn new material[7]. Buechley's research with electronic textiles showed great success in teaching electronics and programming[2]. We believe, through playful and interactive learning, that squishy circuits will also achieve great success in serving as an effective learning tool.

Acknowledgments

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