
Squishy Circuits: A Tangible Medium for Electronics Education

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Abstract

This paper reports on the design of a circuit building activity intended for children, which replaces wires with malleable conductive and non-conductive dough. By eliminating the need for soldering or breadboards, it becomes possible to very quickly incorporate movement and light into sculptures, and to introduce simple circuit concepts to children at a younger age. Future applications in both structured and unstructured learning environments, based on results from a preliminary pilot study, are presented.

Keywords

Children, tangible interface, pilot testing. playdough

ACM Classification Keywords

H5.m. Information interfaces and presentation:
Miscellaneous.

General Terms

Theory, Experimentation

Introduction

The inclusion of play in the learning process has repeatedly been shown to be an effective method. Exciting learning experiences can occur when children are engaged with materials, not just through simple interaction, but through designing, creating, and inventing [8]. Development of these creative thinking

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techniques is important to all fields of inquiry, but particularly critical in the fields of science and engineering [1].

There are numerous tangible mediums that contribute to visual and playful education techniques. Conductive textiles (e-textiles) [2] and conductive paints [3] have been shown effective as tools for introducing children to electronics.

Molding compounds have been used to teach intuitive electrical concepts before. Many introductory physics classes have used commercial molding compounds in labs to teach electrical resistance, and the application of Ohm's Law [5,6,7]. Although the idea of using molding compounds in electronics education is not entirely new, we felt that there was a greater potential for new ways to use conductive, malleable materials. What if kids could build sculptures which allowed them simply to stick in LEDs or motors to complete the circuit? This paper discusses the development of conductive and insulating molding compounds to be used as learning tools, as well as their benefits and application toward basic electronics curricula.

Development of an Educational Tool

Conductive Molding Compound

Most commercial and homemade molding compounds ("playdoughs") are semisolid, ionic substances. Because of this, nearly all of these compounds are naturally electrically conductive, a property that has been used in high school physics classrooms in exercises designed to teach students how to measure resistance [5].

Commercial molding compounds, though conductive, can have very inconsistent levels of conductivity. Some intriguing results have shown that the electrical resistance of a commercial compound can even change with respect to its color [5]. However, given the difficulty in finding an exact recipe for commercial playdoughs, and because there is such a variation in their resistance, it is hard to use them when a predictable, stable resistance is needed.

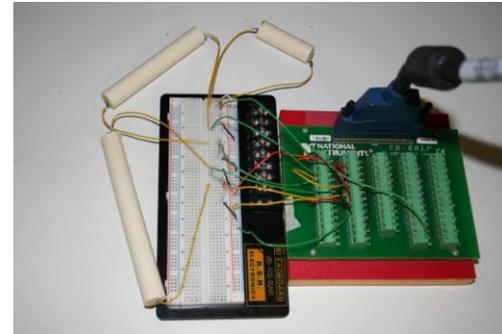


Figure 1. Measuring the resistance of three different lengths of conductive dough.

When developing conductive molding compounds designed for basic circuit implementation, conductive stability is crucial. Typically, the electric current intended to flow through these semisolids is very low. This means that any unexpected resistance increase could reduce current flow to the circuit components and cause them to function poorly, or not at all. To improve the overall conductivity and stability of our compound, we characterized the conductivity of many homemade playdough recipes. To do so, we examined the increase in electrical resistance over time for known cylinder lengths of each recipe. The experiment set up

for resistance measurement is shown in Figure 1 (with three different tube lengths shown). From these examinations, we were able to develop our own recipe that has a fairly consistent, stable, and predictable level of electrical resistance. Figure 2 shows the approximate resistance of commercial dough and the average, stabilized resistance for our developed substances for a small cylinder 10 cm in length.

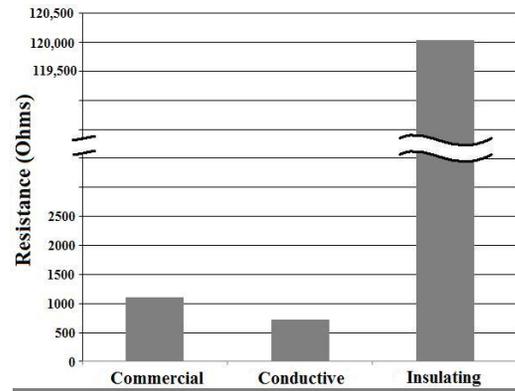


Figure 2. Figure displays a graph for the electrical resistance of commercially available molding compound, as well as our conductive and insulating compounds.

Making Circuits

After developing the recipe for conductive molding compound, we put our dough to use and started building simple circuits. These squishy circuit designs consisted of: the conductive molding compound, a six volt DC power supply (We used four AA batteries inside of a plastic housing.), light emitting diodes (LEDs), and gearless DC motors. The left image in Figure 3(a) shows a simple LED circuit using the conductive dough. As the dough is essentially a wire, care needed to be taken not to short the circuit. Using plastic wrap as an

insulator was a “quick fix” for this problem, but lacked elegance and malleability. It was clear that it would be desirable to have a non-conductive molding compound as well.

Insulating Molding Compound

The use of insulating molding compound is a fun, builder friendly, and aesthetically pleasing method to insulate the “wires” of squishy circuits. Figure 3(b) shows a circuit identical to the one in Figure 3(a), but with a high resistance dough replacing the plastic wrap. Figure 4 shows a slightly more complex conductive sculpture, in which the red and green doughs are conductive, and the white dough acts as an insulator.

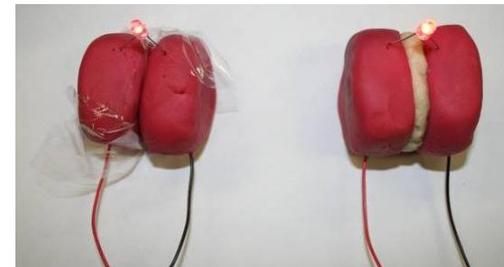


Figure 3. Squishy LED circuits: (a) A circuit using plastic wrap as insulation, and (b) a circuit using non-conductive dough (white) as insulation

The ionic properties of most playdoughs made it challenging to develop a compound with a high enough electrical resistance to insulate our squishy circuits. The conductive substance is salt-based, uses tap water, and contains additional ingredients that are ionic in aqueous solution. Thus, simple modifications to compound’s recipe wouldn’t yield an extremely high resistance. To achieve a resistance high enough for the compound to act as an insulator, a change in the total structure of

the substance was required. Our solution was found with an original, sugar-based, recipe including the use of deionized water.

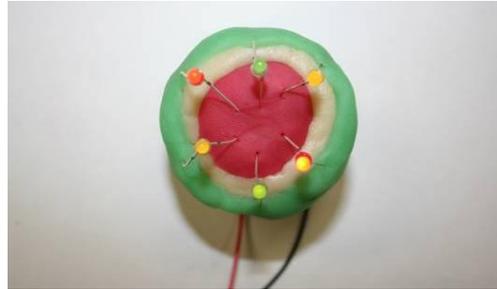


Figure 4. Figure shows a complex sculpture that incorporates multiple LEDs and both dough compounds.

The high resistance dough not only insulates the conductive dough, but also resists mixing with it. This is a vital property for insulating dough, as without this property conductive molding compounds would be very similar to colorful play clays. If a dab of blue mixes with white clay, the white clay is ruined, and will forever be a non-white shade of blue. Without a non-mixing property the insulating compound could receive a dab of conductivity. This risks causing short circuit or reducing the effectiveness by reducing the conductivity of the conductive dough, or lowering the resistance of the insulating dough. Having a resistance too low to insulate, and too high to conduct efficiently, the dough would be less useful for circuit building, unless it was to serve the role of a resistor.

Implications

We believe that there are some exciting potential uses for this “squishy circuit” method. Research by Buechley has shown the benefits of incorporating e-textiles into

beginning electronics and programming curriculum. As an introduction to these subjects, students used conductive fabrics in conjunction with Buechley’s LilyPad Arduino microprocessor. Her trials revealed that the implementation of e-textiles increased students’ test scores significantly. In separate trials, average test scores for circuits increased by 55 percent, and basic programming scores increased by 140 percent [2].

The effects of playful learning are likely the main source for these increases. Playful learning and tangible mediums have been shown provide motivation to learn. Students are most involved in learning a topic when it intrigues their own personal interests. When students care about their work, they develop a profound understanding of their subject matter [8]. Research has shown a disconnect, between scientific direction presented in classrooms and students’ pursuit of science on their own. By late elementary school many students do not see their efforts outside of the classroom as “science” at all [4]. Playful learning through tangible mediums bridges this gap by combining what students learn, and what they do for fun. This deeper level of interest presents unprecedented benefits to their learning process. Student interest can also be sparked by using familiar objects in unfamiliar ways. Playful Invention and Exploration workshops have show that, as students played with familiar materials, they were more comfortable experimenting and exploring. Simultaneously, they became more intrigued when something unexpected happened [8].

Using squishy circuits has the potential to bring playful learning methodologies to electronics education.

Building circuits with the conductive and non-conductive dough, as well as various electronics components, gives students a personal experience, because they are designing their own implementations. Furthermore, this method takes advantage of using a familiar object, playdough, in an unusually unfamiliar way.

In addition to the educational benefits mentioned above, there are many physical benefits to using squishy circuits. The most important is safety. All of our developed molding compounds are water soluble and nontoxic, an imperative characteristic that all playdough must contain. These compounds are highly economical as well. The recipes include inexpensive ingredients that anybody can easily make at home. Moreover, the compounds are reusable and possess long life spans. Lastly, these compounds have extremely low entry barriers; anyone can learn from, and enjoy them. The procedures for implementing basic circuits are very simple as well. As no soldering, or even bread boards are needed, one can almost immediately start building circuits.

Pilot

Our pilot testing for the use of squishy circuits consisted of 11 students participating in a week-long summer course on toy design. One lesson was devoted to teaching electronics through the use of squishy circuits. Students were taught using a lab-only exercise. The purpose of this was to determine if self-guided squishy circuit exploration, using no formal lecture but rather a short packet of “getting started” suggestions for the students, were an effective tool for teaching the beginning concepts of basic electronics. Before commencing the lab activity, all students took a

preliminary test to determine how much existing knowledge they had regarding basic electronic concepts. After the lab activity, the students were given the same test again. Evaluating these two tests in a student-by-student manner suggested that each gained general improvement in their knowledge about circuits and electricity. This learning tool was especially effective among students that, judging from the preliminary test, had almost no pre-existing knowledge of these subjects.

Playful learning was also present during the pilot trial. Observations of the students during the pilot can strongly imply that they were having fun while learning, something which definitely contributed to their overall experience and understanding.

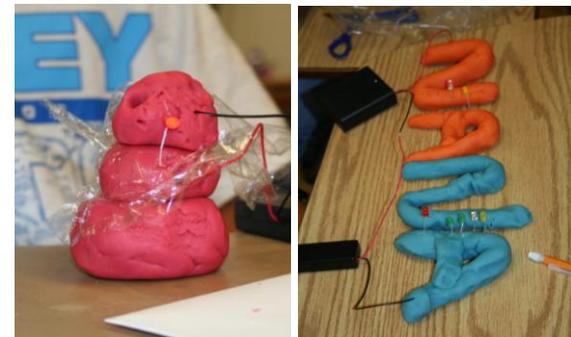


Figure 5. Squishy circuit sculptures made by middle school students.

As this pilot was done prior to the completion of the insulating dough, the students were only using conductive dough. We will be bringing the new squishy circuit kits, including both conductive and

nonconductive dough to classrooms for more testing over the coming year.

Future Work

This paper presents the initial steps in the exploration of dough-based squishy circuits as an educational toy. There are a number of improvements that we feel can be made. Oxidation was a problem over extended use as rust formed on LED leads. Further research could develop modified electronic components, specific to squishy circuits that have longer life spans and better usability. Continued research in squishy circuits could also develop squishy resistors. Through intense examination of ingredients and their quantities, a "resistance formula" could be established to yield molding compounds with controllable and precise electrical resistances.

Another, more playful, continued research topic includes squishy robots. Implementing a microprocessor board with the squishy circuits could be an innovative way to teach robotics and programming as well as basic electronics. The resistance of a specific piece of molding compound is directly correlated to that piece's shape, so speakers to these circuits could be an interesting way to manipulate sound. Students could examine volume and tonal changes in a speaker relative to the shapes and lengths of their designs. They could even potentially change the sound properties as it's playing by stretching and squishing the circuit.

We believe that squishy circuits have the potential to be used in numerous ways, and help students can acquire richer and more personal connections to subject knowledge.

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