ARbits: Towards a DIY, AR-Compatible Electrical Circuitry Toolkit for Children

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Abstract
Augmented reality (AR) is a unique hands-on learning tool that can help students in a pervasively misunderstood area of STEM learning, electrical circuitry. AR technology can help with the construction and debugging of circuits, leading to independent learning and reduced assistance. In this paper, we introduce ARbits, a DIY, AR-compatible electrical circuitry toolkit for children. This toolkit exposes children to the concepts of circuitry at an early age, with components that are easy for little hands to handle. We anticipate that instructors at makerspaces can use our designs to fabricate multiple electrical components for children.

Author Keywords
electrical; circuitry; augmented reality; kit; children; DIY; education; STEM; learning.

Introduction
Augmented reality (AR), which overlays virtual information into the real world, provides a hands-on, "minds-on" educational content. In the last decade, there has been a surge of interest in hands-on learning of a pervasively misunderstood area of STEM learning, electrical circuitry [13]. Ubiquitous technologies, such as tablets, mobile phones, headsets, have enabled a sharp increase in creation of AR applications, which provide the user with an interface to the virtual world. This digital information is superimposed onto

physical objects and can demonstrate concepts and phenomena that would otherwise be too abstract or invisible to the senses [9] (e.g., voltage, pressure, temperature). Likewise, AR can be used as the medium to deliver instructions, feedback, and entertainment in the learning content leading to an increase in the learning retention in children.

Figure 1: Multiple prototypes made with paper, cardboard, acrylic, plywood. The final prototype made with plywood was the most conductive, reliable, and reusable with magnetic terminals. However, cardboard can be used if a laser-cutter is not available in a makerspace.

Past work has shown that children as young as 3 years old are capable of learning STEM concepts [15, 7]. However, electrical circuitry education is typically left for later school years. Exposure to circuitry concepts is made difficult by choice of tools [11] and lack of exploratory learning in a collaborative environment [8], rather than circuitry concepts by themselves. Traditional circuitry tools are not easy for little hands too handle, although new commercial, non-traditional tools (e.g., velcro, buttons, snaps, fabric, paper circuits, LEDs) show promising results to reshape this landscape [14]. Similarly, AR technology can provide dynamic visual representations of electrical circuitry, which have proven to be effective in helping students understand concepts of electricity [4, 16].

In this work, we introduce ARbits: a DIY electrical circuitry toolkit for children that enables AR technology to track components in the scene and provide graphical representations of circuitry concepts.

Related Work

Traditional components for electrical circuitry are difficult to manipulate by little hands, which can impede the learning of circuitry. Other materials have included a wide range of conductive materials to foster creativity, play, and learning. Researchers have advocated that e-textile toolkits, such as the Lilypad Arduino [5], enable exploration of diverse aspects of circuitry. In e-textile creations, the combination of thread and circuits, allows for users to visualize the underlying structures and connections between components tangibly. Teachers have striven to bring these innovative components into their classrooms, given the increasing availability and demand for new methods of interaction with circuits.

In recent years, there has been a growing demand to incorporate circuitry toolkits into makerspaces and classrooms, more specifically to bring these tools into the hands of little children. These toolkits make use of a variety of unconventional materials: conductive playdough in Squishy Circuits [10]; craft polymer that shrinks with heat in Shrinky Cicuits [12]; and pre-built electrical components and boards meant for simple integration and high performance [6, 3]. Commercial alternatives include toolkits such as Chibitronics [1], which provides flexible, flat, paper-compatible electrical components; and Circuit Scribe [2], which provides magnetic components and a notebook to review electrical circuitry concepts. Typically, conductive thread, copper tape, conductive paint and ink, gold foil are some of the materials used alongside the toolkits to facilitate connections between electrical components.

While these toolkits have provided a more tangible way of observing the inner-workings and processes in circuits, electricity phenomena remains invisible. AR technology provides students with visualization of electricity while working, which can contribute to further learning in young children [4]. Similarly, AR technology can provide instructions, visual cues, interactivity, and feedback to users. For example, the concept of *polarity* (i.e., the direction of the current flow from positive to negative terminals) can be explained with AR effects overlaid on the components.

In this work, we present an electrical circuitry toolkit with the following: reusable, reliable, AR-compatible design made with plywood and magnetic terminals.

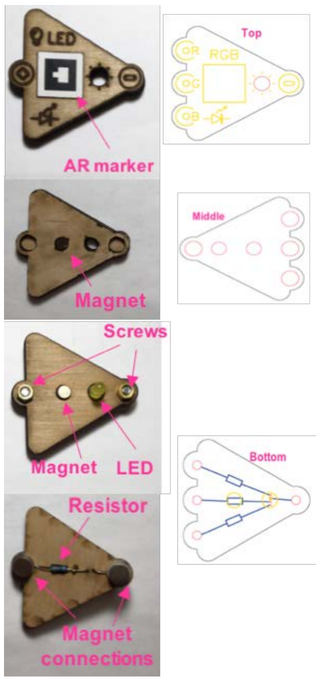

Figure 2: Description of the prototype: Top layer, provides symbols for terminals; inner layer, includes a central magnet to keep bottom layer in place and holes in which to insert head of screws; bottom layer, includes screws, electrical component(s), a central magnet to make contact with inner layer, and terminals of electrical component(s) with a magnet at the end of each screw.

The Toolkit: ARbits

Choosing the Material

Increasing demand for unconventional materials to facilitate circuitry learning in the classroom, prompted us to investigate on what would be the best material for children to handle. We wanted the electrical components to be reusable, inexpensive, and reliable in terms of conductivity to avoid children becoming frustrated with too many failed attempts at creating a circuit and no obvious solution on sight. We tested prototypes made with paper, cardboard, acrylic, and plywood (Figure 1). The final prototype which was made with plywood and had magnetic terminals to satisfy all the requirements we previously mentioned. We created a vector file for laser-cutting and its corresponding CAD file to be an asset in the AR scene, to standardize the shape of each component and streamline the fabrication process. A standard component has a top layer, an inner layer(s), and a bottom layer (Figure 2).

Laser-cutting the components

Laser-cutters, which are commonly found in makerspaces, can simplify the fabrication process to cut and engrave plywood, especially to produce multiple electrical components for several children. However, if a laser-cutter is not available, our fabrication process can be replicated using MDF or cardboard with a thickness of 3mm. Once all the pieces are cut, we made sure that the holes in the circuit layer (bottom) went through the plywood, so that the terminals of the components (LEDs, buzzers, motors, etc.) (Figure 3) were inserted through it. The top layer provides symbols for terminals and the fiducial marker; the inner layer(s) has a central magnet to keep the bottom layer in place and holes for the heads of the screws; the bottom layer has the screws, the electrical component(s), the terminals of the electrical component(s) (made with a magnet at the end of each screw), and a central magnet to make contact with the inner layer. The symbols on vector files for laser-cutting represent the following: black for outer cuts, yellow for inner cuts, yellow for engravings at the top of the layer, blue for engravings at the bottom of the layer, magenta for notes. The bottom layer is the one that makes contact with the conductive surface.

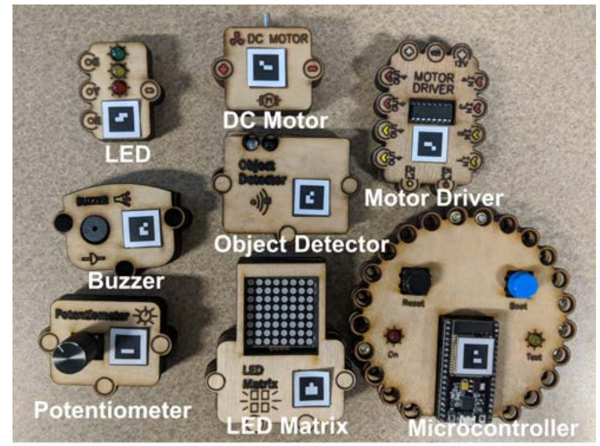

Figure 3: List of other components of ARbits: LED, DC motor, motor driver, buzzer, object detection sensor, potentiometer LED matrix, microcontroller (ESP32).

Making the circuit

In the vector files, the engravings provide instructions for where to place each electrical component in the bottom layer of the plywood piece. For example, lines represent wires–simply to connect the terminal of a component to another terminal; rectangles represent resistors–which are necessary for some components (e.g., traffic lights, LEDs); small circles represent LEDs; squares represent pushbuttons.

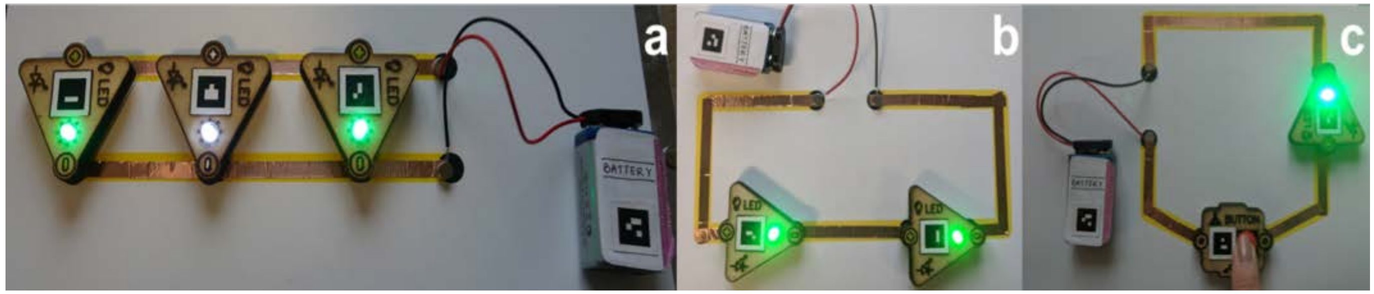

Figure 4: Examples of use of ARbits: (a) connections in parallel, (b) connections in series, (c) pushbutton circuit.

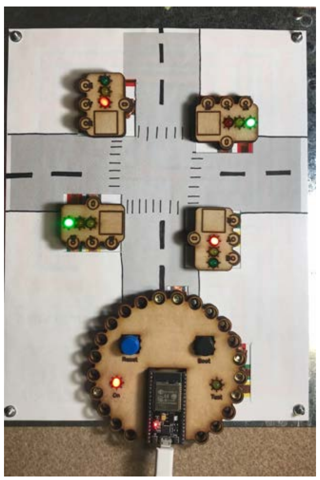

Figure 5: An exercise which includes a more sophisticated circuit: a traffic intersection. Our circuit has four traffic lights (with 3 LEDs each) and a microcontroller which provides the logic of the circuit.

Making reliable connections

For the fabrication of the connections between the screws and the magnets, we used 1/4 inch flat-headed screws with washers, nuts, and magnets of a diameter of 0.7mm or less. A coating of superglue around the circumference of the head of the screw and the magnet kept them in place. We applied superglue only to the outer circumferences, rather than the surfaces to prevent impedance of contact and conductivity between the materials, since each screw-magnet connection is an electrical terminal. Each screw-magnet connection (with its washer) was placed in a hole of the bottom layer and screwed in with a nut. We verified contact between the terminals of the components (e.g., legs of the LEDs) and the screw-magnet connections.

We glued the surface of the bottom layer with the inner layer. Further, we glued a magnet inside the central hole of the inner layer and another one on the small circle of the bottom layer. These magnets allow the bottom layer to be removable, since it is only connected to the inner layer by a central magnet, giving us modularity. Depending on the bulk of the component, it may require more than one inner layer.

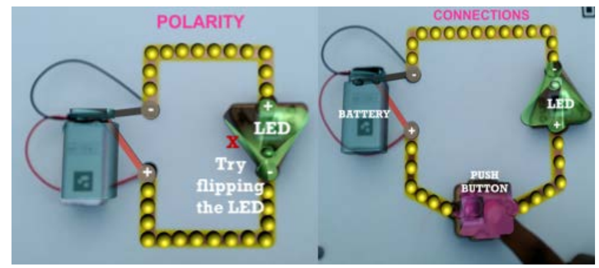

Figure 6: AR animations overlaid on ARbits. Left: AR provides feedback on an error due to polarity. Right: AR provides the instructions to create a pushbutton circuit.

For our demonstrations, we chose copper tape as the material to connect the components to each other (Figure 4). Also, all our circuits had an aluminum sheet underneath the paper to ensure stability of the connections (Figure 5). A more comprehensive guide with instructions will be included with the final vector files.

AR technology and learning

We have created several exercises and demos that we plan to test on future workshops aimed at children. Some of our short exercises include basic electrical circuitry concepts, which include connections in parallel, connections in series, a pushbutton circuit (Figure 4), polarity, circuit flow. We also plan to include more sophisticated exercises with a theme that can help children relate electrical circuitry learning to their everyday surroundings, such as a "circuit your own city". To this end, we have developed exercises including circuits for a smart building, a windmill, traffic lights (Figure 5), etc.

In circuitry learning, AR technology can be a great asset to provide instructions, feedback, and animations to children as they move along their learning process. In our case, we created the technology using Unity Engine and were able to track each component using the fiducial markers placed on the top layer. The process of creating the AR applications was simplified by the assets (CAD files) we had for each component. Thus, we explored applications that included basic instructions, such as how to assemble a pushbutton circuit (Figure 6, right). We also experimented with the application being able to provide feedback given common mistakes of a student. For example, if a student connects the terminals of a component incorrectly–thus misunderstanding the concept of polarity–then the AR provides a hint (e.g., visual, textual cues, etc.) to help students with the debugging process (Figure 6, left).

We envision that AR technology will be even more helpful as we move away from basic circuits and create more sophisticated circuits. Thus, AR will guide the children along and help them debug their own connections.

Conclusion and Future Work

In this paper, we designed a DIY, AR-compatible electrical circuitry toolkit for children. We envision that makerspaces can use our toolkit to produce many cheap and reusable electrical components. We plan to provide vector and CAD files (assets) so that the fabrication of the components and the creation of the AR technology is made simple for the instructors.

In the future, we plan to run several workshops at K-12 institutions or nurseries to evaluate children's experiences while using our toolkit during play and learning. We will conduct pre- and post-tests to gain in-depth understanding of the usability and usefulness of the toolkit from both the children and the instructors. Based on this feedback, we will add components and change aspects of the design to enhance efficiency and likability of our toolkit. We will also offer a workshop for instructors where we demonstrate how to fabricate and assemble the components.

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