Close the Circuit 'N Play the Electrons: Learning Electricity with an Augmented Circuit Exhibit

Elham Beheshti
Northwestern University
Evanston, IL 60208, USA
beheshti@u.northwestern.edu

Michael Horn
Northwestern University
Evanston, IL 60208, USA
michael-horn@northwestern.edu

David Kim
Northwestern University
Evanston, IL 60208, USA

Gabrielle Ecanow
Northwestern University
Evanston, IL 60208, USA

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Abstract
In this demo, we present *Spark*, an augmented circuit exhibit that enables visitors to make circuits using a set of tangible components and observe a simulation of electrons flowing through the circuit. Our goal is to use multiple representations of a circuit to help convey basic concepts of current and resistance. In *Spark,* the electron simulation and tangible circuit components are coupled using augmented reality techniques. We developed our system through a three-year iterative design process. We tested earlier versions of the design at a science museum with parent-child dyads and found that having access to the electron simulation could benefit children to better understand the concepts of electricity. We also observed that coupling the electron simulation through augmented reality can significantly enhance the learning benefits of the exhibit.

Author Keywords
Electrical circuits; multiple representations; augmented reality; agent-based modeling; design; interactive surfaces; tangible interaction; museum learning.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces - Interaction styles

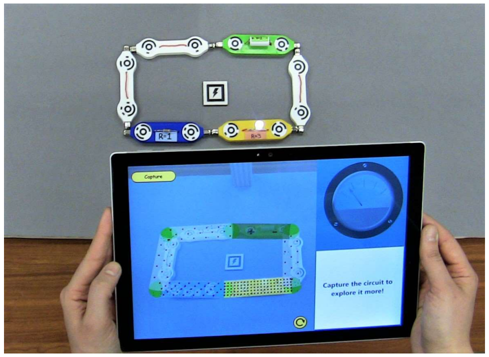

Figure 1. A demonstration of *Spark* Exhibit.

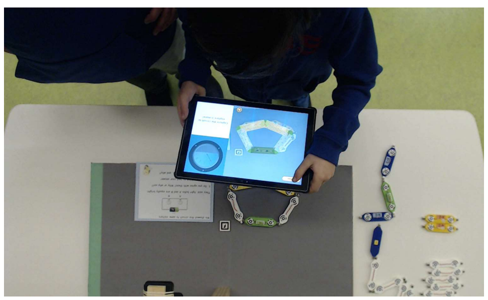

Figure 2. A parent-child dyad using the *Spark* Exhibit.

Introduction

In this demo, we present the design of *Spark*, an augmented circuit exhibit for science museums. *Spark* combines a physical circuit kit with a 3D visualization of current flow inspired by Sengupta and Wilensky's agent-based representation of electrical concepts [11]. Visitors can make circuits by connecting circuit components such as wires, batteries, resistors, and lightbulbs. They can then explore a simulation of electrons moving through the various components of their circuit. We used augmented reality techniques to display the simulation on a tablet computer that visitors hold above their circuit. This creates the illusion of peering inside the circuit (Figure 1). The primary goal of our design is to enhance children's understanding of electrical current and resistance by enabling them to develop meaningful connections between the electron simulation and the circuit components.

Related Work

There are several computational environments and activities that allow children to investigate simple circuits. Examples include the Circuit Construction Kit from the PhET project, which simulates the behavior of simple circuits [5]; and LightUp [4], which uses augmented reality to project a simple representation of current flow on top of an image of the physical circuit. NIELS [11] is an example of an agent-based modeling environment that shows how electrical concepts such as current and resistance emerge from the interactions between electrons and ions in a conductive material. NIELS directly inspired the design of electron simulation in *Spark*.

Contribution

Understanding the flow of current in electrical circuits can be challenging for learners of all ages. Research in Learning Sciences has documented a variety of mental models that novices rely on as they struggle with concepts like resistance and current (e.g. [6]). One promising strategy to help learners understand circuits is to provide dynamic visual representations of electrical concepts [11]. The primary goal of our design is to improve children's understanding by enabling them interact with two representations of a circuit: a collection of tangible components and a 3D visualization that shows the flow of current inside the circuit components (Figure 2). Our findings have implications for design of interactive exhibit environments.

Learning with Multiple Representations

Prior research suggests that using multiple representations can improve learning but that they are difficult to design and that learners might fail to gain from multiple representations if they are not carefully designed [1]. We use AR in our design to *dynamically link* the circuit components with the electron simulation to support an effective translation between the representations. Our findings from testing earlier versions of the exhibit offer insight on affordances of using augment reality in interactive exhibits.

Interaction with Tangibles

We are also interested in studying the effects of working with physical circuit components (tangibles) on visitors learning and interaction. Research has shown that physical manipulatives can support science learning [9]. Recent museum studies also suggest that physical manipulative are more inviting than their virtual counterparts [7,8]. The results of this study will

Figure 3. The physical circuit components in *Spark*.

Figure 4. The electron model display in *Spark*. The blue dots are moving electrons and the red dots represent ions in conductive materials. Resistors have higher ion densities than wires.

shed light on advantages and disadvantages of using tangibles in interactive exhibits.

Design of spark

Through a three-year iterative design process [2,3], we developed an interactive exhibit that enables visitors to construct circuits and then see a simulation of electrons moving through the various components. The system consists of two main components (Figure 1): a tangible circuit kit and an agent-based model of current flow.

Circuit Kit

The design of physical components is inspired by the work of Chan and colleagues on LightUp [4]. Similar to LightUp, the electronic components of the circuit are attached to each other with magnetic connectors. To detect the circuit components and render the corresponding electron simulation of circuit, we use TopCode markers [12] on both ends of each component (see Figure 3).

Electron Model Display

We developed a 3D visualization of current flow using Three.js [13], a browser-based JavaScript library based on WebGL. *Spark* electron model is inspired by NIELS simulation environment [10] and is based on Drude's free electron theory in which electrical current and resistance can be thought of as phenomena that emerge from simple kinetic interactions between electrons and ions in the conductive materials. A Microsoft Surface Pro 4 tracks an AR Toolkit [14] marker to display the electron simulation.

On the tablet display (Figure 4), visitors can tap on a "watch an electron" button to track the movement of a random electron through the circuit. Visitors can also tap on a component to see its electrical measures, a textual description about the component, and also a counter that shows the "electrons per clock tick" rate. This measure indicates how many electrons pass by the cross section of the component over a certain time, which is directly proportional to the measure of current in that component. Finally, visitors can zoom and pan the display using direct touch interaction or buttons in a toolbar.

Audience

We designed *Spark* to be used as an interactive exhibit in informal learning environments. The exhibit is intended to serve novices of any age to learn about electricity and electrical circuits. However, we consider children between the ages of 10 and 14 years old as our target users.

Evaluation

We evaluated the earlier versions of *Spark* at the Museum of Science and Industry in Chicago. Our goal was to investigate different ways to link the circuit with the electron simulation to support an effective translation between the representations. In one version of the exhibit (Figure 5), the simulation is displayed alongside a digital representation of circuit on the same multi-touch tabletop display. In another version (Figure 6), we used AR to display the simulation on a tablet computer that visitors hold above the tabletop display. We recruited parent-child dyads to evaluate these two versions of our design. We also included a control condition in which families could create and test circuits on a tabletop screen, but without the electron model. Our findings show that children gain from using the electron model, with children performing better in the AR condition. Moreover, our analysis suggests that

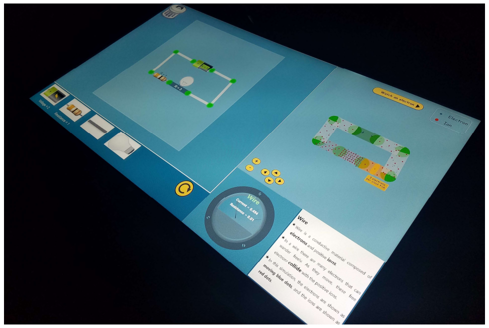

Figure 5. A single-display version of *Spark*.

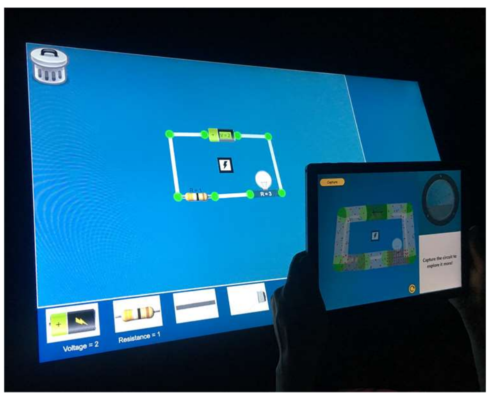

Figure 6. An AR version of *Spark.*

children in the AR condition were more likely to attend to the electron simulation and the behavior of electrons moving in the circuit.

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