MakerShoe: Towards a Wearable E-Textile Construction Kit to Support Creativity, Playful Making, and Self-Expression

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ABSTRACT

Electronic textile (e-textile) toolkits have been successful in broadening participation in STEAM-related activities, in expanding perceptions of computing, and in engaging users in creative, expressive, and meaningful digital-physical design. While a range of well-designed e-textile toolkits exist (*e.g.,* LilyPad), they cater primarily to adults and older children and have a high barrier of entry for some users. We are investigating new approaches to support younger children (K-4) in the creative design, play, and customization of e-textiles and wearables without requiring the creation of code. This demo paper presents one such example of ongoing work: MakerShoe, an e-textile platform for designing shoe-based interactive wearable experiences. We discuss our two participatory design sessions as well as our initial prototype, which uses single-function magnetically attachable electronic modules to support circuit creation and the design of responsive, interactive behaviors.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—user-centered design

Keywords

Construction kits, electronic textiles, e-textiles, wearables

1. INTRODUCTION

'Making' is a creative activity that spans traditional craft, engineering, do-it-yourself (DIY) culture, and emerging physical computing and fabrication technologies [2]. By lowering barriers and expanding the materiality of computing, construction toolkits such as *Scratch4Arduino* [13], *LilyPad* [3], and *MakeyMakey* [5] have broadened participation in digital-physical making activities. Electronic textile (e-textile) toolkits, in particular, have been successful in attracting underrepresented groups to STEAM-related activities [4], in expanding perceptions of computing, and in empowering users to engage in meaningful design that is creative, self-expressive, and personal [9]. While a range of well-designed and popular e-textile toolkits exist [3, 7, 10], they cater primarily to adults and older children and require both programming knowledge and a basic understanding of circuits. Though this complexity supports open-ended design—and thus fits Resnick and Silverman's desire for high ceilings and wide walls [12]—it also presents a high barrier of entry for some users.

We are investigating new approaches to support younger children (K-4) in the creative design, play, experimentation, and remixing of e-textiles and wearables without requiring the creation of code.

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Figure 1: MakerShoe is an e-textile construction kit aimed at engaging young children (K-4) in wearable design. **(a)** Using only a few modules, this MakerShoe buzzes and lights up during movement and turns on 'headlights' when it's dark. The bottom rows highlights a few inspirations including: **(b)** traditional light-up shoes, which are fanciful, fun, and responsive but not modifiable; **(c)** self-expression through fashion personalization (*e.g.,* Crocs Jibbitz shoe charms); **(d)** littleBits electronic construction kit [1]; **(e)** and the LilyPad e-textile Arduino [3].

This demo paper presents one such example: MakerShoe, an e-textile platform for designing interactive wearable experiences in shoes (Figure 1). With only a few components, children can build a wide range of designs, for example, 'headlight shoes' that automatically light a path in the dark, 'theremin shoes' that play tones depending on the distance to nearby objects, or even traditional 'light-up shoes' that flash with movement. While still at an early stage, we see MakerShoe not just as a platform for creative design but as a vehicle for self-expression and an introductory path to basic electronics, sensing, and actuation.

To investigate what interactive behaviors children want to design into their shoes as well as to better understand how children may conceptualize and use wearable, embedded electronics, we conducted two participatory design sessions with children. Informed both by these sessions and our own experiences teaching and building with e-textiles (*e.g.,* BodyVis [11]), we developed the current MakerShoe prototype. The prototype uses a littleBits-like [1] approach with magnetically-attached, single-function hexagonal modules that serve as *inputs, outputs,* or *modifiers*. For example, to create a 'light-up shoe' that responds to movement, the child designer would use three modules: (i) a power module that taps into the power rails embedded in the shoe; (ii) a 'tilt' input module that senses movement; (iii) and an LED output module that lights up when its input is 'on.'

Shoes offer an interesting substrate for e-textile design. Unlike robotic kits, for example, shoes are personal objects worn

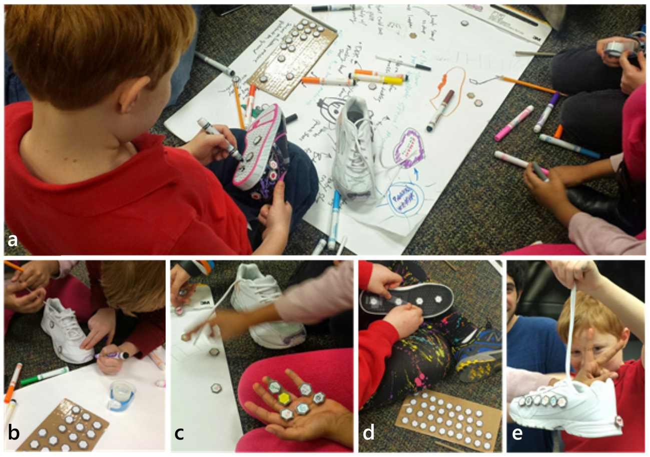

Figure 2: In the first CI session, adult and child teams co-designed their own MakerShoes using 'blue sky' methods. Materials included paper, markers, shoes, and hexagonal cardboard pieces that could be designed to represent functionality and attached to the shoe. For example, **(e)** shows a prototype shoe with a brake light that turns on when the wearer stops moving, a music button that teaches you how to dance, a pulse sensor, and an ice skate button that turns shoes into ice skates.

throughout the day. Young children often imbue their shoes with whimsical notions and powers (*e.g.,* "these shoes are really fast")—making them a compelling platform for interaction design. In addition, children tend to wear the same shoes each day, which offers interesting opportunities for self-expression and identify formation. Finally, shoes have room to package materials (like batteries) without affecting comfort and are not often washed (important for e-textiles).

As early work, we have more questions than answers including: How does MakerShoe engage children in the wearable design process? How will children approach, conceptualize, and use our system? What will children want to design and what can they design? How can MakerShoe scaffold learning of electronics, crafts, and computational thinking? Though we have implemented breadboard- and perfboard-based versions of MakerShoe, we are still working on creating a fully functioning prototype—namely, creating the shoe with embedded wiring and an attachment system. Still, we think there is value in sharing and receiving feedback on our ongoing work from the IDC community, including the findings from our two formative co-design sessions and highlighting our current design. We plan on completing a full working prototype by the IDC conference in June.

2. COOPERATIVE INQUIRY

To help inform the design of MakerShoe, we conducted two Cooperative Inquiry (CI) sessions. CI is a type of participatory design that focuses on the intergenerational partnership and collaboration between adults and children to brainstorm, design, develop, and test technology for children [8]. Our lab hosts weekly CI sessions where a team of six children (5 female) ages 7-11 and five adults (3 female) meet for one and a half hours, twice a week. All children had at least one year of co-design experience in our lab prior to our CI sessions.

For the first CI session, we used 'blue sky' methods to elicit unbounded ideas for interactive shoes. For the second, we used a modified off-the-shelf electronics kit (littleBits [1]) to explore how children would conceptualize, use, and understand wearable electronics. Both sessions followed the same format: children and adults sat in a circle to answer the "question of the day" (a method of transition into the session [14]), completed a design activity, presented designs, and, finally, discussed "Big Ideas" (where an adult synthesizes repeated, popular, and surprising ideas with feedback from the group [8]). Ideas were thus analyzed *in situ* during the CI session. A debrief occurred at the session's end.

Figure 3: In the second CI session, two co-design teams were provided with littleBits and shoes **(a)** modified with Velcro for attachment. Teams first examined and played with littleBits to build up understanding **(b-c)** before designing their own littleBits-based MakerShoes **(d-e)**. In the last co-design activity **(f)**, teams could create new functionality using everyday objects (*e.g.,* a watch) and cardboard (red for input, green for output).

2.1 First CI Session: 'Blue Sky' Shoes

The first CI session began with: "*If you had a shoe that you could customize to do whatever you'd like, what would it do?*" After a round of responses, children and adult design partners were divided into two groups. Each group received a set of low-tech prototyping materials: shoes, a set of blank adhesive cardboard pieces, a large Post-it easel pad ("Big Paper" [6]), and markers. In the design activity (Figure 2), groups designed different interactive behaviors on cardboard pieces and adhered them to the shoes (*e.g.,* a pulse sensor, a brake light, a button to share secrets with other 'MakerShoe' wearers). As a blue sky session, we did not limit the scope or feasibility of ideas.

Several recurring design ideas emerged: (i) being able to personalize the behaviors and look of the shoe (*e.g.,* change color to match clothes), (ii) adding gesture recognizers (*e.g.,* tapping heels together to activate special modes), (iii) adding games (*e.g.,* achieve a step count to unlock a special 'massage' mode), (iv) being able to program the shoe, and (v) and adding social/communication (*e.g.,* tapping toes for Morse code). One common theme across both groups was the ability to design/customize each aspect of the shoe, including the main canvas but also the tongue, laces, and bottom (*e.g.,* Figure 2d).

2.2 Second CI Session: littleBits' Shoes

For the second CI session, we were interested in exploring how children would conceptualize and use actual electronic modules to design wearable behaviors. For this, we used an existing modular electronic kit called littleBits [1], which we adapted with Velcro attachments to easily adhere to shoes (Figure 3). littleBits is a recent but popular commercial construction kit for prototyping electronics through an expansive library of input and output modules that connect magnetically. Similar to the first CI session, we divided the design team into two groups. Each group was provided with a shoe covered in Velcro, a set of littleBits modules including inputs (bend sensor, light sensor, sound trigger, pressure sensor, slide dimmer, oscillator, toggle switch, and roller switch), outputs (vibration motor, dc motor, fan, light wire, led, and buzzer), power (9v battery and cable), and cardboard to describe new functionality (red for input, green for output).

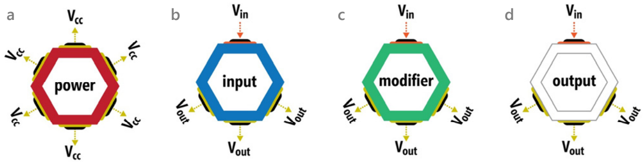

Figure 4: MakerShoe has four types of hexagonal modules: **(a)** power, **(b)** inputs, **(c)** modifiers, and **(d)** outputs. All designs must start with a power module: V_{cc} connects to a module's V_{in}. All subsequent modules connect their V_{in} to a preceding module's V_{out}. Thus, currently, V_{in} is both the supply voltage and the input signal.

Before breaking into groups we began with: "*If you had a shoe with a piece of existing technology inside it, what would it be and what would the shoe do with it?*" and provided a brief demonstration of each littleBit module. The design activity began with five minutes of exploration (Figures 3b and 3c) and then ~20 minutes of rapid prototyping with littleBits (Figures 3d and 3e). Groups then briefly presented their designs before engaging in a second round of rapid prototyping using the cardboard pieces with littleBits (Figure 3f). Groups once again presented their ideas and an adult synthesized the results of both prototyping rounds using 'Big Ideas' on a whiteboard.

For the first design activity, each group was able to prototype at least three unique designs. Recurring themes included the use of sound, light, and haptics, which children described with rich narratives that exceeded the behavior of the modules themselves. For example, the sound-generating modules were used to emit humorous noises (*e.g.,* "derp" noises as one walks), communicate with others (*e.g.,* messaging a friend's phone), and capture others' attention (*e.g.,* "get-out-of-my-way-horn shoe"). Light-generating and glowing modules were used to beautify shoes (*e.g.,* glowing shoelaces), increase visibility (*e.g.,* "headlight shoes"), and provide notifications (*e.g.,* light-up when your friend is nearby). Haptic outputs and actuators were used to make the shoe more comfortable (*e.g.*, "massaging shoe," "air-conditioner shoe").

For the second design activity, groups suggested several new modules for input—a pedometer, motion sensor, temperature sensor—and output—a drawing module, projector module, an LCD display, "bubble blowers", and "sparkle shooters." In addition, groups wanted the ability to combine sensor modules to create custom inputs, and activate multiple output modules simultaneously. In summary, while the ideas ranged in feasibility, there was a clear emphasis on customization, personal expression, and, particularly, designing experiences that reacted to the wearer and his/her surrounding environment.

3. MAKERSHOE DESIGN VISION

From the CI sessions, our own experiences with e-textiles and building early MakerShoe prototypes, and relevant prior work (*e.g.,* [1, 3, 12]), we synthesized the following design goals (not all of which have been met in our current prototype):

- **Support self-expression and personalization:** fundamentally, MakerShoe is about engaging children in the creative production and customization of new wearable designs that allow for self-expression, identity formation, and fashion personalization.
- **Responsive to the world and to the wearer.** MakerShoe should enable children to engage with their bodies (*e.g.,* their pulse), their movement, and their environment through sensing and multi-modal output (*e.g.,* sound, vibration, light).
- **Low threshold, high ceiling, wide walls**: extending from [12], MakerShoe should be approachable and learnable through play and experimentation but also allow for the creation of sophisticated, multi-faceted designs by more experienced users.
- **Simple and prevent costly errors.** Related to the above, MakerShoe should be simple in its design and should prevent costly errors (*e.g.,* short circuits) that would reduce approachability and playfulness.
- **Playful, fun, and educational.** Like many successful construction kits (*e.g.,* Lego Mindstorms, Scratch), MakerShoe should be fun to use, and should engage children in meaningful design experiences that also provide learning opportunities (in this case, related to craft, design, and electronics).
- **Programmable.** While we want children to be able to build a wide range of interactive experiences without programming, to help support a high ceiling and wide walls, our long-term aim is to incorporate simple Arduino-based programmable modules.

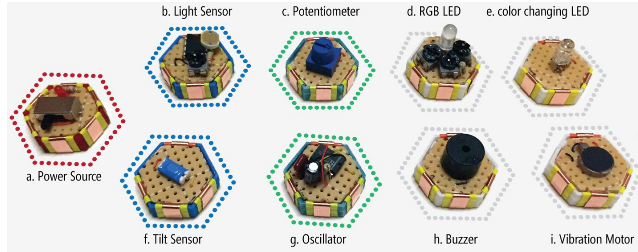

Figure 5: Our current module design is inspired by and extends littleBits [1] and includes nine modules. We plan to expand to a set of ~20 before conducting user studies. See the Conclusion and Future Work section.

4. CURRENT MAKERSHOE PROTOTYPE

The current MakerShoe prototype consists of two parts: (i) custom magnetic hexagonal modules and (ii) an e-textile shoe, which we are still developing, that provides power (V_{cc}) and ground (GND) via internal wiring, which is exposed along a hexagonal. Our current modular architecture is strongly inspired by littleBits—we have remixed their open-source designs from linear to hexagonal configurations and adapted the modules to a wearable context.

Hexagonal Modules. There are four types of modules: *power, inputs*, *outputs*, and *modifiers* (Figures 4 & 5). When placed in the correct orientation in adjacent hexagonal slots on the MakerShoe, the modules form a connection (*e.g.,* Figures 1 & 6). Power modules provide power to all connected modules, inputs sense and translate physical phenomena into analog signals (*e.g.,* switches, photosensitive resistors), outputs translate analog signals into perceptual forms (*e.g.,* sound, light, vibration), and modifiers transform analog signals into other types of analog signals (*e.g.,* oscillators, potentiometers).

Each module has one input (V_{in}, marked in orange) and one output duplicated on three sides (V_{out}, marked in yellow). The two sides next to V_{in} remain open and allow for tightly packed hexagonal configurations (*i.e.,* to avoid accidental connections between neighboring modules). The exception here is the power module where all six sides are output (yellow). Similar to littleBits, all designs must begin with a power module; however, our approach is unique in that the power module is not actually a direct power source (*e.g.,* a battery) but rather the only module to tap into the shoe's V_{cc}—which is available in each mesh and connects to the shoe's internal battery (Figure 7). All subsequent modules receive their power from the preceding module's output (the V_{out} connection) and also tap into the shoe's GND rail. This architecture forms the basis of our connected design[1]. Multiple power modules can co-exist on a shoe, enabling children to design many behaviors together on the same shoe (*e.g.,* Figure 1).

Thus far, we have created 9 prototype modules (Figure 5): 2 inputs (light sensor, tilt sensor), 4 outputs (vibration, RGB

[1] The *input* and *output* modules internally connect V_{in} directly to V_{out} and thus form parallel circuits. Modifier modules, however, translate the input signal (V_{in}) into a different output (V_{out}) and thus are hooked up in series. This distinction is not currently visible to MakerShoe users and is only provided here for explanatory purposes.

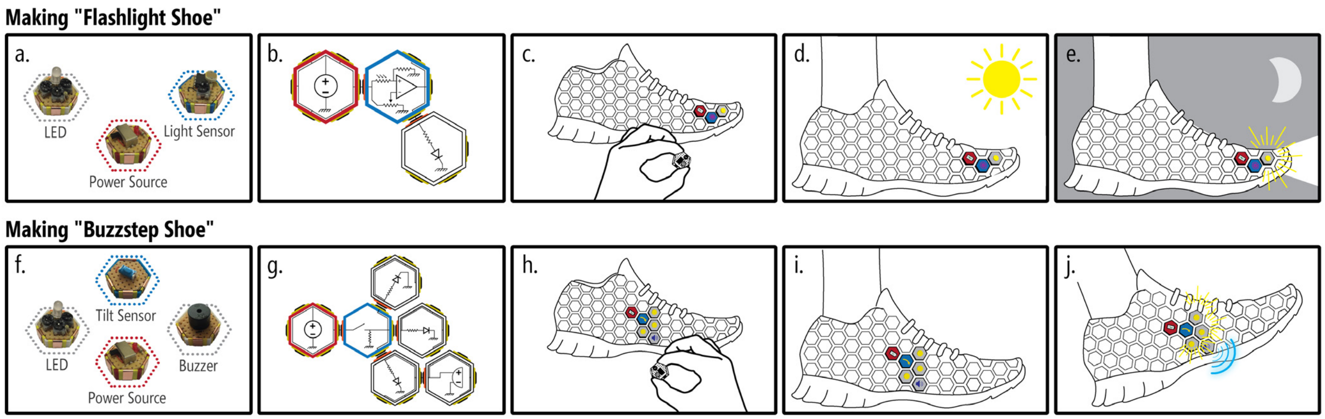

Figure 6: Example usage scenarios with MakerShoe showing the hexagonal modules **(a, f)**, the module schematics **(b, g)**, placing the modules **(c, h)**, and wearing the shoes **(d-e, i-j)**. With enough components, these scenarios could be designed in the same shoe (see Figure 1).

adjustable LED, single-color LED, buzzer), and two modifiers (oscillator, potentiometer). The current modules are 3D-printed with perfboarded electronics and copper tape for connections. Future versions will have a much slimmer profile with surface-mount components on flexible printed circuit boards.

Shoe: While we have not yet built the shoe, we have tested the underlying architecture using breadboards. Here, we describe our planned approach (Figure 7). The shoe will contain an embedded Lithium-Ion Polymer (LiPoly) battery embedded in the sole. Insulated stranded copper wires or conductive thread will distribute V_{cc} and GND to each hexagonal mesh slot. The hexagonal mesh will initially be made of flexible 3D-printed filament, which will stretch around the entirety of the shoe and provide secure magnetic slots for attaching modules. We also plan to experiment with embedding some sensors, which are not detachable but can be accessed by future modules (*e.g.,* flex sensor in the tongue, pressure sensor in the sole). Finally, one long-term aim is to design a 'retrofit' MakerShoe prototype that does not require a special shoe. This would require adapting our module design, providing a method to easily attach/detach modules to ordinary shoes, and adding a wearable 'battery' module for power rather than relying on internal power.

5. CONCLUSION AND FUTURE WORK

In this demo paper, we introduced our early work towards engaging young children (K-4) in designing, remixing, and customizing interactive wearable experiences for their clothes through a construction kit called MakerShoe. As early work, there are countless opportunities to explore, including: (i) participatory design sessions with younger children (4-7 years old); (ii) the development of the shoe itself as well as a retrofit version, as described above; (iii) providing tutorials that allow more advanced users to develop their own MakerShoe modules; (iv) expanding our module library with additional inputs, modifiers, and outputs, and adding more sophisticated modules such as a programmable Arduino and an adapter module that can interface with littleBits; (v) advancing our overall architecture including adding low-power and protection circuitry (*e.g.,* to prevent shorts, to turn off shoe after an idle state reached) and changing how modules are powered to prevent brownout; (vi) applying our approach to other worn objects besides shoes including hats, belts, and jackets; (vii) and, finally, running user studies with children (and novice Makers) to see how they use MakerShoe and what they can design.

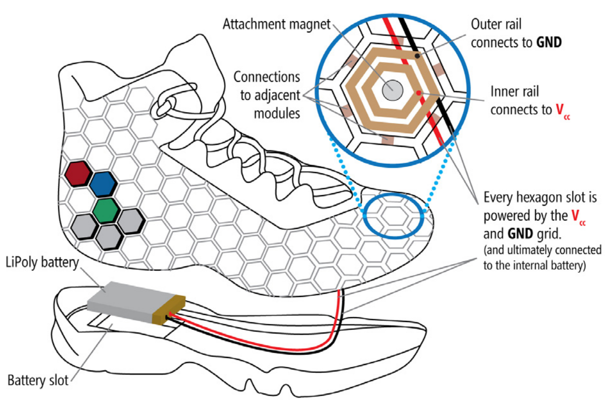

Figure 7: The MakerShoe shoe will provide a hexagonal mesh with magnetic slots to attach the modules. V_{cc} and GND are exposed at each mesh slot. Power is provided by an internal LiPoly battery.

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