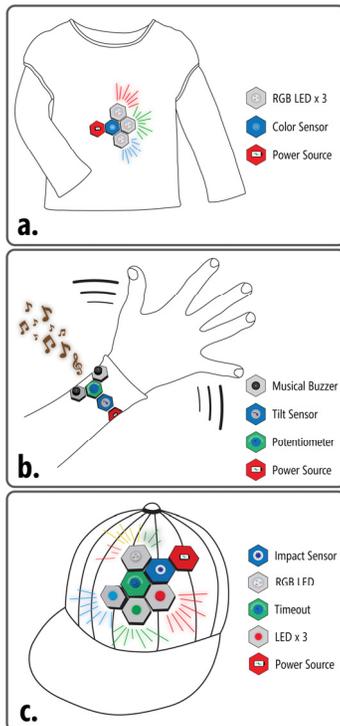


# ReWear: Early Explorations of a Modular Wearable Construction Kit for Young Children



**Figure 1:** With ReWear, children can create: **(a)** a ‘chameleon’ shirt that changes color based on surroundings, **(b)** a bracelet that plays different tones depending on arm position, and **(c)** a hat that flashes with movement.

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## Abstract

We present ReWear, a modular ‘plug-and-play’ construction kit for retrofitting existing textiles (*e.g.*, hats, scarfs, shirts) with interactive electronic and computational behaviors without sewing or the creation of code. While a range of well-designed e-textile

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toolkits exist (*e.g.*, LilyPad), they cater primarily to adults and older children and present a high barrier of entry for some users. ReWear is part of a larger research agenda, called MakerWear, that is aimed at engaging younger children (ages 4-12) in the creative design, play, and customization of e-textiles/wearables. We discuss our initial ReWear prototype, contrast it with past work, and describe a preliminary evaluation.

## Author Keywords

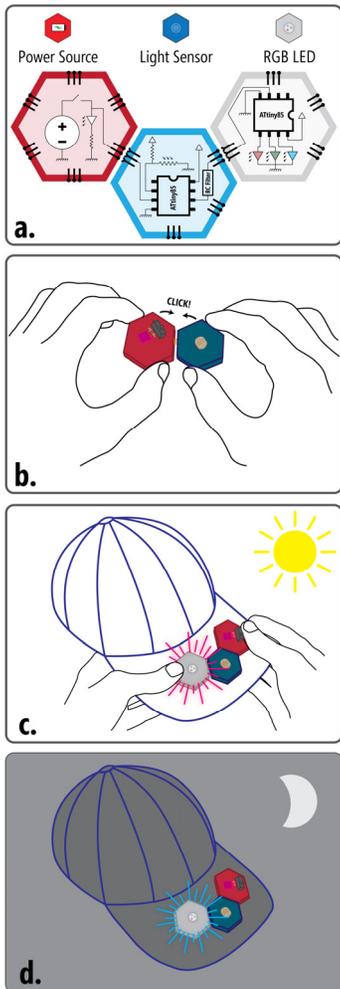
Construction kits; e-textiles; wearables; children

## ACM Classification Keywords

H.5.m. Information interfaces and presentation (*e.g.*, HCI): Miscellaneous

## Introduction

Electronic textile (e-textile) toolkits have been successful in broadening participation in STEAM-related activities [8], expanding perceptions of computing [16], and empowering users to engage in meaningful design that is creative, self-expressive, and personal [14]. While a range of well-designed e-textile kits exist (*e.g.*, LilyPad [5,8], Flora [1,2]), they are primarily targeted at older youth and adults and require programming, a basic understanding of circuits, and craft skills like sewing. Though this complexity allows users to create diverse and increasingly sophisticated designs—fitting Resnick and Silverman’s notion of “wide walls” and “high ceilings” [33]—it also presents significant



**Figure 2:** Making a hat that changes color based on ambient light levels: **(a)** electronic schematics, **(b)** connecting modules, **(c,d)** testing behavior.

challenges to young children and can impede rapid prototyping of ideas (echoing [12,13]).

Our research group is investigating new approaches to support younger children (ages 4-12) in the creative design, play, experimentation, and construction of interactive wearable e-textiles—a large, ongoing research agenda that we call *MakerWear*. We have been pursuing two simultaneous efforts, both of which utilize a custom modular ‘plug-and-play’ electronic approach: *MakerShoe* [18] and *ReWear* (**R**etrofit **E**-Textile **W**earables). While similar, the two platforms represent different research trajectories and distinct architectures. *MakerShoe* is a ‘blue sky’ platform, which allows us to explore ideas that require custom e-textile clothing (*i.e.*, special shoes with built-in wiring, power, charging circuitry). In contrast, *ReWear* (Figures 1 and 2) is a retrofit platform aimed at imbuing existing textiles (*e.g.*, hats, scarfs, clothing) with interactive electronic behaviors.

While many efforts exist to engage children in electronic construction (*e.g.*, littleBits [3,20], roBlocks/Cubelets [23,37]), clothing is a particularly interesting design substrate because, critically, constructions are *wearable* and thus, inherently social, mobile, and potentially always with the child. This creative context is fundamentally different from robotics or electronic kits, which are typically used and designed for static spaces (*e.g.*, classrooms). Wearables present new design challenges and opportunities related to the self, changing environments, social interactions, and daily life—*e.g.*, a ‘chameleon scarf’ that changes hue based on sensed nearby color, a ‘speedometer shirt’ that tracks and visualizes the speed of the wearer, or ‘headlight shoes’ that turn on in the dark.

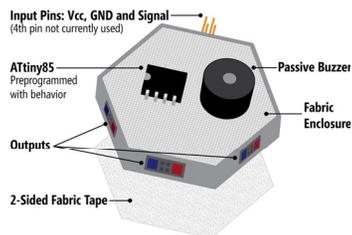
Our work thus far has been focused on two areas: first, conducting formative investigations to better

understand *what* types of interactive wearable behaviors children want to design and *how* children conceptualize modular, electronic kits; second, designing and developing *MakerWear* prototypes. As our recent IDC Poster [18] focused on *MakerShoe* and presented findings from two formative participatory design investigations with children, this paper’s focus is on *ReWear*—both its design and a preliminary evaluation with 9 children. As early work, our research questions are largely exploratory: How do children react to and engage with *ReWear*? What do they attempt to design and for what pieces of clothing? What aspects seem particularly promising or problematic?

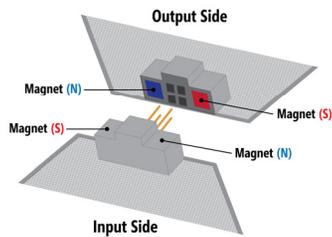
In summary, our contributions include: (i) the novel design of a modular ‘plug-and-play’ e-textile kit, called *ReWear*, aimed at engaging young children in creative making activities for their clothing and (ii) results from a preliminary evaluation with 9 children. Our findings should inform the design of future wearable construction kits as well as digital-physical kits more broadly—especially those aimed at young children.

### Background and Related Work

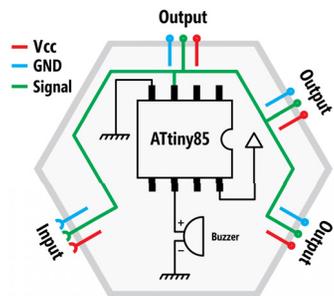
Our work is rooted in Papert’s theory of constructionism, which suggests a strong connection between design and learning, and posits that ‘remarkable learning’ occurs when children are working with materials to design, create, and invent external and shareable artifacts [15,31]. Learning through design and the dual influence of tools and materials on thought, which Papert called “objects-to-think-with” [31], has a rich pedagogical history dating back to Fröbel’s establishment of the first kindergarten in 1837 and the development of educational toys (known later as ‘Fröbel Gifts’). This physical, experiential, and playful approach to learning has since been adopted and expanded by educational innovators and scholars such as Dewey [11], Montessori [24], Papert [31], and



a. ReWear buzzer exploded view



b. A close-up of our connectors



c. Buzzer module electronic schematic

**Figure 3:** ReWear’s physical design and electronic architecture.

Resnick [32,35], and serves as the theoretical underpinning of our work.

ReWear is a type of construction kit—a creative platform, like LEGO or Erector Sets, that enables users to “design and create things” through interworking components [33]. Resnick [34] provides a useful historical breakdown: while early construction kits enabled children to build *structures* and *mechanisms* (e.g., towers, pulleys), more modern kits, called digital-physical kits, allow children to build *behaviors*. These digital-physical kits, including ReWear, often combine programming, physical materials and electronics for dynamic, reactive, and “smart” constructions (e.g., a car that follows a light). Typically, kits are aimed at supporting creative play, new types of design activities, and new learning experiences. Studies of robotic kits, for example, have found improvement in children’s systems understanding, critical thinking, and science process skills [38]. While robotics kits are probably the most common digital-physical kits (e.g., Lego Mindstorms [22], Cubelets [23]), others aimed at circuits (e.g., Lightup [9,19]) and computational electronics (e.g., littleBits [3,20], SAM [36]) are emerging, though not always targeted at children.

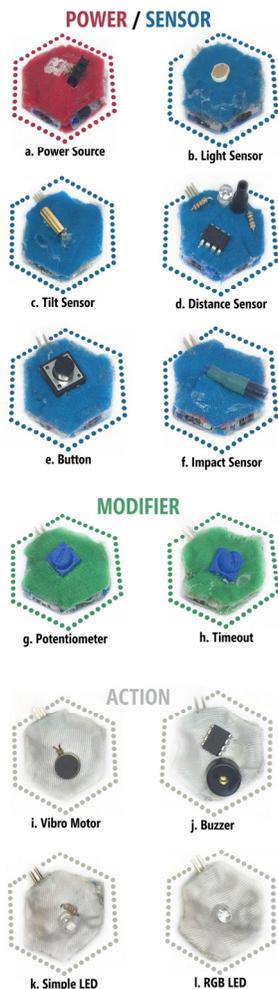
As noted in the introduction, clothing/wearables are a unique context that not only affords new types of designs, creative thinking, and problem solving but also attracts a potentially broader userbase compared with traditional digital-physical kits. Ngai *et al.* [27] found, for example, that underrepresented groups participated in e-textile workshops to a greater degree than in robotics workshops. For wearables, the most popular kits offer flexibility, transparency, and functionality, but also have high barriers of entry for some users (e.g., LilyPad [5,8], Flora [1]). More similar to our work are projects such as TeeBoard [26], i\*Catch [27,28], bYOB [25], Quilt Snaps [7], and EduWear [17], which

attempt to mitigate some of these barriers (e.g., by reducing sewing requirements). However, these kits are still aimed at older children and novice adults, do not allow for easy retrofitting, and have received limited evaluation ([27] is an exception), making it difficult to synthesize reusable design principles. Moreover, we are unaware of work that utilizes our swappable, plug-and-play module approach, which we believe better supports rapid iteration, experimentation, and a younger userbase.

### ReWear Design

Our prior work [18] enumerated six design goals for wearable construction kits for young children, which were drawn from participatory design sessions with children, relevant literature (e.g., [4,6,33]), and our own experiences building e-textiles (e.g., [29,30]). In summary, these goals include: (1) Supporting self-expression, self-exploration, and inquiry; (2) Reacting to the world and wearer; (3) Lowering the threshold of use while maintaining high ceilings and wide walls; (4) Reducing cost of errors for rapid iteration and experimentation; (5) Promoting playfulness while providing educational value; and (6) Providing extensibility through programming and a modular electronic architecture.

With ReWear, we have an additional design goal: the ability to augment any (existing) garment with computational/electronic behaviors. This requires a completely different approach from MakerShoe, which relied on specialized, custom-built clothing with embedded wiring, power, and pluggable sockets for modules. For ReWear, the main technical challenges are thus: How to power modules? How to connect them without embedded wiring in the clothing? And how to easily attach/detach modules to clothes to promote rapid design iteration? As ongoing work, we have not yet achieved satisfactory solutions to each challenge.



**Figure 4:** Our initial ReWear fabric module library, which we plan to expand based on results from our preliminary evaluation.

Below, we describe our current ReWear architecture, the initial module library, and some example designs.

**Modular Architecture.** Both MakerShoe and ReWear use a modular approach comprised of four module types: *power*, *action*, *sensor*, and *modifier*; however, ReWear’s underlying electronic architecture is unique (e.g., how modules are powered, connected, and how data is transmitted). All designs must start with a *power* module, which contains a tiny Li-Poly battery. The *sensor* modules sense and translate physical phenomena into analog signals (e.g., light levels, distance, movement), *actions* translate analog signals into perceptual forms (e.g., sound, light, vibration), and *modifiers* transform analog signals into other types of analog signals (e.g., potentiometers).

Modules are hexagonal in shape with 17.5mm sides with colored fabric enclosures that represent module type (Figure 3 and 4). Each hexagonal side is a potential connection point and connections are formed by snapping two modules together—a 3-pin male connector (output) to a 3-pin female connector (input). For example, the simplest possible fully functional design is a power module + an action module like an LED (which would always be on in this case). Small, neodymium magnets embedded on each input/output side help hold connections and physically repel incorrect links (e.g., if a child tries to put two female sides together).

The three connector pins and their function are similar to littleBits: *Vcc*, *GND* and *Signal*. Currently, modules can have only one input side but up to five output sides (with the exception of the power module where all six sides are outputs). The hexagonal shape allows designs to extend and branch into different non-linear forms (e.g., Figure 1). While two output *sides* cannot be connected, two action modules can connect to one another as all action modules forward their input *Vcc*,

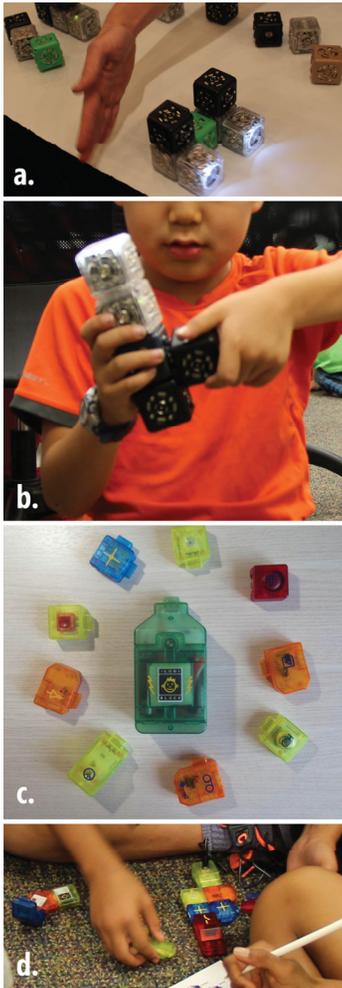
*GND*, and *Signal* to their output pins, enabling cascading designs.

Thus far, we have created 12 different modules (Figure 4): 1 power module, 5 sensor modules (light, distance, tilt, impact, button), 2 modifier modules (timeout, potentiometer), and 4 action modules (vibration, RGB LED, single color LED, buzzer). The modules are labeled with child-friendly names (e.g., the potentiometer is called a ‘tuner’ module). Six of the 12 modules contain embedded ATtiny85 microcontrollers to read, process, and, optionally, manipulate the *Signal*. For example, the RGB LED module uses the ATtiny’s ADC to read the input *Signal* and translate this into one of eight colors. A simple design with electronic diagram is shown in Figure 2.

We are still investigating approaches to allow children to attach/detach modules to their clothing. Ideally, the attachment mechanism would be robust, quick, and easy-to-use but non-permanent and non-destructive. We envision children quickly shifting back-and-forth between different work surfaces—a table or floor to prototype different behaviors and shapes and then affixing these designs to their clothes for testing. Currently, the back of our modules are covered by double-sided fabric adhesive tape, which allows children to quickly and easily attach/detach modules to their clothing but does not create a strong adhesion (especially to sustain the type of vigorous movement we hope to support) and also loses its adhesive quality over time. We have brainstormed other approaches (e.g., safety pins, fusible bonding web) but this remains an important open challenge.

### Preliminary ReWear Evaluation

We performed a preliminary, exploratory evaluation of our initial ReWear prototype in a single two-hour study session with 9 children (ages 6-11; 6 female). To help contextualize our findings, participants used three separate modular digital-physical kits (Figure 5), which



**Figure 5:** The two other digital-physical kits used in our evaluation: **(a,b)** Cubelets and **(c,d)** Logiblocs.

were placed at different ‘maker’ stations in our lab: (i) a robotics kit called Cubelets [23], (ii) an electronics kit called Logiblocs [21], and (iii) ReWear. The nine participants were split into three groups; each group had three children and two adult facilitators, which rotated stations every ~25 minutes. The first five minutes included an overview of that station’s kit followed by ~20 minutes of open-ended, creative play. For the ReWear station, we reserved the last 10 minutes for two small design challenges: (i) a hat that changes color with movement, and (ii) a bracelet that makes sound when the wearer’s hand is raised. Finally, after rotating through the stations, all of the participants reconvened to discuss likes/dislikes, design ideas, and their favorite kit. This discussion was summarized on a whiteboard by a facilitator.

#### Findings

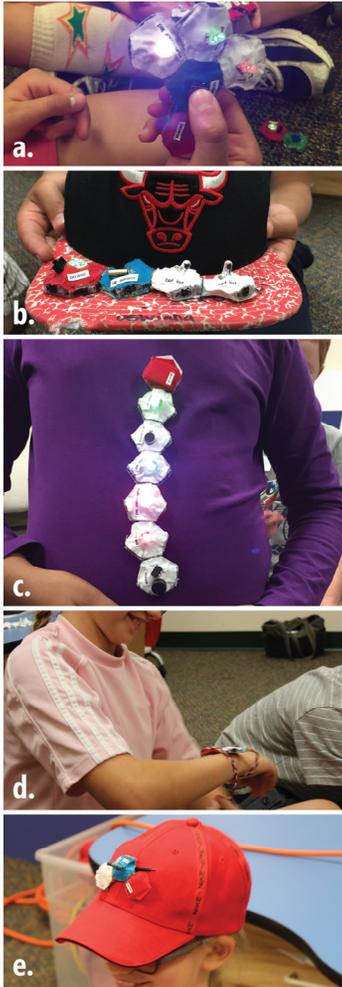
We collected video recordings and pictures of the making activities and the final all-group discussion. For analysis, we pursued a mixed deductive and inductive approach (informed by Chi’s 8-step process [10]). Two researchers independently analyzed video recordings and developed summaries with examples and photos. The researchers then met to discuss and co-interpret common themes. We summarize our findings below.

**Making Process.** For all three kits, we observed an iterative process of playful experimentation, ideation, creation, testing, and debugging. As children were in groups of three, the making activity was highly social and iterative, with children collectively brainstorming, problem solving, and critiquing designs. Some children would immediately dive into the making activity and experiment with modules. Others were more tentative, watching first before constructing. Sometimes a child would break off from the core group to focus on his/her own design but would soon return with a new design or insight to share.

The Cubelets and ReWear designs seemed considerably easier to iterate on compared with Logiblocs—perhaps due to their magnetic connections and swappable, unified modules. In contrast, Logiblocs come in many different shapes and sizes, with plastic, slotted connections that some found difficult to use (*e.g.*, to pull apart). With ReWear, we also observed a slightly different testing procedure that involved first examining a design’s behavior by manually simulating a wearable experience (*e.g.*, holding and shaking a design) before actually placing the design on clothing where it was tested again. Even before the design challenge, seven of the nine children tried to wear their creations (*e.g.*, on a sock, shirt, or pants).

**Common Problems.** Common problems across all kits included: difficulty comprehending specific module identities and behaviors (*e.g.*, “*What does this module do?*”) and misunderstanding the correct order of modules. With ReWear, we observed children putting action modules before sensor modules, forgetting that power modules needed to come first in a design, and struggling to understand some modifiers and sensors (*e.g.*, tilt sensor, timeout module). Unlike action modules, which could be directly attached to a power module to examine their behavior, modifiers and sensors required more sophisticated designs for testing. Some children brainstormed creations that would require combinational logic (*e.g.*, ANDing sensors), which we do not support. Others suggested a new ReWear module type, a *bridge*, that would function simply as a ‘wire’ between modules to allow for longer designs (both Cubelets and Logiblocs have these).

**ReWear Creations.** Children made a wide range of creations (Figure 6) from the simple—a button-activated wearable light—to the more complex—using an impact-sensor module and LED module to light up clothes upon a shoulder tap. Even for the simpler



**Figure 6:** Some example ReWear designs made during our study session with 9 children.

designs, children would provide backstories (“*whenever you score a goal, you would press the button and light up*” or “*this is a back massager*”). One child connected all of the action modules together to make her shirt simultaneously light up, vibrate, and buzz. Standing to show her design, she said “*Look at me, I’m beautiful.*” Another hid an RGB LED module beneath her scarf, which caused an interesting diffusion of light. After positive feedback from her group, she added a light sensor so that the scarf also changed color based on light levels. While making, verbal expressions reflected excitement and satisfaction: “*Yay, I’m shining!*”, “*You’re glowing!*”, “*You are magic!*”. Overall, children retrofitted socks, shoes, hats, pants, and shirts.

**The Design Challenge.** Two groups successfully completed both design challenges, while the third group completed only the hat. While some groups struggled initially to determine which modules were necessary to complete a challenge, they eventually arrived at a solution through discussion and experimentation. For example, one group initially used an impact sensor for the second challenge rather than a tilt sensor but discovered their error through testing. The group that did not finish both challenges ran out of time.

**Preferred kit.** At the end of the design session, we asked children to vote for their favorite kit: five chose ReWear (4 female) and four Cubelets (2 female); no one chose Logiblocs. Children who chose ReWear liked that it was wearable, simple but versatile, and easy to reconfigure. They also appreciated having multiple power modules that could be used to create and wear more than one design. For Cubelets, children liked that their designs could move autonomously and that it was also versatile. Logiblocs was perceived as, comparatively, too complex and the connections did not always work even when properly placed. Children also struggled with knowing what to design with it.

## Discussion and Conclusion

We introduced ReWear, an e-textile construction kit aimed at enabling young children (ages 4-12) to imbue their existing clothes with interactive, computational behaviors. Our preliminary evaluation demonstrated interest in our platform, showed how it could be used with minimal training to create fun, expressive, and interesting wearable designs, and uncovered problems that future designs should address. Below, we enumerate limitations and describe future work.

**Limitations.** Our small, exploratory study is useful for uncovering usability issues, identifying particularly promising or problematic design features, and studying initial impressions; however, more in-depth work is necessary to explore longitudinal patterns of use and sustained impressions. In addition, our nine participants (ages 6-11) represented only the mid-to-upper age range of ReWear’s target userbase and were recruited as part of a technology summer camp; they likely represent ‘expert users.’ Finally, our study design only included explicit design challenges for ReWear rather than for all three kits. This imbalance may account for some differences in engagement and feelings of satisfaction with ReWear.

**Future work.** As early work, there are countless opportunities to explore, including: (i) developing a more robust attachment mechanism for easily attaching/detaching modules to clothes; (ii) expanding our module library to address ideas that came up in our evaluation (e.g., bridge modules, investigate logic modules); and (iii) adding graphical icons and better labels to help children understand module functions. In the longer term, we hope to support programmable modules (similar to SAM [36]) and wireless debugging through an accompanying tablet application. Working with local partners, we also plan to perform longitudinal studies with a larger set of children.

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