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Infinite - an E-textile Toolkit for Fashion and Textile Designers

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Abstract

More fashion and textile designers are becoming interested in interactive technology, however, there is a lack of support for them to experiment or embed the technology in their work. There are a variety of e-textile toolkits made for engaging people from diverse backgrounds into electronics and computing (Buechley et al., 2008; Katterfeldt et al., 2009; Walusinski, 2008). Those toolkits reduce the complexity of circuits and target towards a more engaging learning dynamic for electronics and programming. However, they might not be suitable for designers as they often overlook the desire for harmony between aesthetic design and its functionality.

Purpose: In this paper, we introduce Infinite - an e-textile toolkit developed with a low entry threshold for designers who have no prior experience in electronics to use e-textiles in their designs, whilst also supporting functions that require more complex circuitry. The toolkit encourages designers to experiment with interactive technology from a material perspective and customize interfaces that can be better integrated with designs.

Toolkit and methodology: The toolkit consists of a microcontroller, small modular blocks of hard components that provide ready to use functions, a soft printed circuit board (PCB) that is made on fabric and sized 96mm*62mm, less than 1mm in thickness (*figure 1*), a range of conductive materials,

online sensor tutorials, sensor templates, toolkit instructions and code packages as supports to functions.

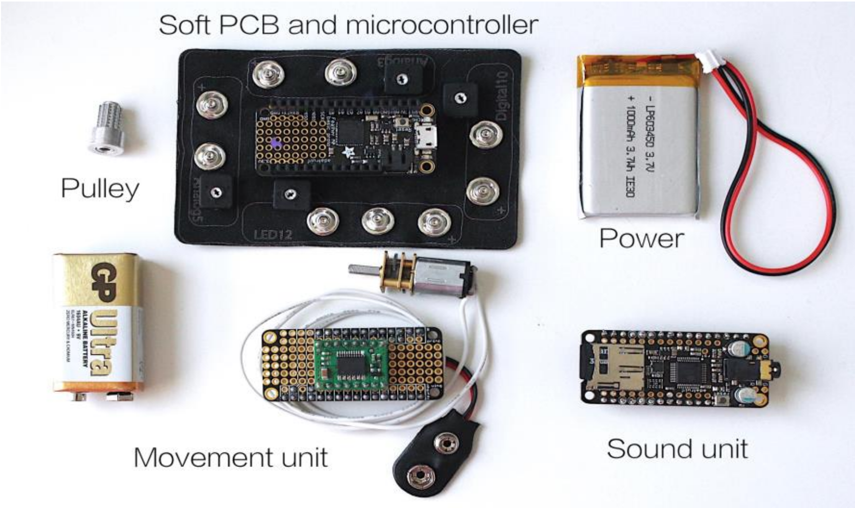

Figure 1. toolkit hardware elements

Each function is assembled with several digital components into a single unit. Designers can simply attach the unit to the microcontroller to complete the circuit, and upload the example code provided to achieve the function.

The toolkit provides a wide range of conductive materials to encourage customisation of interface in the context of physical designs. The online tutorials document step-by-step instructions of making e-textile sensors, sensor explanations and external links to sensors made with the same principles. The toolkit also contains a multi-layer fabric PCB that is light and flexible to be embedded in textile and garments. The circuits inside are constructed through copper fabric that provides a good conductivity. On the PCB surface, there are metal snaps on the edge that are connected to a specific circuit inside of the PCB, and designers can simply complete the circuit by snapping their e-textile sensors on the snaps.

To evaluate how well the toolkit achieves its goals of supporting designers' understanding and flexible use of technology, we conducted workshops to six fashion and textile designers interested in interactive technology. We invited them to make sensors and complete interactive prototypes with the toolkits in a given time. After the workshop, designers took the toolkits home and started their individual design projects with toolkits over eight weeks. Throughout the process, the first author had regular one-on-one meetings with each designer to provide technical support and track their progress. In the end, all designers successfully made their designs with embedded interactive systems that present a diverse use of simple functions and creation of interfaces.

We collected data through questionnaires, interviews and designers' diaries documenting both design and technical experiments over the eight-week design process. We also did ethnographic research on the workshops and one-on-one meetings, observing and taking note of designers' reactions and communication with the facilitator. We used thematic analysis to evaluate the collected data.

Findings: By evaluating designers' feedback and design process, we found that the toolkit's modularity significantly improves the efficiency of prototyping. The design results and designers' feedback suggested the sensor tutorial and conductive materials play an essential role in supporting open-ended textile interface exploration. Apart from e-textile sensors, the soft PCB can also support other sensors, such as light-dependent resistors. Therefore, the toolkit can be a gateway for designers to explore a broader range of digital components that toolkit itself has not provided.

By simplifying circuits and assembling components into units, the toolkit allows designers to create interfaces within their physical designs independently, and its flexibility allows for rapid testing and prototyping that contribute towards a better design result. Lastly, suppose design projects head into a more sophisticated technical development. In that case, the toolkit might become a foundation of more effective collaborations between designers and technologists, as it supports designers' understanding of technology, making them able to express their design intentions to technologists better.

Originality/Value: This research supports fashion and textile designers to design with interactive technology, encouraging technical exploration from a material perspective and in the context of physical designs. This research also delivers a design guideline for future e-textile construction kits which aim to engage novices to design personalised interfaces.

Keywords: Interactive technology; Fashion tech; E-textiles; Embedded systems; Personalisation; Smart Textiles; Wearables; Construction kits; Tangible; Creativity Support

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Introduction

Electronic textiles (e-textiles) are textiles embedded with electronic elements. They are structured through conductive thread, fabric and/or more conductive materials. E-textiles enable interfaces to be developed around the body, presenting soft and flexible features that other electronics cannot achieve (Stoppa and Chiolerio, 2014). As more and more fashion and textile designers have shown interest in interactive technology, e-textiles can provide them expanded design possibilities such as energy harvesting, responding to wear/environment and more.

However, it is time-consuming for fashion designers to experiment with electronics, an entirely new subject to their expertise. Although, the existing interactive fashion works were commonly done collaboratively between designers and technologists, related works pointed out communication difficulties in interdisciplinary collaboration (Seyed and Tang, 2019; Zeagler et al., 2013; Zeagler et al., 2017). Designers are less able to communicate their needs to technologists without basic technical knowledge, so the creative opportunity in collaboration might be lost, and the dependence on technologists might ensure functional projects, but it can also limit designers' divergent creative thinking and initiative in design. Therefore, we encourage designers to have a basic understanding of the potential of interactive technology to be used in design by hands-on experiments. This would help them initiate independent technical experiments in the early design stage and help achieve effective communication with technologists when they come to the collaboration for more sophisticated design projects.

In this paper, we introduce an e-textile toolkit developed with a low entry threshold for fashion and textile designers who have no or minor experience in electronics. The toolkit features modularity that enables users to quickly assemble or disassemble the technical functions by attaching or removing modules. It also features in material exploration, which encourages open-ended approaches in crafting interfaces from raw materials that result in personalization and rich exploration without preset constraints. We also evaluate whether the toolkit has achieved its design goals through user studies.

Existing e-Textile toolkits

A variety of e-textile toolkits have made technology easier to engage people in learning electronics and programming. Modularity is one of the most common features, reducing the complexity of circuits that users need to deal with. For example, the LilyPad Arduino kit is the first widely available e-textile toolkit (Buechley et al., 2013). It provides sewable microcontrollers, sensors and actuators that are assembled on round PCBs with petal-like electrodes allowing for sewn electrical connections which allows a more robust connection. FLORA, an open-source wearable electronics platform with a processor, has a similar appearance to the LilyPad Arduino, whilst providing detailed open-access online support and tutorials including code, wiring and other instructions (Learn.adafruit.com, 2020).

In contrast, there are toolkits encouraging personalization with a focus on material properties. Notably, Kit-of-No-Parts is an approach encouraging people to craft personalized interfaces from a diverse palette of materials without predetermined functions existing in the modular toolkits (Perner-Wilson et al., 2011). Their approach leads to a better understanding of material properties, which results in a more aesthetic and expressive technical exploration. Such an approach makes technology more understandable and apparent (Perner-Wilson et al., 2011). Building on this crafting approach is embelashed (Embelashed.org, 2020), a toolkit for prototyping embodied audio interfaces, which provides paper templates and online image-let tutorials guiding people to craft sensors from paper materials.

Prior works have explored how to support cross-disciplinary collaborations between fashion designers and technologists (Seyed and Tang, 2019; Zeagler et al., 2013; Zeagler et al., 2017). MakeFashion is a community that introduces wearable to fashion designers through hands-on designer-lead workshops, and pairs designers and artists with technologists to create fusions of light on fashion and performance (Seyed and Tang, 2019). The cross-disciplinary collaboration has been found difficult due to the lack of shared understanding in two different fields and poor communication across disciplines (Seyed and Tang, 2019; Zeagler et al., 2013; Zeagler et al., 2017). It is essential to build a shared language that allows a common understanding of design intention and visions (Mamykina, Candy and Edmonds, 2002). Seyed and Tang (2019) brought Mannequette, a prototyping tool for avant-garde fashion-tech garments that support sensor inputs and light-based outputs through a DJ mixer-like interface and they found the tool helps facilitate and support communication between designers and technologists in teams. Zeagler et al. (2013; 2017) used an e-textile swatch book to support interdisciplinary collaborations. It contains types of e-textile interfaces, by connecting swatches to laptops, users can interact with it. The e-textiles swatch book enables designers to understand types of interaction and how different the functional interactions could be through different forms of textile structure. The swatch book gives technologists and designers a way to discuss possibilities and identify design opportunities (Zeagler et al., 2013; Zeagler et al., 2017).

Toolkit Design

Glossary of Relevant Electronics Terms

Term	Description
Microcontroller	A small computer constructed by integrated circuits, they are commonly used in embedded systems. Arduino Uno is one of the most popular microcontrollers
Arduino IDE	Short for Arduino integrated development environment, a software used to write and upload programs to the Arduino compatible microcontrollers. For example, Feather M0 is Arduino compatible
Interactive systems	Computer systems that support the interactions between human and computer, the mapping of interactions is sensing - processing - actuating
Output	Actuation in response to the sensing signals being processed by the microcontroller
Sensing	Detecting changes from its environment through sensors, then sending data to the microcontroller to be processed. Sensing is also the input of interaction
E-textile	Textiles integrated with electronic elements, presenting textures and flexibility that cannot be achieved in traditional electronics
PCB	Short for printed circuit board, electronically connecting electronic components through conductive elements and etched on the non-conductive surface(s)
Analog sensors	Sensors that produce continuous signals for various parameters, for example, pressure sensors are to sense the amount of pressure acting on it
Digital sensors	Sensors that have binary output, which means they have only two states. for example, a switch has on and off states
Potentiometer	A variable resistor with an adjustable terminal. For example, a knob on the lamp controlling the amount of light could be a potentiometer. In the toolkit, we also use it as a positional sensor.

Table 1. Glossary of Relevant Electronics Terms

To understand the difficulties and intentions designers have in interactive technology and form an idea of how to better develop the toolkit, prior to the work reported here, we surveyed 16 fashion and textile designers who were interested or had some experience in designing with integrated interactive systems, asking about their interests and concerns in interactive technology. The result suggested that designers concern the electronics' size and texture, as these features determine whether the system can be well integrated into designs. From functional perspectives, movement, sound and light are the most demanded outputs, and touch and pressure are the most popular sensing types.

The survey gave us an overview of what functions and appearance need to be presented in the toolkit. Inspired by the modularity of the existing e-textile toolkits and the open-ended handcrafting interface approach of the Kit-of-No-Parts (Perner-Wilson et al., 2011), we aim to create the e-textiles toolkit to allow both easy access and free technical exploration with materials. Keeping mind that the targeted user group - fashion designers most likely have no electronics experience, but they require both aesthetics and functionality to be balanced in design. We proposed the following goals for the toolkit development:

- Easy to access without a background in electronics
- Allow for rapid prototyping
- Hardware can be integrated into textiles or garments
- encourage personalising interface in the context of fashion designs

The toolkit consists of kits, that are a set of physical objects needed to implement specific functions (*figure 2*), and tools to guide using the kits and support understanding in e-textile sensors.

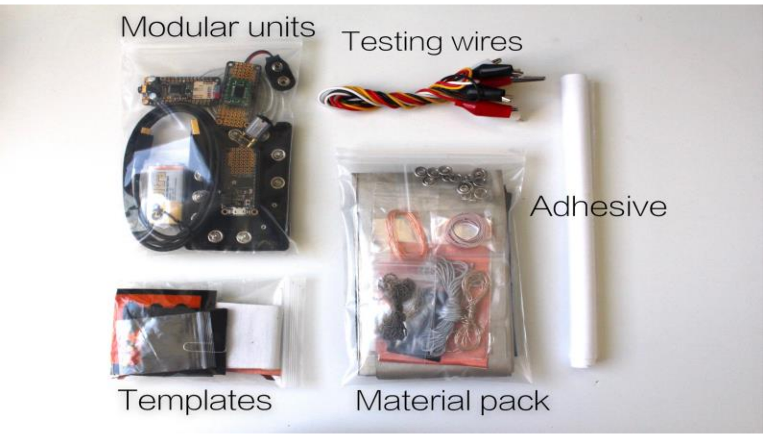

Figure 2. Physical parts of the toolkit

The Kit

We aim to provide movement, sound and lighting functions in the kit as the survey reveals that designers commonly required these outputs. For the microcontroller choice, although there are available boards that have a small scale and lightweight and allow for sewing electronics, we did not put any of those in options as they do not provide enough functional pins to accommodate the proposed number of outputs. Also, their sewable features make them inconvenient for prototyping. Keeping in mind that both scale and functionality are important, we decided to use Adafruit Feather M0 as the microcontroller due to its small size, and more importantly, it has an add-on attachment of a music player - Adafruit Music Maker FeatherWing, this would save our labour for constructing the sound output function.

We made functions into units by assembling the required electrical circuits and digital components on the prototyping boards that match the size and the pin design of Feather M0. Such constructions enable the function units to be fitly attached. So designers no longer need to wire up circuits themselves. Instead, they can simply attach the function unit on the microcontroller to complete the circuit. Figure 1 shows the toolkit hardware.

We assembled a dual motor driver onto the prototyping board to support movement function, which can control the maximum of two motors' speed and direction. A DC micro motor was connected to the motor driver through a 30cm conductive thread with isolated coating. A 9v battery snap was assembled on the prototyping board for connecting with power. Therefore the movement function becomes another ready-to-use unit to be attached to the microcontroller. Embedding the complex wiring into the unit makes the design iteration easier and helps adjust when the components break down.

For the function of lighting, we decided to use Lulu (Lulu.etextile.org, 2020), a toolset for implementing lighting on textiles and garments through side glow optical fibers. It contains light-scale PCBs designed for WS2812B MINI-3535 RGB LED, and the PCBs are designed with gaps for sewing conductive thread that wires up each LED and fixes components on textiles and garments. Optic fibre can be set on the edge of the PCBs where the LEDs are soldered. However, we did not receive the LEDs from the manufacturer in time, so the lighting hardware was not provided in the user studies.

To allow customised e-textile sensors to be connected with the microcontroller, a PCB with the layout for Feather M0 and sensor inputs is needed. Although there are many e-textile toolkits targeted to soft textiles or garments, few were designed into a soft texture. However, the survey result suggests the designers desire a soft texture of electronics, as a soft texture could make components better integrated on textiles and garments. Therefore, we proposed the following goals for the PCB design:

- maximumly simplify the circuit that designers need to deal with
- allow the mainboard and the function units to be removed or added easily
- provide easy and robust connections to e-textiles sensors
- enable better integration on soft surfaces

We designed the PCB with four series of connections, including two for analog inputs, one for digital input and one for RGB LED output. The circuit consists of laser-cut traces and pads of copper fabrics bonded onto a non-conductive fabric substrate (*figure 3*). Considering the resistance of e-textile sensors is determined by the choices of conductive materials, this can make the input vary widely. Hence, the PCB needs to provide adjustable resistance in the voltage-divider circuit. We used potentiometers in each sensor circuit, with default values to support the sensors created by the templates. With such a design, users can adjust the resistance for their circuit by turning around the knob on the potentiometer. The preset connections on the PCB would determine how to connect e-textile sensors to the circuit. We chose snap buttons as connections, as they are not only materials designers are familiar with, but also are conductive and can be easily assembled on textiles. There is another layer of non-conductive fabric glued onto the PCB to prevent accidentally damaging the circuit and short circuits. To make the PCB more explicit, we laser-printed instructions on the PCB surface, which divide snap connections into groups and mark each group as analog or digital connections. In addition to e-textile sensors, the PCB also supports some other sensors, such as a light dependant resistor and reed switch, etc.

Notably, to make the PCB texturally fit fashion contexts, the PCB is designed mainly through fabrics. Its thickness is less than 1mm and the size is 96mm*62mm. Unlike the traditional PCBs, this fabric-based PCB is flexible enough to be bent, so that it can be well embedded into garments. Figure 3 shows the appearance and the inside circuit layout of the PCB.

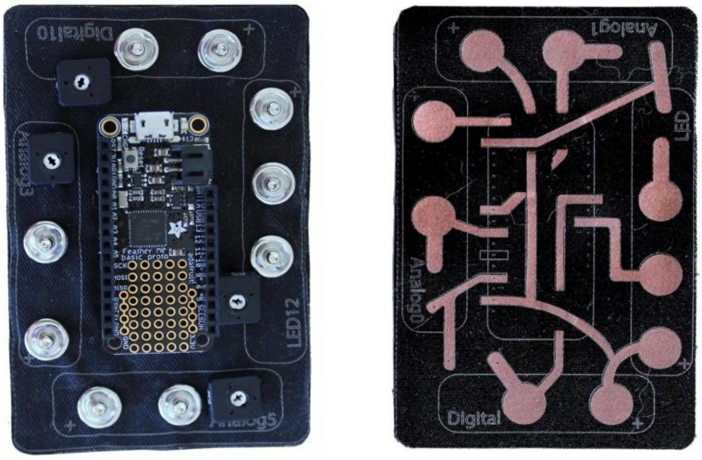

Figure 3. The appearance (left) and the insides circuit layout (right) of the PCB

Apart from digital components, we provide a large selection of conductive materials in a pack, including types of conductive yarn, thread, fabric, foam, copper tape and snap buttons. We believe the material pack is essential to supporting the freedom of e-textile interface exploration, as they have fewer predetermined constraints. Moreover, we encourage designers to also find any electrical conductivity within their own design materials. We believe materials play an essential role in building a flexible understanding and use of the technical knowledge acquired. With preferred materials, designers can decide the texture and the form of their sensors regarding their design content. The snap buttons provided are for constructing connections on sensors, so by snapping on the soft PCB, the circuit is completed. Besides, a set of crocodile clip leads is provided for quick testing and prototyping.

The Tool

The tool includes sensor tutorials and sensor templates to support the learning of the sensor principles; online instructions and code to guide the use of the kit and achieve the basic interactive tasks.

The online sensor tutorials document the principles and the step-by-step making process of four types of e-textile sensors, including switch, pressure sensor, bend sensor and potentiometer (*figure 4*). Each tutorial consists of a short introduction to the sensor, a picture of what the template sensor looks like, a graphic drawing and a text paragraph explaining its sensing principle, lists of materials and tools needed, step-by-step making instructions, and external links to sensor designs based on the same principle. The visual graphs are crucial to assist text description, as they support a more apparent explanation to technical knowledge and vivid process documentation to avoid the understanding issues caused by the technical terminology. The tutorials aim to make the knowledge and process as straightforward as possible, so designers could easily understand even if they do not have relevant experience.

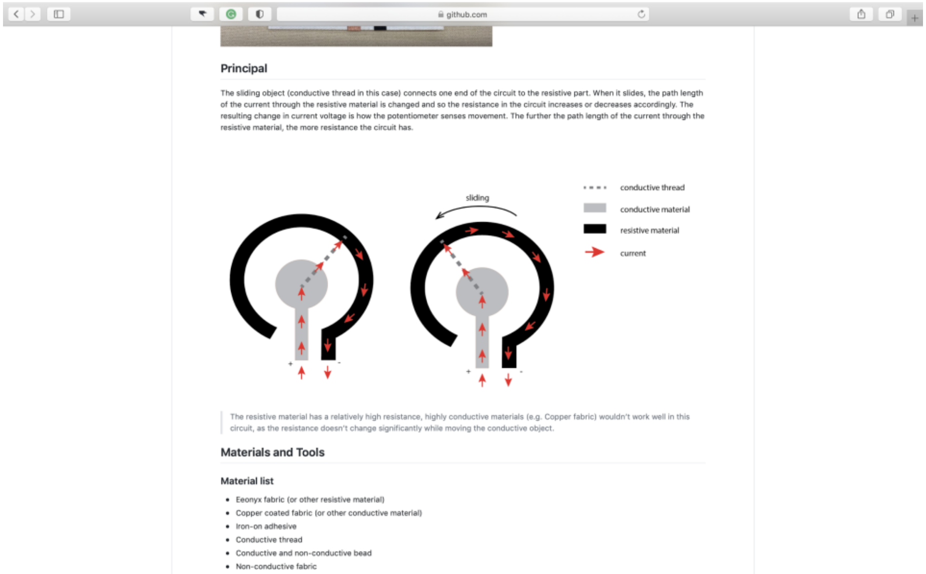

Figure 4. Online sensor tutorial

The laser-cut templates of the switch, pressure sensor, bend sensor and potentiometer are provided as supplementary learning materials to the sensor tutorials (*figure 5*). The templates allow designers to learn by making and embody the abstract technical knowledge into practices. As Perner-Wilson et al. (2011) noted in their Kit-of-No-Parts e-textile sensors workshops, it was proven useful to let participants recreate the sensor from their existing sensor collection, as it could be too challenging for participants to personalize sensors at the beginning. "So simply re-creating a design is a good place to start"(Perner-Wilson et al., 2011). Making sensors following step-by-step tutorials and templates leads to a good understanding of principles, which we believe would contribute a flexible use of technical knowledge and personalized sensor designs.

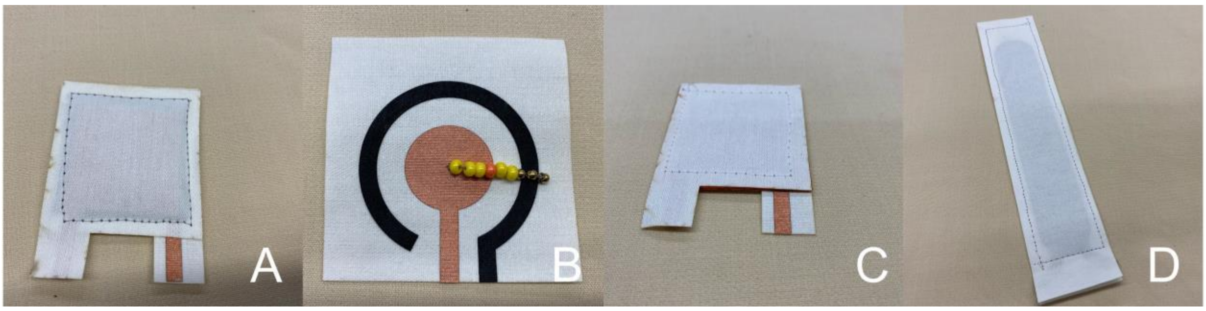

Figure 5. Template sensors: pressure sensor (A), potentiometer (B), switch (C), bend sensor (D)

To help get started with the function units, a series of online instructions is provided to guide downloading and installing environments on the Arduino IDE. The microcontroller and functional modules can be programmed with the Arduino IDE only with the compatible environments installed. There are tutorials for each function unit listing the straightforward steps of how to attach physical modules and how to operate the code to be uploaded to the microcontroller.

Following each instruction, we provide basic code examples for achieving interactions. For example, there are codes for processing signals from a digital sensor to activate a motor, and processing the signal from an analog sensor to trigger a sound and adjust its volume. Considering designers are most likely not familiar with coding, we try to make the instruction as straightforward as possible, and point out which part of the code contains parameters that can be edited to achieve a different outcome. For example, in the motor function instruction, we pointed to a line of code, and gave the explanation of parameters indicating which controls the direction and speed of the motor, and which controls the duration, with suggestions of the range of each value. In this way, designers do not need to spend the effort to deal with the code's complexity. Instead, they can adjust the motion by simply modifying the parameters without understanding the rest of the code.

Case study

To evaluate if the toolkit design reaches its goals. We firstly conducted two two-day workshops with one fashion designer, three textile designers and two textile designers coming from a fashion design background. In the workshops, each designer was given a toolkit. Then following the instructions by the facilitator, they made sensors using the template and online tutorials, tested the conductivity of their own conductive materials and the materials provided in the toolkit, designed personalised sensors out of raw materials, then they were given a task to complete an interactive prototype in three hours which were demonstrated at the closing of the workshop. The study took place under ethical clearance from Queen Mary University of London. Participants' designs, reactions, and conversations with the facilitator were recorded through photos, videos, and field notes. We also conducted interviews and closing surveys to collect designers' feedback.

After the workshops, participants were invited to the long-term exploration with the toolkit in which each of them created interactive textile/fashion projects over eight weeks. During the process, the first author had regular one-on-one meetings with designers in which she provided technical support if it was requested and took notes on designers' working progress. The designers were also invited to keep both design and technical diaries. We analysed the collected data through thematic analysis.

In this section, we will report a fashion designer's work and evaluate the feasibility of the toolkit in supporting fashion designers, and also discuss a textile design case that reveals how the toolkit can lead to a free and expressive functional interactive exploration in design contexts.

Fashion Design Case Study

Loy is a fashion graduate from the Royal College of Art who had some experience in wiring up simple circuits with batteries, but he did not have any experience in coding and constructing sensors or using microcontrollers before the toolkit study. He participated in both the workshop and the 8-week design project with a strong interest in embedded interactive technology.

Loy made a sleeve during the workshop, the soft PCB and function units are placed on the shoulder and connected to a side of a zipper used as a digital sensor - a switch. At the beginning of the workshop, Loy was taught to use multimeters to test the materials' conductivity. His idea was then informed while testing the materials placed on his desk, including both conductive materials provided in the toolkit and his own design materials. He found that the zippers that were often used at garment design have good conductivity. He then proposed the initial ideas of making the zipper into a switch or a positional sensor. The zipper can be used as a switch triggering shape changing on the garment, turned on or off by closing or opening the zipper. It can also be used as a positional sensor triggering and controlling a sound and its volume while sliding up and down the puller. Although the proposed ways of using the zipper as a sensor can take more effort to be achieved, we see this is evidence that Loy understood the sensor principles taught in tutorials and mastered flexible use when encountering different materials.

Due to the time and equipment limitation, Loy adjusted his original plan - by snapping the puller on the soft PCB placed on the shoulder, the circuit is switched on, and the motor is triggered.

In the 8-week design activity, Loy designed a project called Digital Interlink that is conceptualised as the future (*figure 6*). He imagined how people interact with the environment in outer space. The project consists of a pair of gloves and a potted "flower," presented by three rotatable round objects. Each glove's fingertips are covered with the conductive fabric, and they are also electrically connected with the circuit fixed in between the fabric layers. The pair of gloves structure eight switches, in either glove, by contacting different fingers with the thumb, the relevant circuit can be switched on. The LEDs are placed in the gloves to indicate the status of switches. Alongside the gloves, Loy made three rotating objects with three motors, on their surface, there are strips of copper tape. On the edge of each, three LEDs are distributed evenly, so the LEDs on the objects would be switched on and off while the copper stripes stick on the objects are rotated to a specific angle where they close the circuits. The three motors under each object are connected to the microcontroller, and they can be triggered by a switch that covers the function module. The circuit was buried under the soil, and the rotating objects are on the surface to represent the flowers, Loy explained the movement makes the "flowers" viable, giving a vibrant feeling of the imagined outer space.

Figure 6. Digital Interlink by Loy Chan

Figure 7 shows Loy’s design diary, and figure 8 shows his process of testing the conductivity with various conductive materials before project implementation. Unlike the popular e-textile toolkits, such as LilyPad Arduino and Adafruit Flora, which require users to understand circuits, digital components, and programming, our toolkit supported Loy to keep the focus on the design itself by encouraging material exploration and providing attach-on modular function units. Therefore it helped Loy spend less effort learning additional electronics and programming and guided Loy to start by testing and designing from a range of materials that are as familiar as prototyping a fashion project. The outputs are ready-to-use functions, so Loy can only focus on creating motions in projects by embedding the movement unit instead of worrying about wiring and programming. The toolkit embeds most technical efforts that are of little or no importance to designers but left open-ended space for designers to explore interface designs with a focus on materials freely. In Loy’s project, he explored interactions between gloves and hand gestures and achieved an interface that enabled eight inputs for eight common hand gestures.

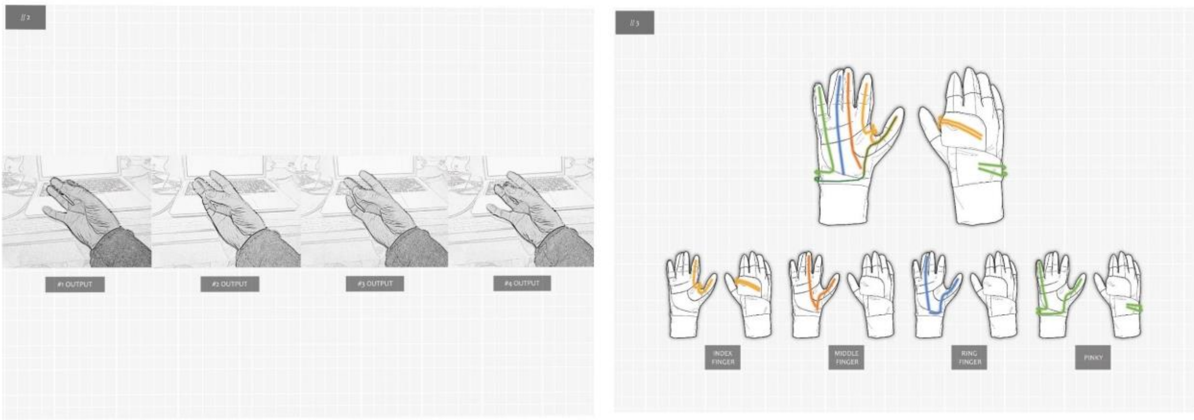

Figure 7. Loy's design diary

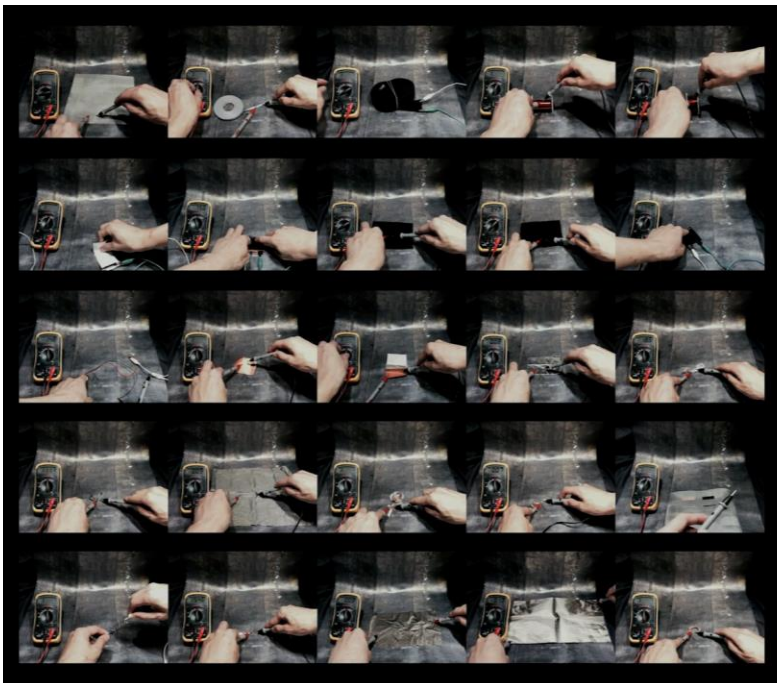

Figure 8. Material conductivity tests

Textile Design Case Study

Besides the fashion work, there are also textile projects presenting the diverse outcomes based on the single function provided in the toolkit. One example is the God Creation Project by Jiaxi Li, who is a textile student at the Royal College of Art coming from a fashion design background. She is interested in creating gallery-based interactive textiles but did not have relevant experience before the toolkit workshop.

The project is a series of floor-based knitted sculptural textile work (*Figure 9*). The movement function is for the dynamic effect and resulting sound through the bells installed in the textile design. Five pieces were designed with five different motions, including knocking metal pieces in sizes for different pitches; mechanical shaking left and right; mechanical rotating left and right; transporting metal materials through a spiral wire; wave rising and falling. Jiaxi designed and achieved all these motions using a simple rotating motor in the toolkit's movement function. Various parameters can be designed to achieve the variety. For example, a shaking motion could be achieved by creating a specific shape of gears. While the shaft rotates, the irregular rotating gears could push objects to move when it's at a particular angle. Modifying the speed, direction, and duration of the motor rotation in the code can also result in various movement effects.

Figure 9. God Creation Project by Jiaxi Li

Existing modular toolkits enable users to “plug and play” and lower the entry barriers for novices and even children. Our toolkit features such an easy access, and more importantly, it does not preset constraints, so designers are given a large space to design diverse expressive results. Jiaxi’s work presents an insight into how a single rotating motor in the movement unit results in multiple interesting movements on textiles. Based on the simple motor rotation, Jiaxi started by investigating how to shape and structure objects on the rotating shaft to achieve the desired motions. For example, Jiaxi structured a spiral wire on the shaft. When the motor rotates, the rotating spiral shape will transfer the object from one side to another. In figure 10, inside the structure the shaft was designed with bent extensions connected to poles, so when the motor rotates, the spinning extension will drive the poles to wave up and down. Figure 11 shows Jiaxi's design diary.

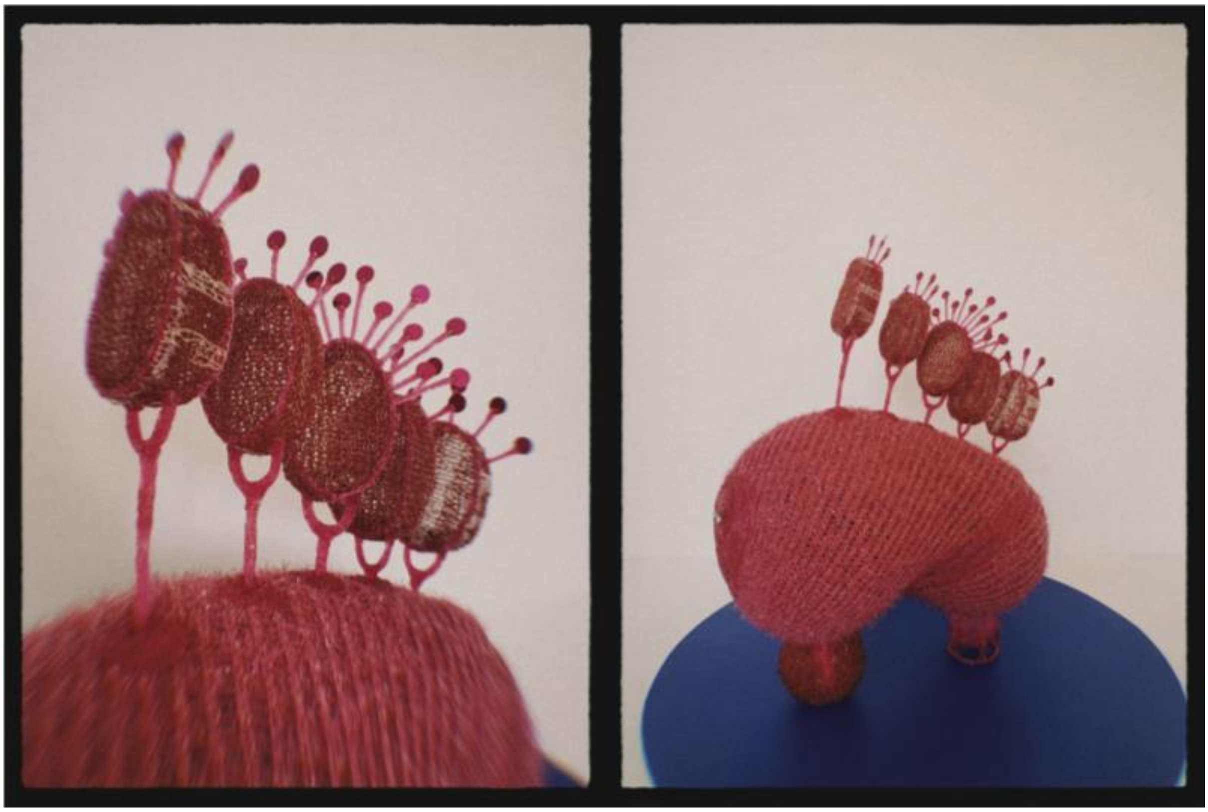

Figure 10. The piece with wave rising and falling motion

The code provided for the movement unit is also supporting creative expression. With the straightforward instructions of where on the code can be modified to change the speed, direction, and duration of motor rotation, Jiaxi independently modified the parameters on the code to get control of the motor. For example, to achieve the movement of shaking left and right, she modified the motor rotating duration for both clockwise and anti-clockwise, or to achieve the effect of transporting metal materials through the spiral wire, she made the motor rotate for longer for either direction. As Jiaxi reported in the interview, "the code provided for the movement function is sufficient, as it allows for many different outcomes by even only modifying the direction and speed."

Figure 11. Jiaxi's design diary

Finding and Future Work

Easy to access

Our toolkit study was conducted with designers who have no or minor experience in interactive technology. All of our previous participants reported that the toolkit was easy to use, and the steps in tutorials were easy-to-follow. Notably, the COVID-19 lockdown happened during our study, so the designers had to design more independently without in-person technical support from us. In the end, all of the participants successfully completed their interactive projects.

In the interview after the 8-week design project, designers reported the online tutorials were especially helpful when everyone was working from home. The tutorial explains principles by directing them to the sensor making steps that would ultimately result in personalised interface designs. And the images support the understanding of the text description by making it straightforward. However, some designers suggested if there were videos to document the step-by-step making process, the learning process would be even more efficient. The sensor templates guided designers to go through details in the tutorials, which built up a deeper understanding of the principal while making.

The tutorials try not to hide underlying technical knowledge that might be overlooked, and the online instructions explicit the technical details that might be obvious to technologists, for example, the way of uploading code to the microcontroller through Arduino IDE is a basic skill that does not need to be specified to a technologist, but in the toolkit instructions, such steps are well explained in case designers have trouble with it.

From the observation to the participants, we testified that the toolkit's physical part is easy to get started with. For example, breadboards have a mass of pins on the board and are often used in the prototyping stage of electronic engineering. The soft PCB replaces the complex wiring on the breadboard and transforms the circuit into a fabric layer between non-conductive fabrics, so designers would not be puzzled. All they need to do is to connect their sensors to the PCB snaps with marks directly pointing out which snaps to use. As designers reported, the PCB with the laser-cut instructions are beginner-friendly, so they can understand how to connect sensors in seconds.

The assembled functions free designers from dealing with the complexity of circuits. The existing modular toolkits either require users to have basic electronics and programming skills or provide “plug and play” solutions to reduce the entry barriers but maintain significant preset constraints. For example, ReWear is designed for children to achieve interactions by plugging function modules to the power source module. Our toolkit is designed into units to reduce the complexity of technical implementation that is unnecessary for designs themselves. More importantly, it provides a high ceiling that allows for self-expression without many constraints. The design cases revealed diverse outcomes using the same output function.

We provided example codes to each function and a brief guide of redefining the parameters of the output from the code. Designers reported that such guidance is straightforward that they can quickly edit the code and achieve their desired effect. A designer told us, the codes provided are just to the point, or it would be confusing if there are more options.

Allow for rapid prototyping

As we discussed above, the toolkit's modularity has assembled the most of circuit but only left connections for connecting to the sensors, and it largely simplifies the part of circuit designers need to deal with. As it saves the effort from building up the circuit, designers can achieve different functions in minutes, so the prototyping efficiency is improved. Also, by embedding the complex wirings into the PCB and the modular units, the hardware's aesthetics improved.

There are adjustable resistors on the soft PCB. When the circuit needs a smaller or bigger resistance for specific sensors, the resistance can be adjusted by rotating the knob instead of replacing resistors from the circuit. A set of crocodile clips wires are provided for more convenient prototyping. By clipping each end to the PCB snap and the sensor, the circuit is completed. When designers decide which sensors to use, they can then replace the wires with the snap buttons provided in the material pack.

From our observation, the modularity largely enabled rapid prototyping. Designers simply attached or removed the function units on/from the PCB to complete or disconnect the circuit. They can achieve functional interaction easily.

Encourage self-expression

The toolkit encourages open-ended interface exploration with raw materials. We found that providing conductive materials and requiring designers to pay attention to their own materials enable free interface exploration. We do not offer premade sensors that can be grabbed and used, instead, designers are situated in various materials, being taught with the sensor principles, they can create a diverse interface in the context of their design which is not limited to shape, form, and materials compositions. For example, the fashion designer found the conductivity of the zipper. Then he made the zipper into a sensor while also maintaining the zipper's original function. There are textile designers crocheting or knitting the conductive yarn and thread with their non-conductive material, and making textiles into different types of sensors. The toolkit, therefore, leads to designers' flexible use of technical knowledge with their expertise.

The material exploration the toolkit encourages helps designers build an understanding of technology from a material perspective. They feel materials, find conductivity out of their own materials, and construct textile interfaces using textile or garment construction techniques. The tangibility also allows them to explore how the structures of interface would influence its functional interaction. With a clear understanding of the feasibility of materials and how their properties relate to the potential functionalities, designers can better integrate digital technology in designs rather than using technology as an add-on object that might be an addition to design itself. A good understanding of material properties and flexible use of function units enable designers to balance aesthetics and functionality on designs.

Apart from material exploration encouragement, the toolkit's modularity made technology much easier to use and maintained the open-endedness. For example, the motor rotation is a basic output directed from a movement unit, but it allows designers to create multiple motions beyond rotation by designing shapes and accessories on the shaft. This also encourages an in-depth investigation of materials and structure of fashion or textile designs themselves. The straightforward code instruction cut to the essential point without drawing sophisticated and less important parts of the code, improving designers' custom control of the movement effect.

Through the toolkit, designers have learned the basics of e-textiles and interactive technology, knowing the mapping of interactions and essential points contributing to interactive systems. Therefore, we assume in cross-disciplinary collaborations, they can communicate their design intentions better to technologists and initiate and keep track of the technical development throughout the whole design process.

Insufficiencies

<u>Wearbility</u>

Although we have tried to make the hardware as small as possible, it is still too chunky to be embedded into wearable projects. The fashion designer attempted to place the hardware on the sleeve, but its thickness became a barrier to be embedded naturally, neither in his 8-week project, the hard components were separated from the glove design. The designer suggested a thinner technical design can be much better even if it might be wider than the current. The thick and heavy hardware could be a burden when it is structured with garments and reduces aesthetics. However, the fashion designer liked the soft PCB design, as he commented: “the soft PCB is really built with a fashion and textile language” the snap buttons and fabrics translate the traditional electronics into a textured and flexible interface.

Although the toolkit’s modularity supports fast prototyping, its predefined units also have their constraints. For example, they need accessories to allow the attachment, which enlarges the scale. We propose the toolkit could be used in prototyping stages, where designers could build up technical knowledge with their material expertise. When it comes to a greater design that might need collaborations with technologists, the toolkit can assist interdisciplinary communications, which ultimately contributes to a design that coordinates both functions and aesthetics to the best extent.

<u>Safety</u>

The soldered elements on each module were found fragile to be used in soft projects. For example, the fashion designer’s motor connections were broken when he tried moving the sleeve. Future development needs to build more flexible and robust connections between hard components and soft materials.

In the end, we want to emphasize electrical security. Misoperation to the circuit might damage textiles and burn wearers, or even cause a fire hazard. Although we pointed out that the batteries need to be disconnected when circuits are not in use, some participants kept the circuit powered and left it aside while doing other tasks. Then they found the board and battery were too hot when they wanted to use the board. Future work needs to provide a self-isolation device or resettable fuse to ensure a secure circuit even if it keeps connecting to the circuit.

Conclusion

We introduced an e-textile toolkit, which aims to support fashion and textile designers to use interactive technology. The modularity of the toolkit integrates the complex circuits inside of units and enables easy access and rapid prototyping, while the toolkit also provides tutorials and raw materials to encourage open-ended interface exploration. In the user studies, designers successfully made their interactive fashion/textile projects that present success in technical implementation and the integration of designs.

We found from study participant feedback and observation that the toolkit has mostly achieved its goal: 1. It is simple to use that designers can quickly get started, and the image-led online tutorials make the technical knowledge straightforward. 2. The modularity allows rapid prototyping, as interactions can be achieved by attaching function units on the microcontroller and clipping the sensor on the soft PCB. 3. By exploring materials, designers learn to leverage their material expertise in technology, which leads to better integration of technology and materials. We found the wearability of the toolkit is weak due to its thickness. For future work, more effort is needed to reduce the scale of modular units. As the toolkit helps designers build understanding and flexible use of technology, we propose that the toolkit can also support interdisciplinary communication if projects require collaborations with technologists.

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