



DanceBits 'It tells you to see us': Supporting Dance Practices with an Educational Computing Kit

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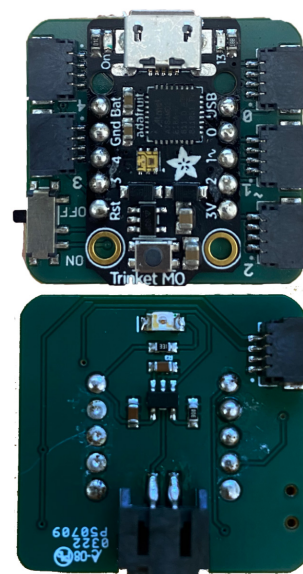
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(a) Dance instructors pose in rapidly prototyped costume concepts created with DanceBits



(b) DanceBits Microcontroller Board Front and Back

Figure 1: DanceBits Dance Wearables and Microcontroller Board

ABSTRACT

Wearable electronics expand the ways learners can create with computing as they gain proficiency with programming and electronics. Dance is one domain where wearables can support creative, embodied practices in computing education. However, wearable

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electronics need to be small, durable, and easily integrated into clothing to meet the constraints of dance contexts. These features are challenging to achieve, especially when working with novices. We present *DanceBits*, a wearable prototyping kit for dance that was co-developed with a justice-oriented, computing and dance education organization. DanceBits' plug-and-play system uses small PCBs with solderless connectors to support dancers in rapidly designing, building, and performing with electronic costumes. Our user studies exploring the system with dance instructors and youth participants show that DanceBits enabled fast development of wearables, offered users a breadth of expressivity through computational and choreographic choices, and empowered dancers to see wearables as a tool for developing their movement practices.

CCS CONCEPTS

• **Social and professional topics** → **Computing education**; • **Applied computing** → **Performing arts**; **Electronics**.

KEYWORDS

Physical Computing Education, Dance Education, Wearables, Creative Computing

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1 INTRODUCTION

Wearable electronics have made it possible to connect electronics education with creative expression in visual arts, fashion, performance, and craft [5, 6, 15, 29, 33]. When developed with learners in creative environments, wearable technologies have the potential to make STEM and computing education more inclusive and interdisciplinary [8, 34, 35]. That said, novices may find that getting electronic prototypes to function reliably on a moving body is both time-intensive and physically difficult. Prior work in educational wearable electronic kits falls mainly into two camps: *from scratch prototyping kits*, like the LilyPad Arduino [5], which often include electronic-textile (e-textile) materials that learners use to sew or otherwise craft connections in their circuits; and *rapid prototyping kits*, like the i*CATch System [26] that use prebuilt elements to reduce circuit construction time. These two approaches offer different learning affordances, which may be appropriate to different educational contexts. *From scratch* kits often offer opportunities to engage in low-level electronics learning, but also limit the complexity of electrical components that can be used, while requiring a significant amount of time for circuit construction. With skill, time, and effort they can be developed into final products. Kits for rapid prototyping emphasize accessible prototyping and reusability, but they are not typically designed to transition into a "camera-ready" final product. *DanceBits* is a novel addition to the wearable rapid prototyping landscape that facilitates both iteration with electronics and integration into performance-ready interactive costumes.

DanceBits is a custom wearable learning kit that we designed to support rapid prototyping in ways that met the needs of our community partner, STEM From Dance (SFD). SFD combines dance and STEM education to provide unique learning opportunities for girls of color across various U.S. cities. Their educational programming requires wearable technology that can be built quickly, function reliably in a dance context, and look great on stage. This emphasis on performance-readiness is integral to supporting authentic dance practices. STEM From Dance's final showcase is a public-facing performance that serves as a foundation of their community- and confidence-building work with youth participants. In this paper, we present the *DanceBits* kit design along with two usability studies that were run with five youth participants and six instructors from SFD, respectively. We explore the research question: *What design decisions within a wearable electronics kit are important for*

supporting authentic dance practices while learning about computing? We specifically explore how the design decisions within the kit impacted: (a) users' breadth of computational and choreographic expressivity (b) their ability to create synergies between their technology and choreographic choices, (c) their experience integrating computing components into clothing, and (d) how the computing components functioned in both the prototyping and performance contexts.

We show how participants were able to leverage *DanceBits*' expressive capabilities by distributing sensors across their bodies, emphasizing the benefit of peripheral components over sensors grouped onto a single microcontroller board. We highlight how, compared to from scratch systems, *DanceBits*' solderless connection system reduces the overall construction time of wearable costumes, which frees up time for iteration and for bidirectional learning across the engineering, computing, and dance disciplines. That is, not only does the performance context create opportunities for culturally relevant learning about electronics and code, but the wearable technology may also become a dance learning aid. We also report the main challenges we encountered, including reaching a performance-ready aesthetic, supporting robustness in the construction process, and managing on- and off-body construction.

2 BACKGROUND

2.1 Educational Wearable Kits

Educational wearable kits can be divided into two camps: those that support low-level circuit construction "from scratch," and those that use "plug-and-play" interfaces to support faster iteration and rapid prototyping. Educational research involving from scratch e-textiles have demonstrated efficacy in teaching computing skills, broadening perceptions of engineering, leveraging a range of craft skills within a computing environment, and supporting engagement between learners and their communities [17, 18]. Time is often dedicated to circuit construction and to learners' creation of personally meaningful designs. Constructing circuits with e-textiles directs learners' attention toward how electricity flows between components, supporting learning that is typically scoped to concepts such as shorts, power, ground, and the polarity of components [30, 32]. The use of conductive thread and sewing to make circuit connections can limit the complexity of learners' projects, however, as it is time-intensive, requires fine motor skills, and introduces extra electrical resistance.

Plug-and-play rapid prototyping kits black-box elements of wearable circuit design by providing prebuilt parts, such as snap connectors, that eliminate the need for soldering or sewing. This practice limits some aspects of electronics learning, however it also frees up time for iteration and increases reliability of electrical connections. In the context of SFD, where creations made by learners will be used in a live performance, black-boxing can expand expressive options by enabling learners to explore a broader range of inputs, outputs, and design decisions. While rapid prototyping kits enable open electronics exploration, additional skills are required to transition designs into a durable, attractive final product. The transition from prototype to final product requires extra attention when supporting a culturally relevant or sustaining experience, where learners' creations need to be in line with legitimate practices within a discipline

or community [2, 21]. In the dance context, for example, learners' electronic creations need to look great, withstand a range of movements, and perform reliably on stage. Through our examination of DanceBits, we draw attention to the tension between designing tools to support educational exploration and the development of hi-fidelity outputs.

2.2 Custom Connector Systems

As noted above, the Lilypad Arduino [5, 6] and subsequent innovations in e-textile materials [31] enabled learners to use flexible, sewable materials in wearable designs. Because sewing circuits can be time-consuming and difficult [32], alternative connector systems have proliferated. MakerWear [20] and the related ReWear [19] both use "a flexible, magnetic socket mesh that is either pre-integrated into clothing or attached post-hoc like a fabric patch," allowing users to easily plug in magnetic components. These systems are highly visible and are not designed to aesthetically fade into the background. Other plug-and-play systems alleviate the need for users to lay out circuit connections with thread by using either prefabricated base garments with buses laid out similar to a breadboard [24], fabric-based cables with PCB modules that snap into place [25, 38], or snap-based systems with shorter buses or no buses [4, 7, 16] to expedite e-textile prototyping. Custom fabric cables are difficult to produce with 100% consistency and have a higher resistance than wire [25, 26]. Snap-based systems have a larger connector footprint because a separate snap is required for each signal.

DanceBits has been informed by the emphasis on "iterative and exploratory learning" [25] in prior wearable prototyping kits, as well as by plug-and-play prototyping systems that are not designed for wearables, such as Sseed Studio's Grove system for Arduino, which uses JST-based connectors [14]. DanceBits takes the design one step further by focusing on a particular context for high fidelity application, enabling users to distribute sensors across the body and integrate them into clothing. Distinctively, DanceBits has been created to facilitate use both as a prototyping tool and as a durable, camera-ready, *wearable* for performance.

2.3 Wearables in the Dance/Performance Context

Beyond electrical connections, a challenge of building wearables for dance lies in the need to securely attach components to clothing and to hide and/or encase parts of the components to meet a particular aesthetic goal. Professional performance contexts often use sewing and iron-on or other adhesive materials to make strong connections between electronics and garments. The Brookdale system, which uses the 3.5mm audio cable-based JacDac system for connectors, was developed for the runway context, with fashion designers applying their machine and hand sewing skills to mount electronics [36]. Custom gluing and sewing were also employed in a collaboration between wearable technology students and drag performance artists [40]. These high fidelity designs were made possible because of the high skill level of the practitioners involved. Similarly, cross disciplinary teams with expertise in design, lighting, and choreography, collaborated with an opera company to create an edition of electronic costumes for a live performance

[12]. The teams used a remixable "base design" for diffusing LEDs with custom 3D printed parts. In industry, companies such as Cute Circuit¹ and Tron Dance² have developed custom attachment methods involving sewing and specialty manufacturing to facilitate the creation of high fidelity wearables for performance.

Custom, permanent attachments to fabric may be the gold standard in professional costume design, but this approach is not practical in educational settings. Supporting groups of learners working on individualized designs necessitates non-specialty attachment processes that can be executed independently. Non-permanent connections between electronics and clothes encourages iteration and allows hardware to be reused. Finally, removing electronics allows clothes to be washed, which is a significant challenge with embedded e-textile costumes [13]. For these reasons, we relied on easy to use, off-the-shelf attachment methods, such as magnets, Velcro, and tape. While such methods are of course common in user testing and prototyping [9, 27, 39], our use case meant they had to withstand dance practice as well as function during a final performance.

3 DESIGN CONTEXT

STEM From Dance (SFD) creates learning opportunities for middle-school and high-school-aged girls, with a focus on historically underrepresented groups in STEM and computing fields. They offer in-school and after-school programming, as well as two- and three-week summer intensives. Summer cohorts of 75 to 80 students are divided into classes of around 15 students with one STEM instructor and one dance instructor who both attend all of the educational sessions. Throughout the summer weeks, students engage in both dance- and STEM-focused activities, using creative computing technologies such as earSketch [10], P5.js³, danceON [28], and Circuit Playground⁴, to create interactive music, graphics, and costumes for use in their choreography. The program culminates in a final performance, which is attended by families and friends and sometimes also alumni guests and inspiring speakers from STEM and dance fields.

Our understanding of the learning context was first informed by interviews with students, instructors, and the founder of SFD. A key finding from these conversations was the emphasis on building a supportive community of learners, an atmosphere of psychological safety, which sometimes took precedence over STEM learning-objectives [8]. While many interviewees praised the effectiveness of community-building and STEM identity-work, our conversations also revealed stress created by technical challenges. One of the earliest agreed-upon goals of our collaboration was to improve the usability of wearable technology for dances. We identified three main areas of need:

- (1) *Reliability* of the physical connections between elements in the circuits, particularly for use in the final performance
- (2) *Expanded expressive capabilities*, with freedom over where sensors could be placed, to create a stronger connection between the technology and the dance

¹<https://cutecircuit.com/>

²<https://www.trondance.com/>

³<https://p5js.org/>

⁴<https://learn.adafruit.com/category/circuit-playground>

- (3) *Reduction of the cognitive load* required to design and build a circuit from scratch, to divert time toward high-level understanding of electronics design and interaction design that is synergistic with dance

4 DANCEBITS KIT: SYSTEM DESIGN AND COMPONENTS

DanceBits (Figure 2) consists of (1) a small, custom shield for an off-the-shelf microcontroller which streamlines connections to the I/O pins and the integration of battery power, (2) A JST-based system for electrical and mechanical connections that allows users to easily plug and unplug components, (3) a set of inputs and outputs for use in the dance context, and (4) connection options for clothing. *DanceBits* is a wire and PCB-based system, a decision which improves replicability for our community partners (relative to systems with e-textile components) and ensures the lowest possible resistance for electrical connections with long spans across dancers' bodies.

4.1 Microcontroller

The *DanceBits* microcontroller board is designed to host Adafruit's Trinket M0 (Figure 2), which was selected for several reasons. This controller's small footprint of 1.07" x 0.6" x 0.1" allows it to be discreetly integrated into clothing. The Trinket's ATSAM21E18 32-bit Cortex M0+ processor can be programmed in Arduino⁵ or Microsoft's Makecode environment⁶. It is affordable, costing around \$7 USD/unit (in bulk) at the time of writing. The main board serves as a base shield to surface mount the Trinket and provide access to its five input and output (I/O) pins through JST connectors. Power, ground, and data wires are routed through the custom PCB, freeing users to focus on the higher-level connections and programming of the five I/O pins.

The main board also includes a 2-pin JST connector for an external 3.7V lithium ion battery, which will allow users to disconnect from USB power and dance with their creations. Battery power is turned on or off via the slide switch on the side of the board. An onboard charging circuit allows the battery to charge when plugged into a computer via the Trinket's USB port. The same USB port is also used for programming.

The decision to make a base shield for an existing consumer microcontroller, as opposed to building a microcontroller board from scratch, was made in the interest of long-term viability of the project. As the Trinket is updated and improved by its developers, it can be swapped out of the shield with updated versions. For projects where bulk is less of a concern, header pins can be used instead of surface-mounting, which would allow the Trinket to be removed and reused in other projects. The *DanceBits* JST shield can be fit to other microcontrollers such as the Nano BLE with only minimal changes to the base shield (Figure 3). *DanceBits* joins the ranks of custom shields that expand the capabilities of microcontrollers available through consumer retailers [37] and in the open source community [3, 23]. The design is freely available on GitHub [1].

⁵<https://www.arduino.cc/en/software>

⁶<https://www.microsoft.com/en-us/makecode>

4.2 Connectors

The *DanceBits* components connect through 4-pin 1mm-pitch JST jumper wires. These were chosen because they have a small form factor while still clicking into the 4-pin socket, providing a robust connection under dance movement. Users can easily plug and unplug elements such as sensors and LED lights while experimenting. While most of our current components need only 3 buses (power, ground, and signal), the 4-pin connector provides the option for future components to use the i2c protocol and potentially daisy-chain peripheral devices on the I/O pins.

The kit comes with 4" and 8" wires with JST plug connectors on both sides. In early user tests, 2" wires were also made available, but they were seldom used. Each of the circuit boards has socket connectors that receive the cables. The design of the plug connectors is such that they can only be plugged into the socket in one orientation, so it is difficult to plug anything in backwards. It is possible to break a plastic socket and bend the internal pins, however, if trying to force a wire in backward. To reach the components across the body, users may wish to extend the wire more than 8". For this purpose we have provided *extender boards*, small PCBs with two socket connectors, that allow two wires to be joined together. Users can connect as many extenders and wire as they like to reach their desired wire length (see Figure 4 for a schematic).

4.3 Kit Components

4.3.1 Inputs. Prior wearables developed by SFD participants to wear during dance performances relied on pre-programmed timing of the LEDs. *DanceBits* uses input sensors, which now allow for lighting effects that are responsive to dancers' movements. In selecting the type of input devices to include, we prioritized reliability and robustness of interaction. We eventually settled on including the button switch and the tilt sensor during usability tests. The specifications are detailed below:

- **Tactile Button Switch** - Mechanical buttons are open and temporarily close (connect) when pressed. The switches chosen for this design have a button diameter of 13mm, which is larger than those typically provided in breadboard prototyping kits (around 4mm). This allows them to be easily accessed when dancing (Figure 2).
- **Tilt Sensor Switch** - Mechanical switch that changes state according to the position of the metal ball inside. The switch is open when the ball is tilted away and closed when it rolls down to make contact with the base of the switch. This allows the state of the switch to change based on its orientation. The tilt sensor board uses the same PCB as the button board, for manufacturing efficiency.

We also developed and explored the use of Hall effect, capacitive touch, and motion sensors. Although they were included in preliminary tests, we *did not integrate them in our usability tests*. Reasons for exclusion are detailed below:

- **Hall Effect Sensor** - Latching switch that turns to high in the presence of a magnet. This allows a specific actor to turn the switch high, for example, by using a prop with a magnet in it, but the switch will not be accidentally turned on by other physical movements. A challenge we found in preliminary tests was that the magnet needed to be very close

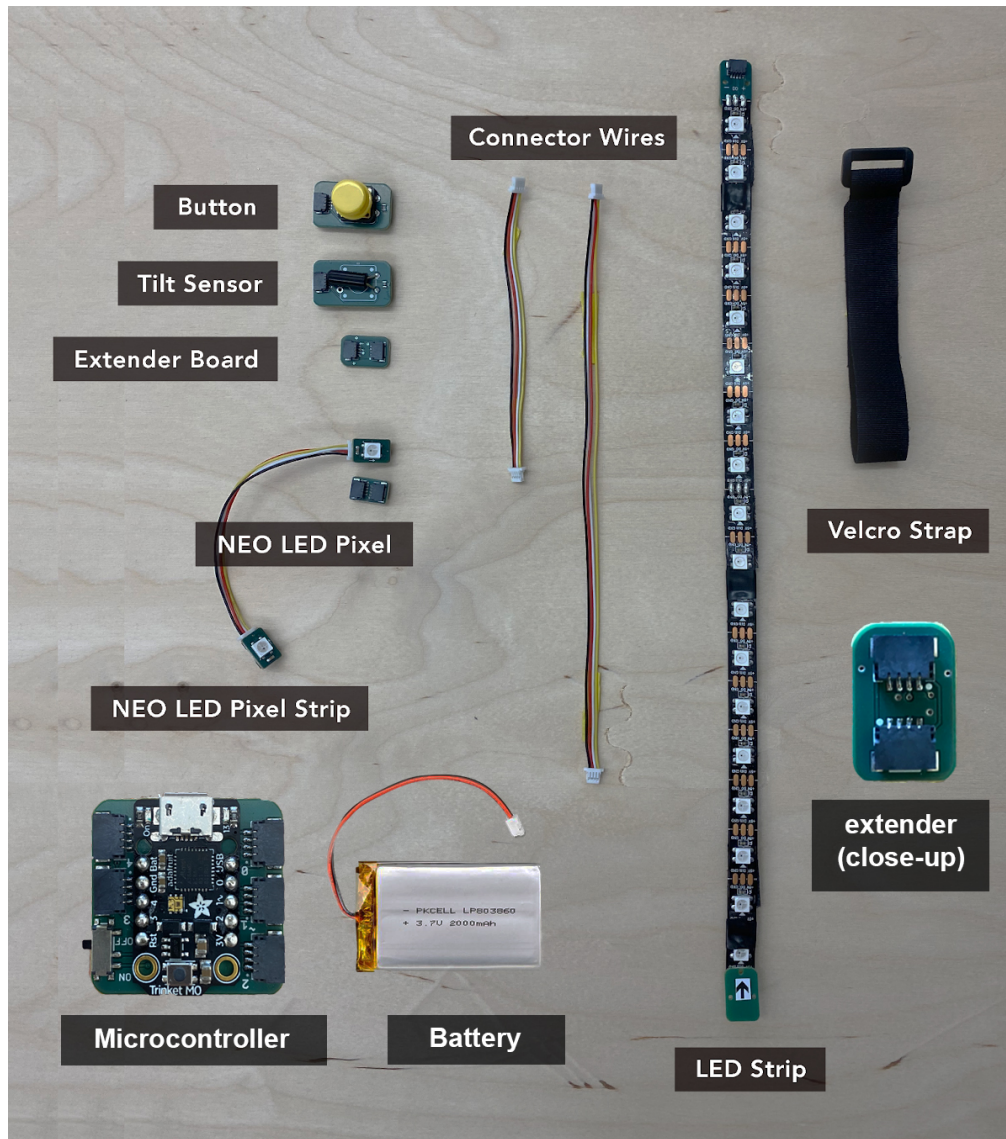


Figure 2: Components of the DanceBits Kit

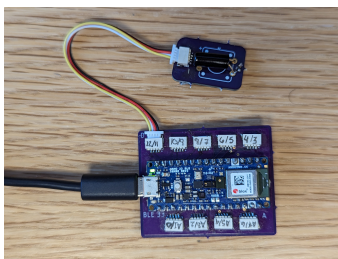


Figure 3: Arduino Nano BLE Shield for DanceBits

to the switch to turn it HIGH, and required precision that was difficult to achieve while dancing. The latching switch

was also difficult to turn off. A non-latching switch would provide more flexibility, because the latching functionality could be emulated in code.

- **Capacitive Touch** - Three I/O pins of the Trinket can be used as hardware capacitive touch sensors. This board provides a large conductive pad with a surface mounted conductive snap. Conductive fabric with a socket snap is provided, which users can cut to make custom capacitive sensors (see Figure 5a). The advantage of capacitive touch is that it is very sensitive and can provide a large area to act as a switch. Furthermore, it is easy to integrate with soft materials that might be more comfortable for dancing. A challenge for our context was calibration. Changing the size of the sensor affects its sensitivity and can require changing the “threshold” of the

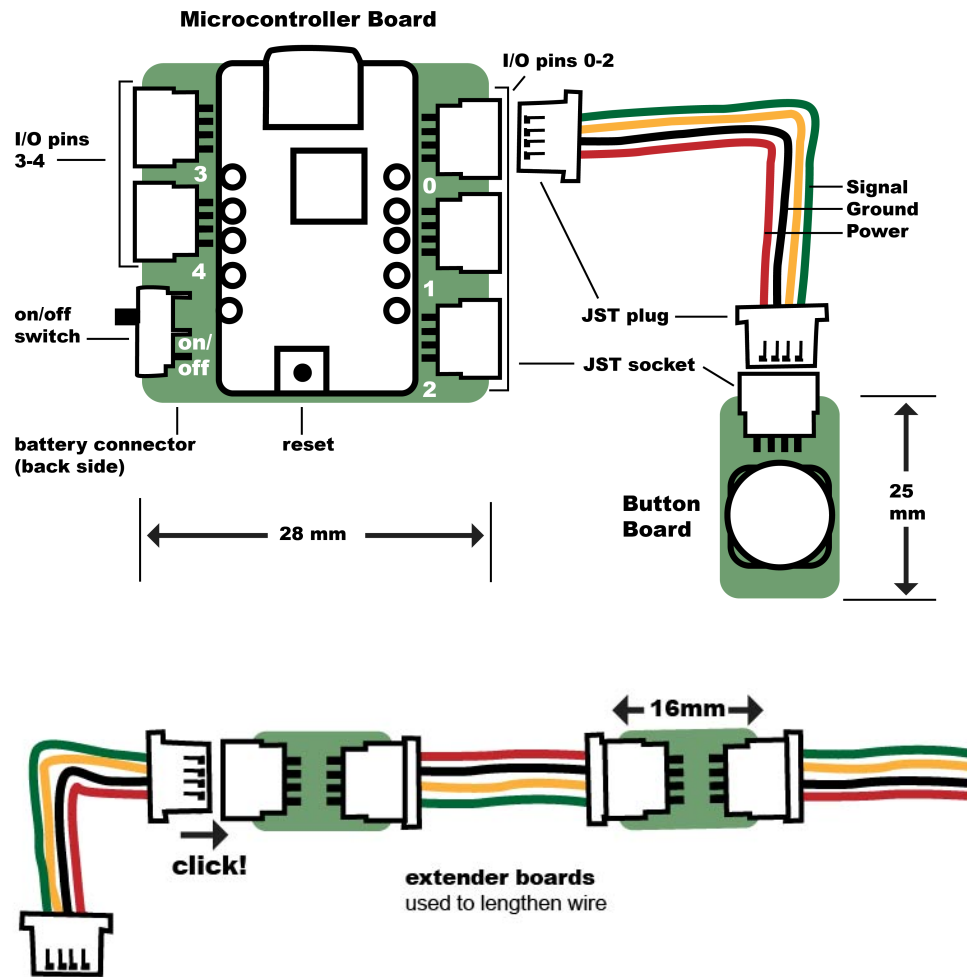


Figure 4: DanceBits Design Drawing

switch. This is straightforward to do in Arduino but not so in MakeCode, which did not have a reliable way to access serial data of the Trinket at the time of the study. MakeCode was a design constraint of our community partner because of its block-based coding interface. Consequently, capacitive touch was not included in user studies.

- **Motion sensor (IMU)** - We tested a 3-axis accelerometer and gyroscope inertial measurement unit (IMU; see Figure 5b). Our thought was to use the motion sensor to detect specific gestures such as head tilt, spinning, or a high kick. However, similarly to the capacitive touch board, we needed access to the serial monitor to use this board to its full potential. This MakeCode limitation is an area of ongoing work; specifically, we are developing a custom extension for serial data monitoring.

4.3.2 Outputs. Output devices in our user studies were LED neopixel modules and RGB strips.

- **LED neopixel modules** - Each kit contains individually addressable LED pixels that can be chained together with connector wire to function as an LED strip. Providing the LEDs in this separate format enables participants to vary the space and layout of the LEDs. Using wire to chain LED pixels together can also result in a more flexible “strip.” Additionally, these can be chained in combination with the LED strips.
- **LED strips** - Addressable RGB LED strips that have been cut and soldered to PCBs with JST socket connectors. Each LED strip has an input port and an output port, allowing multiple strips to be chained together with connector wire. The orientation of how the LEDs are plugged matters, as they can only be addressed from the input side, and extensions should be added to the output side. We labeled the back of the PCBs with a large arrow, to help users identify the direction that the signal should flow. For testing, we provided three strip lengths: small (18 pixels), medium (30 pixels), and large

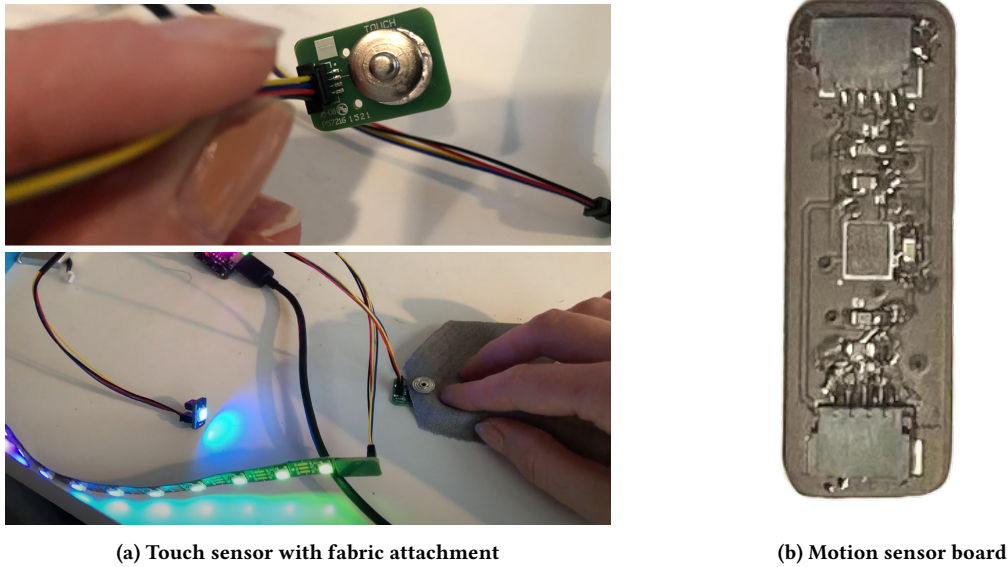


Figure 5: Additional DanceBits sensors not included in usability tests

(40 pixels), with the recommendation that no more than 60 pixels be turned on simultaneously to avoid drawing too much power from the board.

4.4 Designing for Clothing Integration

The backs of most of the components used Velcro with several options made available for connecting the LED strips to their clothes. We sought attachment methods that would be low-impact on users' own clothes (initially avoiding pins for this reason) and that were relatively easy to remove while also being stable enough to perform in a tricky combination.

- **Velcro** was attached to the LED strips in short lengths spread across the strip in early iterations, and then in one long piece across the entire LED strip in subsequent iterations. Participants were provided with adhesive backed Velcro they could connect to their clothing directly, as well as Velcro straps that could be wrapped around limbs and tightened, without making any adhesive contact with clothes.
- **Magnets** were hot glued to the LED strips in 3 to 4 equidistant locations. Participants were provided with additional magnets, which could be placed underneath clothes and connected to the LED strip magnets. This method allowed them to place LED strips on their clothes without any visible connection apparatus, but it was not as strong as Velcro over longer tests.
- **Tape** was provided mainly for wire management. As participants chained extender boards together to produce longer wires, they needed a way to secure the wires to their body during performances and used low-adhesive black tape for this purpose.
- **Cutting Holes** in generic black sweatpants and sweatshirts was demonstrated to participants as a way to both stabilize

the wires and conceal them by weaving them between the body and the garment.

5 METHODS

5.1 Data Collection & Analysis

In this paper, we present data and findings from the pilot study, usability study with the instructors, and usability study with the youth participants. Data was collected in the form of pre-/post-study surveys; observation notes; audio data on the various participants; video data capturing the wide angles of the environment; pictures and videos of the dance artifacts, wearables, and performances; and post-study group debriefs. The pre-study survey was designed to gain an understanding of the participant demographics and their prior experience with computing, electronics, dance and choreography. The post-study focused on the experience within the usability study and creating with DanceBits. Observation notes were recorded by the three to four researchers present within each of the studies. They focused on the use of the wearable technology, how it was being integrated and reasoned around, and what challenges and affordances the users encountered when working with it.

We conducted our analysis using a case-study methodology, which focuses on descriptive accounts of the cases attuned to the context, participants and environment [11]. The unit of analysis in our study is at the level of the various dance performances and integrates the artifacts used for project planning, images and documentation of the wearables that were constructed, video of the dance performances, and associated audio data. We attend most closely to the work produced in two user studies where participants were able to build a full performance including the wearable, choreography, and live demo, triangulating data [22] across the various

sources. We summarize the six cases in Section 6 and then present our findings across the cases within Section 7.

5.2 Study Protocol

5.2.1 Preliminary Work. The hardware was tested in two preliminary stages to gain feedback on the usability and design of the learning activities and to generate example material for further tests with stakeholders. In the first preliminary stage, we introduced the hardware to a SFD dance instructor, Shanelle (pseudonym). Over the course of an informal three-hour workshop, researchers and the instructor built designs alongside each other using the LED strips, push buttons, and tilt sensors. Following the workshop, we worked asynchronously with Shanelle to develop a design for an example project that would be used in subsequent studies. Shanelle designed an 8 count dance sequence featuring arm movements with exaggerated tilts of the wrist. She proposed a tech setup of tilt sensors on the wrists and an LED strip running down each arm from shoulder to wrist. Researchers programmed the microcontrollers so that each tilt sensor would change the color of one LED strip, allowing the wearer to control the color of each arm. This example became the basis for Task 1 (see Table 1).

The second stage of preliminary work was in the form a pilot study with college students from a creative technology program. The goals were to test the protocol tasks and identify immediate usability problems with the hardware, software, or workflow. Feedback from this soft launch led us to introduce more visual aids in the form of diagrams explaining the technology alongside oral explanations in Task 1, and a worksheet to help participants plan their designs in Task 3 (see Table 1). It was also noted that Velcro was generally more reliable than magnets for attachment, so we procured additional Velcro options, including Velcro straps, and Velcro with adhesive backing for subsequent studies.

5.2.2 Usability Study Protocol. We started each study with a *pre-study survey* to understand who our participants were. The researchers then took about 20 minutes to introduce the wearable technology and provide an opportunity for the participants to hold and look at the different components.

Task 1, after the introduction to the wearable kit, was a *guided construction* activity. Participants followed a diagram to assemble an example project where tilt sensors were used to light up LED strips. Each tilt sensor controlled the color of one LED strip. This activity gave participants experience in building a (predetermined) working project, testing out interactions between the inputs (tilt sensors) and output (LED lights), and mounting the electronic components to clothing (Figure 6a). The microcontroller was preprogrammed for the task.

Task 2 built on the previous task by integrating the Task 1 project with choreography taught by a dance instructor. While performing the choreography (as a group), participants wore the technology they assembled from Task 1; this enabled them to see the tilt sensor used within an actual choreography sequence and to get used to exploring dance, storytelling, timing, and tempo with the technology they assembled (Figure 7).

Task 3 invited the participants to work in pairs to develop (a) a wearable design based on a theme and (b) their own choreography.

Table 1: Study Protocol for Usability Studies

Pre-survey questions	Gather participants' experience dancing and integrating wearable technology into their practice.
Introduction to the wearable (20 min)	Introduction of the kit components, consisting of a microcontroller, wires, push buttons, tilt sensors, LED strips, LED pixels, extenders, Velcro and magnets.
Task 1: Guided Construction (60 min)	Participants assemble and test a guided example with tilt sensors on the wrists controlling LED strips on the arms.
Task 2: Dance Warm-up with Wearable (20-60 min)	Participants learn and perform an 8-count choreography designed to highlight the tilt sensor example that they are wearing from Task 1.
Task 3: Custom Choreo and Wearable Design (90-120 min)	In pairs, participants developed a theme-driven wearable design and 16-count choreography, which they perform.
Post-study group reflection	In a group, participants reflect on their experience with the technology, activities, and performance.
Post-survey	A quantitative measure of the participants' overall experience with the wearable technology.

To aid in the design of their wearable, they were provided a worksheet (i.e., planning sheet) with a human figure where they could sketch out the placement of the electronics on the body and describe their theme. They built and mounted their device onto their clothes and developed their choreography with assistance from the dance instructor and the researchers. Working with each pair of dancers separately to understand their design goals, researchers reprogrammed the microcontrollers.

In a final *post-study group reflection*, participants shared and discussed their experiences on assembling their wearable device and developing their dance performance with it. They also filled out a *post-study survey* on their overall experience with the wearable technology. The study protocol is summarized in Table 1.

6 USABILITY STUDIES

6.1 Instructor Participants & Context

Six dance instructors were recruited through our partner organization, STEM From Dance, with choreography experience ranging between 3 to 10 years. Three participants had no experience with wearable technology in dance, one was unsure, and two had some experience. Five participants identified as having some coding experience through SFD. Half of the participants had more than three years of experience teaching dance. All participants were involved with teaching dance at SFD at the time of the study.

6.2 Instructor Artifacts

We present the artifacts that the instructors created in Task 3, in which participants worked in pairs to develop custom wearable designs with DanceBits, choreographed a dance to correspond to their wearable choices, and demonstrated their designs in a short performance for the broader group.

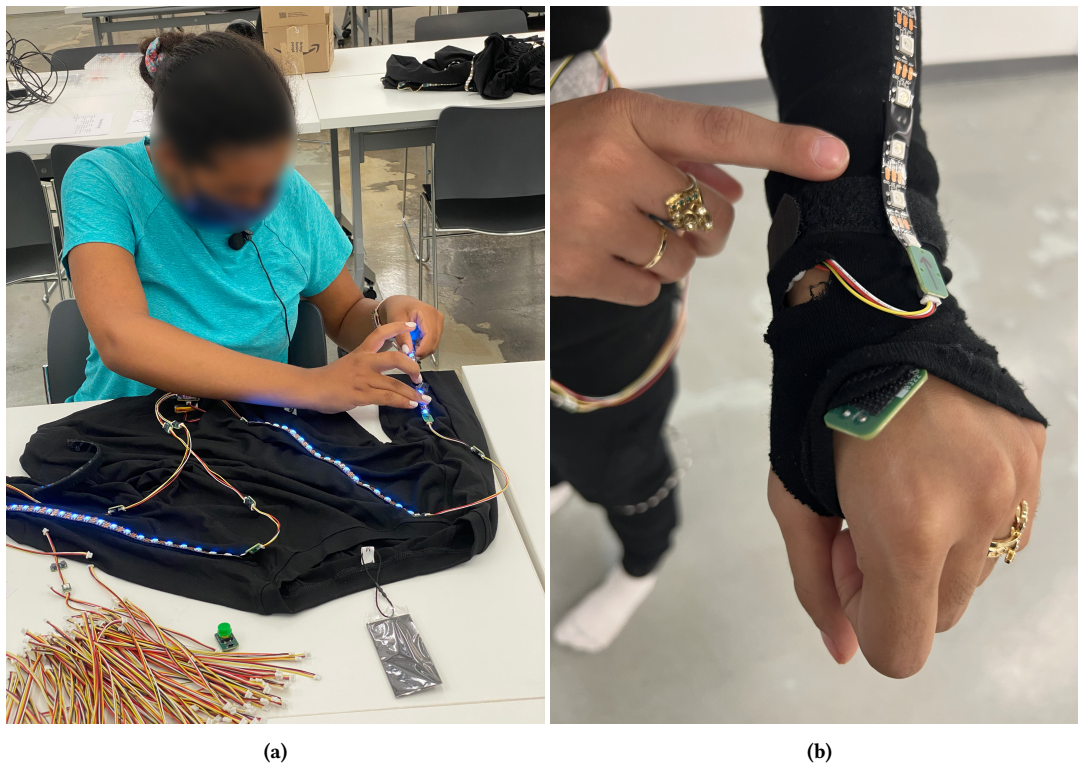


Figure 6: Youth production in Task 1: (a) A participant attaches electronics to their clothes. (b) Tilt sensor placement



Figure 7: Youth participants learn choreography (Task 2)

6.2.1 Step Routine: Push buttons on lower thighs and chest. This design was described on the planning sheet as a “step dance routine” where “lights would coordinate w/ sounds made by hand hitting buttons.” The design used three LED strips and three tactile push buttons. One LED strip was positioned diagonally across the chest, from left shoulder to right hip, with a push button in the middle. Two LED strips were wrapped around each thigh above the knee, each with a button in the middle (Figure 8). In post-interviews, the designers noted, “We wanted something militant in step. We thought

about something, we were like, ‘Stomp the yard, come out.’” Button presses cycled the LED colors between blue, red, yellow, and purple, and were activated as the dancers slapped their knees and chest in time with the music.

6.2.2 All of the Lights: Push buttons on wrists. This design was described as having a party theme, “like a pop anthem feel,” and used two push buttons on the wrists. The LED strips were positioned along both arms and around the torso (Figure 9). When the buttons were pressed, the LEDs changed from pink to rainbow and stayed rainbow when the buttons were held down. In the choreography, the participants used the dark/light contrast of dancing with LEDs to make it look as though one performer appeared behind the other one. They described their aesthetic goals as “VMA type performance... very production,” (referencing the Video Music Awards). They chose to press the buttons when the beat dropped, which was also when they created a dynamic change in their choreography from smooth, slow movements to strong, fast movements.

6.2.3 Happy and Upbeat: Tilt sensors on hips. This group designed a dance with a happy and upbeat theme, using two tilt sensors located on their hips. The LED strips were placed along the outside of both legs (Figure 10). When the tilt sensors were activated, the LEDs turned from pink to green. The initial design used two sensors to change the color of each leg separately, but post-interviews revealed that the final design used one sensor to control both legs simultaneously, because the users felt this allowed more freedom

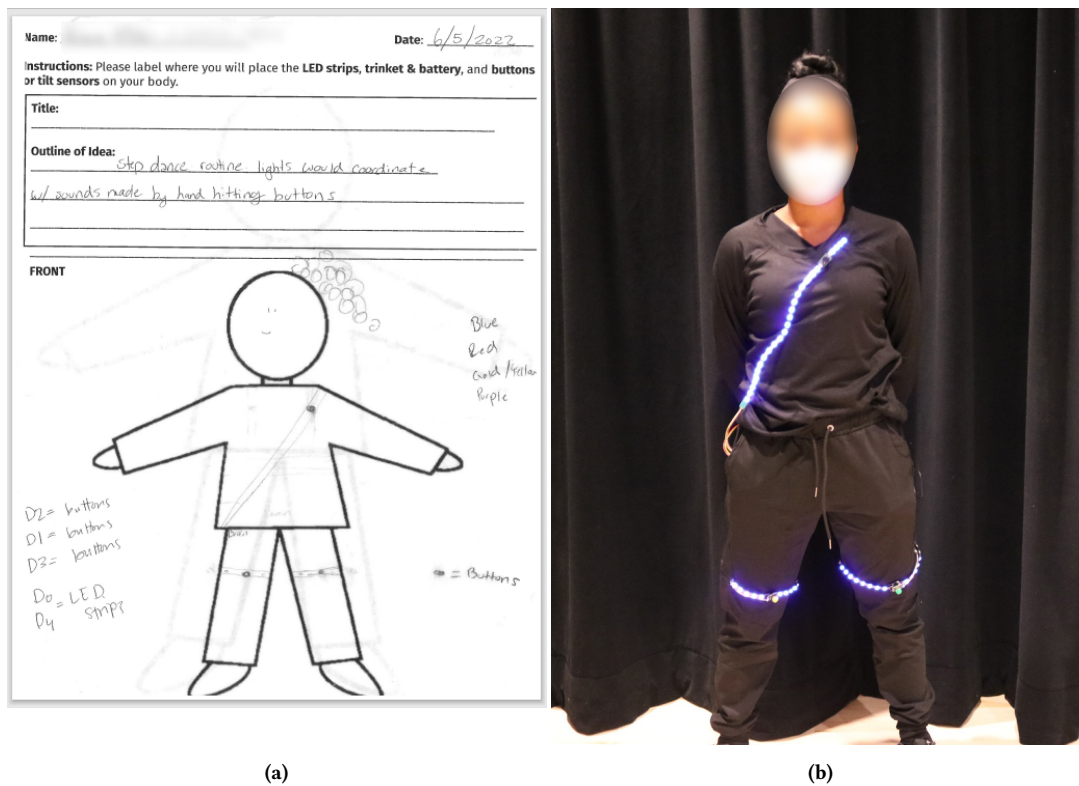


Figure 8: Step Routine: Instructor Images & Artifact

of movement. The choreography featured Latin-inspired hip movement to trigger the color change and highlight the lights on the legs.

6.3 Youth Participants & Context

Five high school students aged 15 to 17 were recruited through our partner, SFD. Three of the participants had more than four years of dance experience. Two participants considered themselves experienced in choreography, while the other three did not. Four of the participants had done choreography either with SFD or through personal experience. Two participants described themselves as comfortable with programmable technology and three were neutral. Four participants had used wearable technology in SFD projects and described themselves as somewhat comfortable using wearable tech in dance. All participants had moderate to in-depth knowledge of coding from both personal experience and participating in SFD projects. Participants worked in teams of two to develop three unique wearable designs and choreography. One student was paired with the dance instructor to even out the group.

6.4 Youth Artifacts

Similar to the instructor study above, we present the artifacts that the students created in Task 3, in which participants worked in pairs to develop custom wearable designs with DanceBits, choreographed a dance to correspond to their wearable choices, and demonstrated their designs in a short performance for the broader group.

6.4.1 Determination: Push buttons on upper thighs & tilt sensor on wrist. The first group chose a theme of determination and female empowerment, using leg and arm movements to symbolize a powerful march through struggle towards success. Each of the steps was emphasized with color changes, alternating between blue and white on the LED strips along their leg. Light changes were controlled by buttons positioned on their upper thighs. One student had an additional LED strip on her left arm that changed colors based on input from a tilt sensor on the wrist (Figure 11). The microcontroller for the LED strips was positioned on their left hip (inside the pocket/under the waistband of the trousers).

6.4.2 Energetic: Tilt sensors on wrists. The second group worked with the theme of confidence, boldness, and empowerment. They wanted to relay an upbeat and energetic hip-hop routine. The elements of their wearable consisted of LED lights along their arms that changed color based on the tilt sensors on their wrists. They also had LED strips around their knees controlled by the same sensors (Figure 12). They chose blue and white colors to blink alternately when the tilt sensor was triggered. The microcontroller was placed on their left hip (inside pocket/underneath the waistband).

6.4.3 Girl Power: Tilt sensors on shoulders. The third group chose the theme of girl power. LED strips were placed along both arms, and a dance move involving flexing to signify female strength was used to change their color to pink. The movement was sensed by a tilt sensor placed on the shoulders. Another LED strip was placed

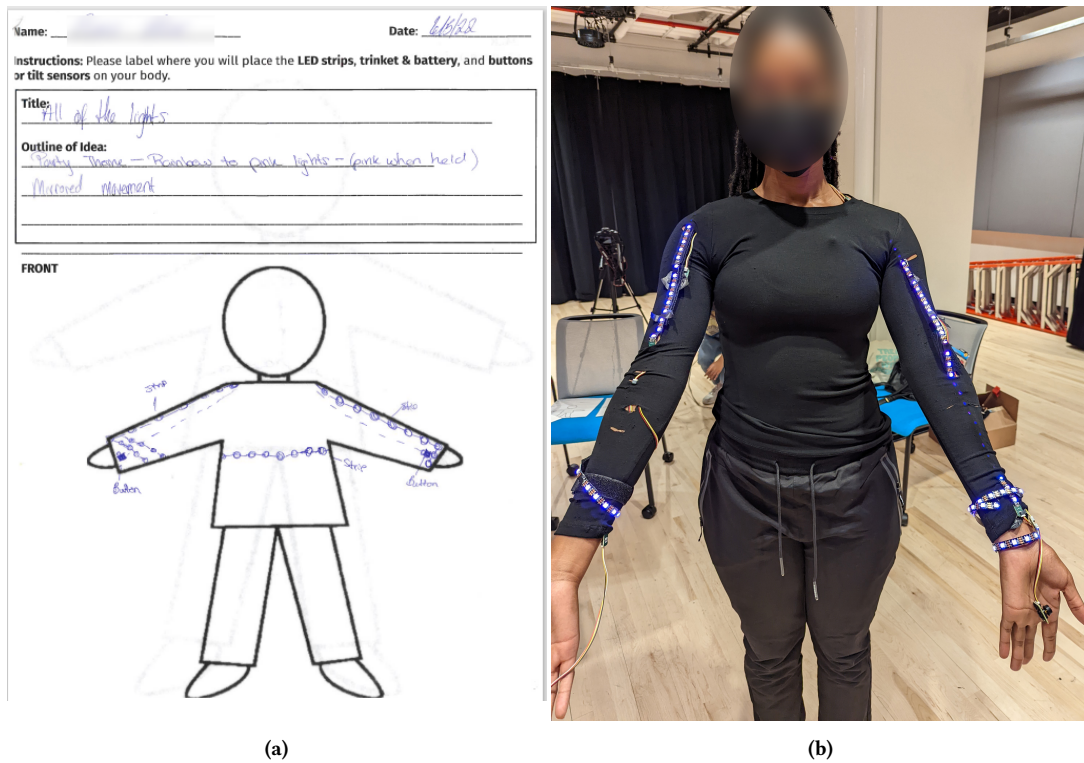


Figure 9: All of the Lights: Instructor Image & Artifact

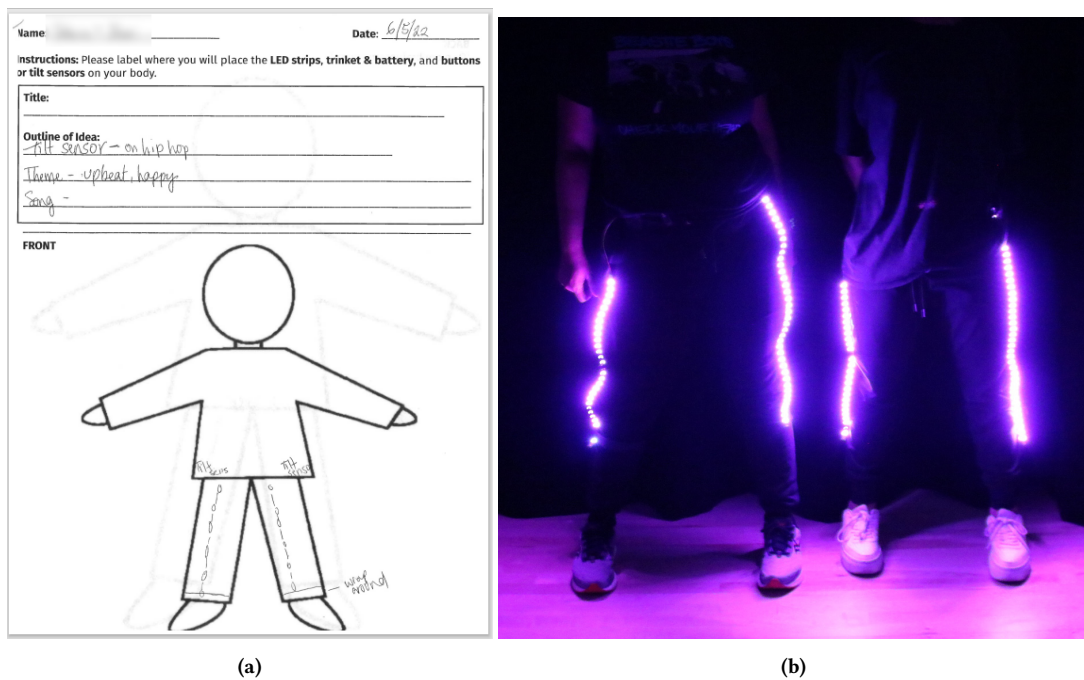


Figure 10: Happy and Upbeat: Instructor Image & Artifact

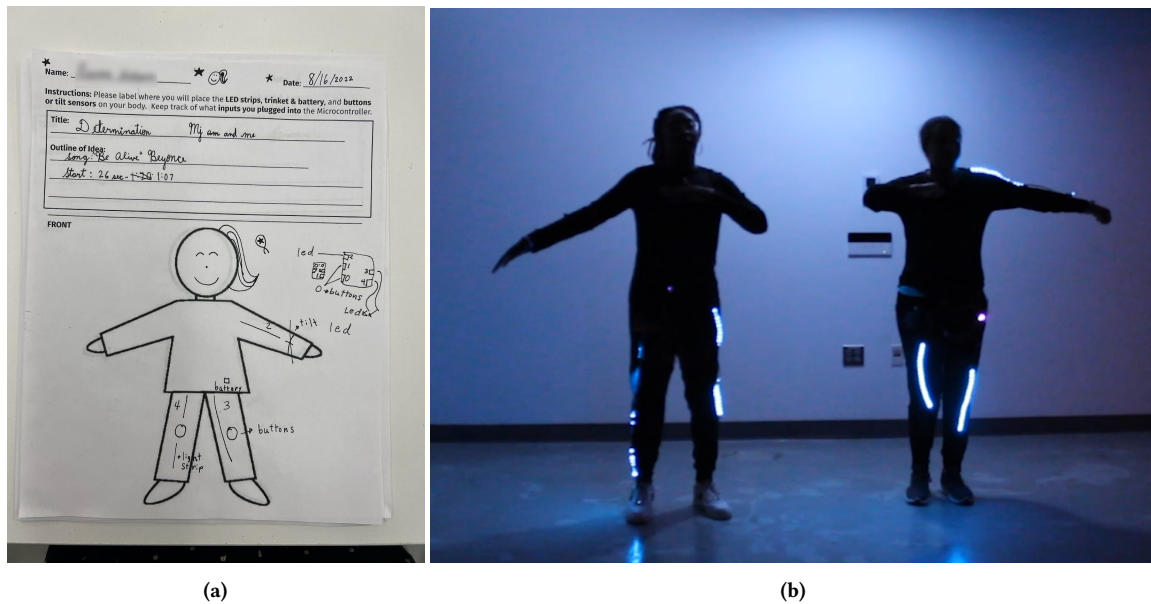


Figure 11: Determination: Youth Image & Artifact

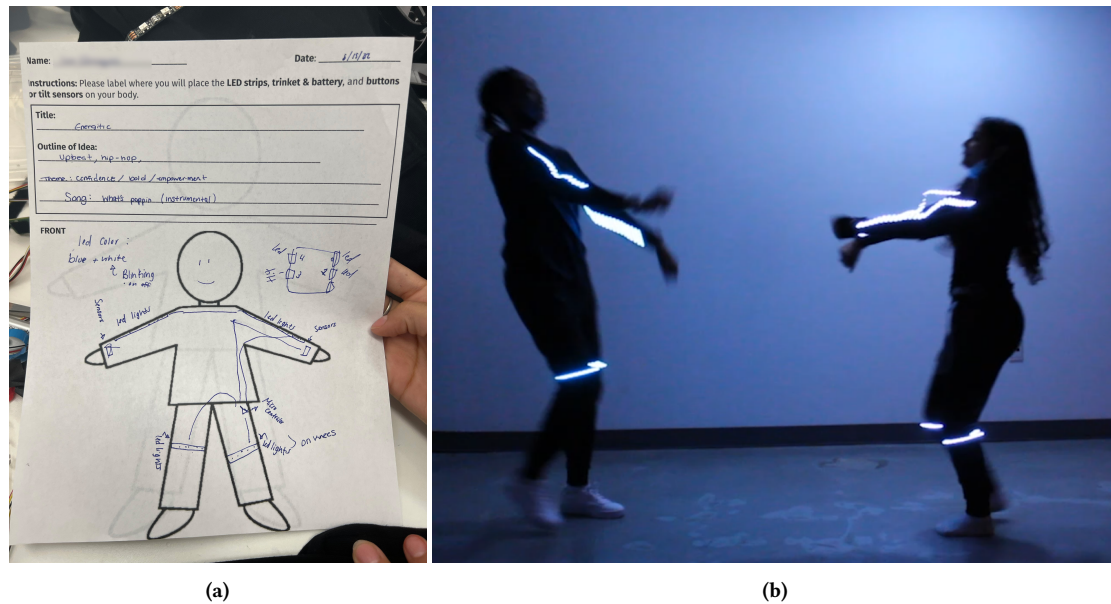


Figure 12: Energetic: Youth Image & Artifact

along the upper thigh of the left leg, along with a button, which ran through the colors of the rainbow. (Figure 13). The student noted that the rainbow colors signalled “inclusivity.”

7 FINDINGS

We present findings from the usability studies with instructors and youth participants, highlighting both areas of potential and areas for improvement for DanceBits.

7.1 Affordances

7.1.1 Rapid Wearable Construction & Iteration. Both youth and instructor participants were able to design and build unique wearable designs with DanceBits relatively quickly and independently. Following the introductory tasks, participants in both the instructor and youth groups completed their original wearables (Task 3) in around two hours. This contrasts to prior SFD experiences with sewable electronics, where 12 to 16 hours were required for construction. However, our study did not include the additional time

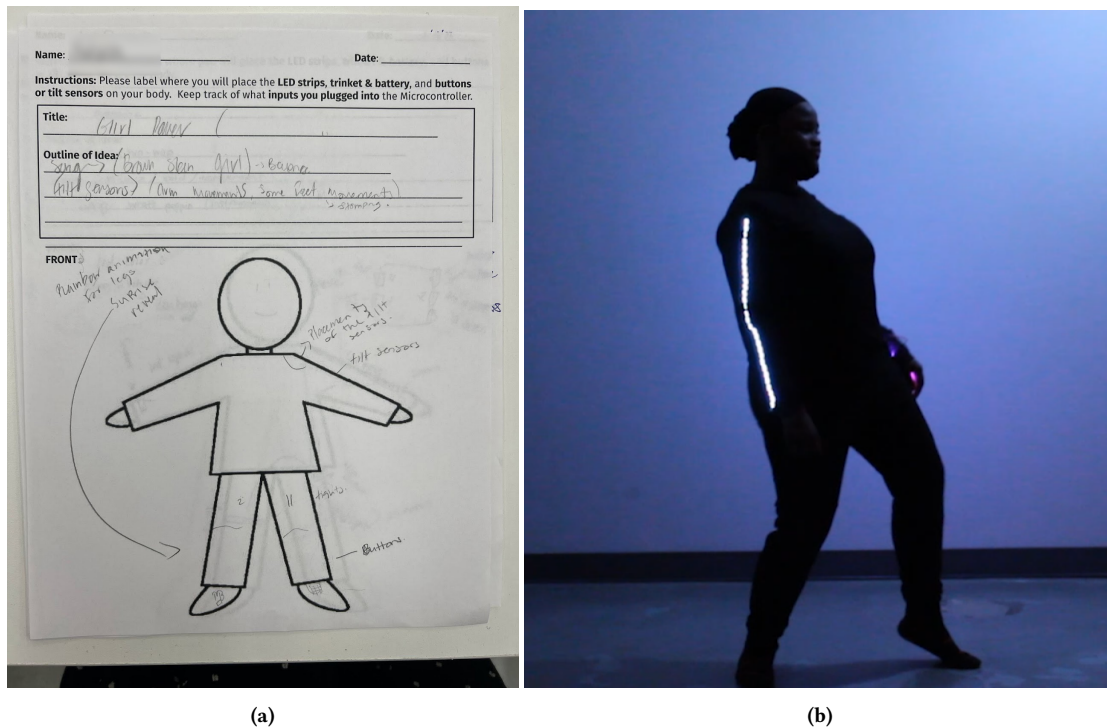


Figure 13: Girl Power: Youth Image & Artifact

required to create more robust connections and a seamless aesthetic (more below in Section 7.2).

The wire connectors in DanceBits also facilitated iteration. A youth participant noted that she changed the location of her lights from her hands to her shoulders, “*Because there’s more movement in the hands than it is on my body*,” and she found the sensors were more reliable in this more stable position. The easily changed construction of the wearable fed into her understanding of her body movement, strengthening somatic awareness.

7.1.2 Creative Expression Across Computing & Choreography. Participants were able to develop thoughtful connections across their creative themes, electronics choices and placement, and choreographic decisions. In the instructors’ *Step Routine*, which integrates body hits, participants placed buttons on the chest and lower thighs (Figure 8b). This enabled corresponding body hits to accentuate the percussive dance moves with LED color changes that were incorporated into choreographic choices. In post-study interviews, one instructor from the *All of the Lights* performance noted how the lights helped bring the theme of their dance together, “*It was world of dance. That’s what I said. Very production, and then the lights, with the lights...it just helped us really tie everything together, for sure.*”

The youth participants also created thoughtful connections across their themes, movements, and sensors. In response to a question from researchers asking whether the technology impacted their choreography, the participant who worked on the *Girl Power* dance noted the thematic significance of her gesture-responsive wearable: “*I used a button, and I used the tilt sensors because the tilt is for when you move your arms. You know how girl power is you move your*

arms and stuff like that, but this one, I used it because, to represent the different colors and everything, but what it tells you...You see it’s not just women and girl power...It tells you to see us.” An example movement of her arms can be seen in Figure 14. Another student noted the importance of using movements like these to draw audiences’ eyes to highlighted portions of the body, “*It made better focuses, like for someone to focus on the movements, because of the lights. They would be more focused on this part, than the other parts.*” The participants were able to think about their intersecting choices as they reasoned around how an audience would engage with the performance and receive their creative expression.

7.1.3 Supporting Computing & Electronics Education. DanceBits enabled quickly ramping up from prototype, to finished product for use in dance. Participants in both groups responded positively to the pre-programmed example in Task 1 and enjoyed testing the interaction of button presses and tilt sensors to control the LED colors. One instructor noted the high potential for engaging students with this interaction: “[T]his was almost **immediate gratification**. As soon as you plug it into the brain, you see something light up, you’re like, ‘Wow, it’s working,’ and not to even get into this generation of immediate gratification, but that works. It really can work and use that to your advantage.” The same instructors felt that hands-on electronics activities were particularly well-suited to dancers, who may gravitate to this type of learning. Indeed, SFD’s executive director had previously expressed concern that in some STEAM environments, the fun, playful experience of learning dance was juxtaposed with a stagnant, decontextualized experience of learning computing. An instructor reflected on how DanceBits brought

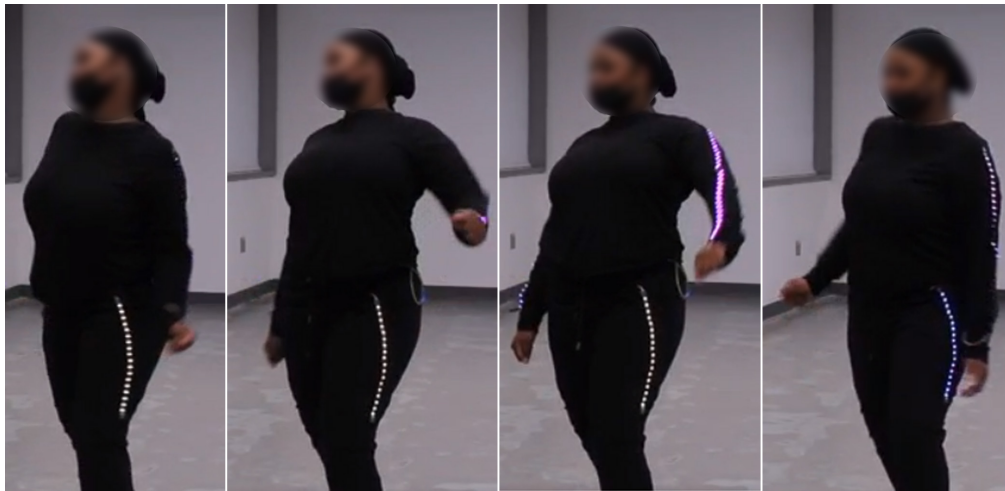


Figure 14: Girl Power: Tilt Sensor Arm Movement

computing closer to the embodied, experiential learning that is central to the practice of dance: *“Dancing is using your body, using your hands, getting into it, and I feel like this allowed you to do that. You were able to do the brain work before, but it really, really got into the meat of it when we were putting things together. I feel like a lot of dancers can relate to being really good at actually doing the thing, whatever it is, and learning best that way and seeing it happen.”*

Although the plug-and-play technology masked (black-boxed) some of the electronics learning that may have occurred in wiring from scratch, it allowed participants to focus on the sensing capabilities of components and their connections to body movement. For example, when exploring how to accentuate a hip movement, an instructor participant (Jarika) was able to quickly plug in a tilt sensor, mount it to her leg, and explore choreography while gaining input from her partner (Shanelle) and a facilitator (Haley).

Jarika: *“What do you think?”*

Shanelle: *“Oooo. Oh ok, can you like kick to the side?”*
(Jarika dancing with rapid foot movement, both laughing)

Jarika: *“...Alright lets do it.”*

Haley: *“...So it does work”*

Jarika: *“Kind of. It’s not as consistent as the...”*

Haley: *“As the arm”*

Jarika: *“But it changes”*

Haley: *“If you do like a stomp, like a light stomp, does anything happen?”*

Jarika: *“Yeah...this one is purple...So it has to be strategically placed”*

Participants noted that the buttons and tilt sensors have different creative and teaching affordances. One instructor noted, *“the buttons, you do have more control, and if you are working with fifth graders or younger—buttons.”* In contrast, the tilt sensors could work in a piece *“where it was more freedom based.”* The instructors in the *Happy and Upbeat* dance chose the tilt sensor for this reason, integrating it in Latin-inspired choreography which centralized hip movement, allowing the tilt sensor to bounce to their movement

and trigger corresponding light changes: *“We were only wearing one [tilt sensor] instead of one on each leg. One leg was controlling both sides.”* This choice was seen as more forgiving than having one tilt sensor on each leg, which would have required more precise movements to trigger the lights. A single sensor allowed more *“freedom.”*

7.1.4 Supporting Dance Education. The instructors also identified how the electronics could help within dance education practices, specifically noting that placement of the technology could lead to increased body awareness, and identified opportunities for bidirectional learning between dance and computing. Referring to the dance practice of *cleaning*, which refers to the ability to execute dance motions repeatedly with consistency, an instructor noted, *“Even going further into cleaning, if you’re really strategic on the design of it, if everyone has their button right there and the move is hit to here, everyone is here, their placement is here... It can help a lot with body awareness, cleanliness of the piece, etcetera, which could be very, very cool, and help someone who is not that well aware of their body just yet to get there.”* The moderator clarified, *“Thinking about where they’re hitting,”* and the instructor responded, *“Yeah. You can also incorporate that in choreography easily, the buttons. ‘And six, you press the button.’”* Contrary to how these technologies have been positioned as solely contributing to the performance, we found that the interactive design of DanceBits was viewed as supporting the holistic practice of dance within the experience.

7.2 Challenges

On top of the affordances, we also noted the various difficulties the participants faced throughout. In some cases, we created iterative changes to the system which we outline where applicable.

7.2.1 Reliability of Connections on the Body. Reliability of the physical connections between electronics and the body was the primary issue cited by participants and observed by researchers, as the Velcro, magnet, and tape connections were difficult to plan and sometimes failed under the stress of dancing. Most participants

constructed their electronics and connected them to sweatshirts and sweatpants with the garments laid flat on the table. This created challenges, in some cases, when putting the garments on, because the electronics were not always in exactly the correct place. Constructing directly on the body is also difficult, as we observed when participants were making real time changes, because it is hard to see what you are doing. Participants and researchers often had to help each other make changes to the placement of electronic components. This issue is often dealt with in garment construction through use of mannequins and mirrors.

Another cause of failure in the connections was the use of long wires to connect elements across the body, which were not always taped down or weaved into clothes, and led to them being accidentally pulled when dancing. Most of the youth participants had loose wires hanging out from their garments (Figure 15). Not only did this have implications for reliability, but this aesthetic would not be acceptable as a final product for a performance.

The instructors were more diligent when constructing their wearables, creating more robust and aesthetically pleasing connections. The instructors had more experience attending to detail within performances, which seemed to carry into the care they put into the tidiness of their wiring (see Figure 16, where the only wires hanging out are from the recorder we used for data collection). This demonstrated that there were potential processes that we could have guided the youth participants to use, to achieve the same results as the instructors.

The length of the LED strips also caused challenges in getting them to conform to the shape of the body. We found that the Velcro, which was originally only placed on particular sections of the LED strips, sat much better on the garments when it was attached throughout the whole strip, increasing the surface area of adhesion. Figure 17a shows an example of the LED strips with intermittent Velcro where the strip can be seen lifting off at the edges (also pictured in Figure 15b). In contrast, Figure 17b shows LED strips with Velcro along the full strip, adhering tightly around the pant leg.

7.2.2 Reliability of Electrical Connections. Reliability of the sensor connections was an issue caused by the wires coming apart throughout the participants' construction process. In order to connect sensors across the body and up and down the lengths of the arms and legs, four to eight wires needed to be connected with the extender boards (depending on the length needed to be achieved). This meant that there were multiple points where wires could become unplugged, which became even more difficult to identify when the wiring was routed within the clothing and already being worn by the user. The wires were pulled out of the extenders when they were not securely taped down, causing them to snag as the user put on their clothing, or when there was not enough slack wired into the design, causing the wires to be pulled out of their connections when the clothes were stretched over the body. This led to students voicing issues with the technology, like one participant who noted *"the button is sometimes unresponsive, which is annoying."* After recognizing the prevalence of wires pulling apart during the usability studies (Figure 18), we began securing the wires with tape. Ideally, we would provide longer connection wires to minimize the

need for extender boards; this may require the creation of custom connector wires for future work.

Another electronics issue stemmed from the tilt sensors needing to be oriented in a precise way such that they would trigger based on a specific gesture. This led to multiple instances in which participants needed to reorient and re-secure their tilt sensors to achieve the responses they wanted with the movements they choreographed, and these attempts were not always successful. As one instructor commented, *"I feel like my tilt sensors weren't, at least on this side, this side was responsive and then this side was wonky at times (distinguishing the tilt sensors on her left and right arms). That's why I feel like we used the buttons because at least we knew we had full control over it. I felt more secure with the buttons."* Lack of a debugging framework made it difficult for participants to identify the cause of their sensor issues, which could be due to disconnected wires or wires plugged into the wrong I/O pin number. To minimize points of intermittent failure, we have since come up with a board design to support pinning the tilt sensors and buttons to clothing, a more secure attachment method than Velcro (Figure 20).

In a similar vein, we have developed a 3D printed case for the microcontroller and battery with a slide attachment for a pinback, to ensure more reliable attachment between the case and clothes (Figure 19d). The case is also intended to protect the battery from impact and prevent strain on the wire connecting it to the microcontroller board. It features cutouts that allow users to access the I/O connectors on the microcontroller board, the USB port, and the on/off switch (see Figure 19). There are slots for up to four pinbacks to slide into, for attachment to dancers' clothing.

8 DISCUSSION

By working in collaboration with SFD, we were able to situate the design of DanceBits within a community organization that values authentic dance practice and youth empowerment. The expressive, theme-based dances and the ways the instructors and youth were able to iteratively engage with the technology, were representative of these values. Designed in consultation with SFD staff, our user studies revealed that the DanceBits technology not only facilitated learning about computing, but also enhanced users' understanding of their bodies and dance performance.

DanceBits created opportunities for users to creatively engage with wearable computing beyond the constraints that many current educational kits for wearables face. No two wearables were the same as the dancers creatively distributed the electronic components within their wearable designs. DanceBits' attention to iterative properties and integration into clothing enabled users to develop wearables that supported synergistic relationships between technology design and the practice of dance. For example, users were able to place sensors and LEDs on the body, test dance moves, and then make changes. The shorter circuit construction time allowed more time to be spent on exploring intersections across the themes, technology, and choreography, with participants beginning to note that some sensors paired better with different styles of dance, ("free" tilt sensors were contrasted with more "controlled" button presses). Participants were able to create connections between their dance styles, such as stepping, and sensor choice and placement, such as buttons located on the knees and chest for body



Figure 15: Final Youth Wiring Images

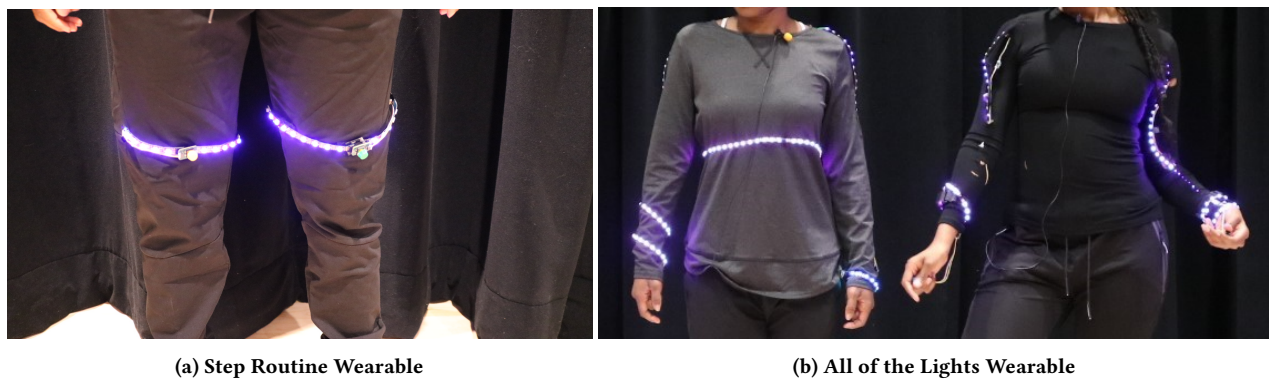


Figure 16: Final Instructor Wiring Images

hits. The plug-and-play nature enabled the dancers to focus on the interaction design while also attending to the thematic and affective goals of their dances.

While the instructors were able to develop a polished wearable that in one instance gave them the feeling of a VMA (Video Music Awards) performance, the youth participants overall had less finished wearables. This indicates a need to develop the learning resources and processes to support them, while also allotting more time for the total process. The study spanned only a few hours, much shorter than physical computing experiences typically offered by SFD, which take place over several days. In these longer

instructional contexts, the shorter construction time of DanceBits would leave more time for finishing and mounting the components in ways that would increase robustness and hide loose wires for a more performance-ready piece. Additionally, the shorter construction time frees up more time to focus on the programming of the electronics. It thus provides more opportunities for learners to reason around the connections between the technology and dance.

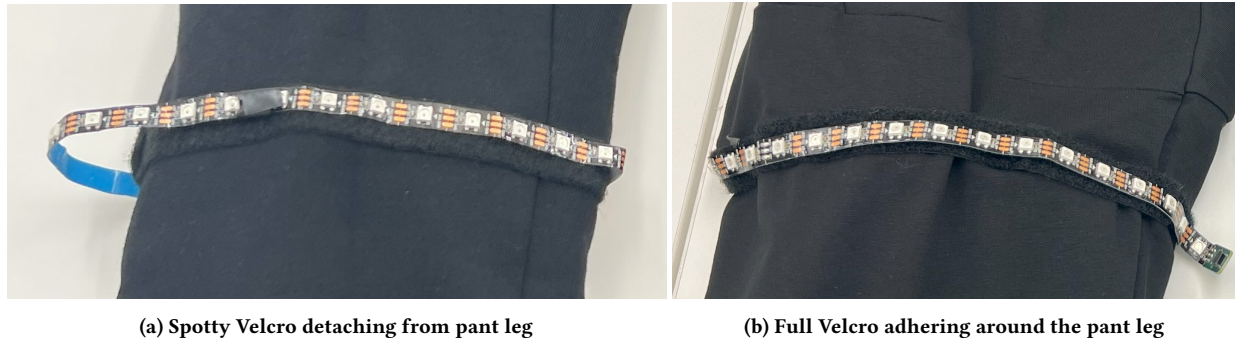


Figure 17: Adhering to Clothing with Velcro

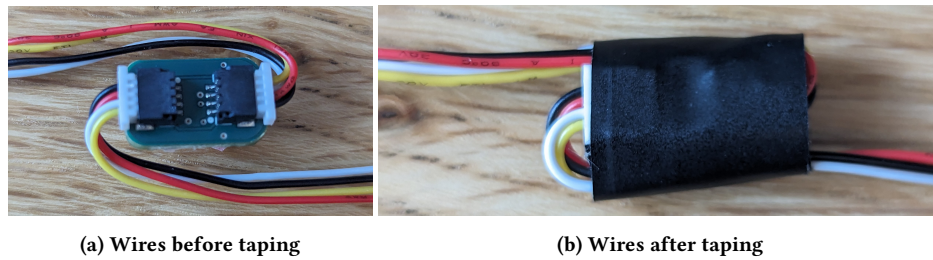


Figure 18: Securing extender board connections to prevent wires from ripping out and disconnecting

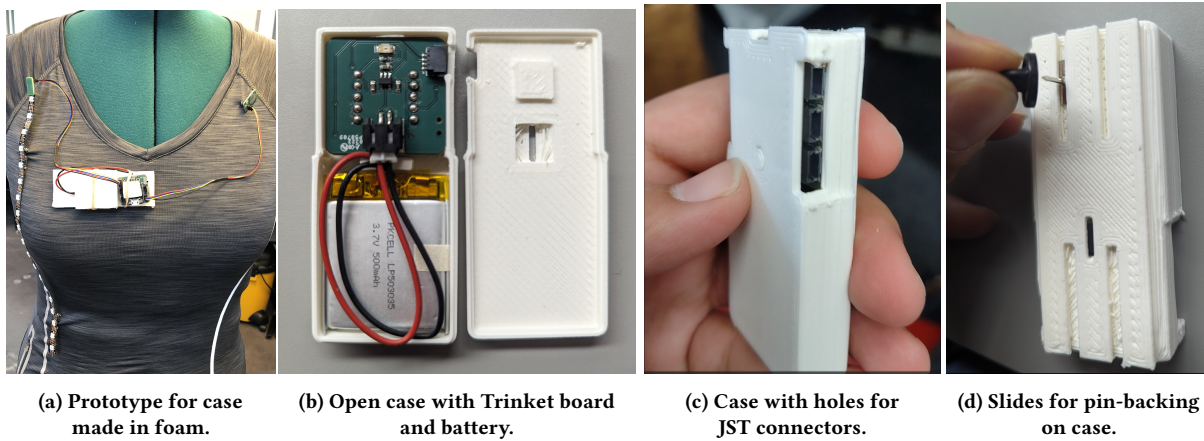


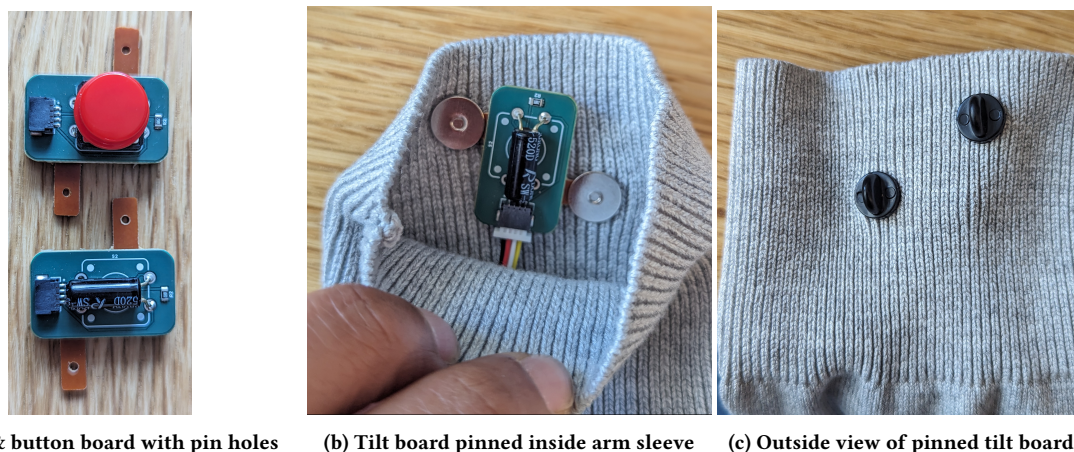
Figure 19: 3D printed case for DanceBits Microcontroller

9 CONCLUSION

DanceBits' iterative capabilities, combined with its ability to transition into a performance-ready piece, supported meaningful integration of technology into dance choreography. The plug-and-play connector system enabled participants to direct their attention toward creative interaction design, allowing them to create synergies between their wearable design and dance choices. By centering dance in the system design, we contribute a culturally sustaining technology that builds on a dance community and brings exploratory embodied learning to computing educational experiences.

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(a) Tilt & button board with pin holes (b) Tilt board pinned inside arm sleeve (c) Outside view of pinned tilt board

Figure 20: Tilt and button redesign with pin holes support stronger attachment to clothing

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