FabricBoards: Utilizing Craft Techniques for Inclusive Prototyping of E-Textile LED Circuits with Fabric-Based Breadboards

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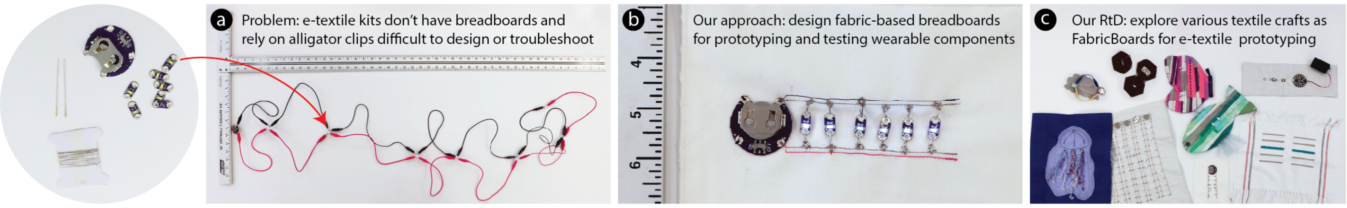

Figure 1: a) Existing e-textile kits lack fabric-friendly breadboards and rely on alligator clips, making fabric-based circuits difficult to design or troubleshoot. b) Our approach explores the design of 'FabricBoards' for prototyping and testing wearable components that lower the barrier to entry for beginners and novices. c) Our RtD journey experiments with various textile crafts for creating fabric-based breadboards through machine-sewing, quilting, weaving, knitting, felting, and embroidering.

Abstract

The prototyping process for e-textile circuits presents unique challenges, as traditional electronic prototyping tools are often rigid and incompatible with the flexible nature of fabric. In this paper, we document the iterative design of FabricBoards, a set of fabric-based breadboards designed for e-textile LED circuits. FabricBoards reimagine the solderless breadboard in a textile-based form, using tools and materials native to textile crafting, inviting and accessible to historically underrepresented makers. We experimented with various textile crafts including machine-sewing, felting, knitting, crocheting, digital embroidery, and weaving a breadboard. Our user study with 18 participants consisted of group workshops for ideation and individual interviews. A thematic analysis revealed four themes on the user experience of FabricBoards in terms of familiarity, materiality, and layout; the inherent incompatibility of electronic components with textiles; and the curiosity and engagement that FabricBoards evoke. Finally, we reflect with generalizable insights on computational making when reimagining e-textile breadboards.

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CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI)**; *Empirical studies in ubiquitous and mobile computing*; • **Hardware** → Emerging interfaces.

Keywords

e-textile; rapid prototyping; fabric; breadboard; weaving; felting; machine-sewing; crochet; knit; fabrication; hybrid craft; physical computing; women; girls; inclusive; STEM

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1 Introduction

E-textiles are an expanding area of wearable computing in HCI, where fabrics are enhanced with embedded electronics to create interactive garments [41, 83, 93, 94] and everyday things [41, 54, 69]. A critical aspect of e-textile development is the ability to iterate quickly and flexibly during prototyping [40, 49, 52, 63]. While solderless breadboards in traditional electronics enable rapid experimentation, testing, and debugging, comparable tools in e-textiles remain limited [40, 74]. Makers, especially non-privileged demographics [35, 81], face unique challenges with fabric-based circuitry, including material compatibility, aesthetics, and wearability [74, 85]. Current e-textile prototyping solutions [40, 64, 71] often require non-textile-native components [40] or impose rigid structures that limit flexibility and hinder alignment with the soft tactile qualities of fabric [58, 64].

HCI literature positions textile crafts as a vehicle to introduce more women and girls to STEM and foster a culture of gender inclusivity in computing [61]. Moreover, research [78] has shown some of the limitations of the hardware design of commercial e-textile kits from an inclusive design perspective, underscoring the absence of gender-sensitive considerations. In this work, we use the term 'textile-native' to refer to materials and connection mechanisms that are already familiar, accessible, and meaningful in textile craft practice (such as stitching, weaving, felting, and embroidery), welcoming makers who are typically underrepresented in electronics, such as women. This dictates that the components (like conductive fabric traces) and the tools (like sewing needles and snaps) align with this craft vernacular. These approaches leverage the inherent qualities of fabric and yarn (flexibility, softness, drape) and the tacit skills of textile makers. In contrast, a non-textile-native approach forces textile projects to accommodate electronics-oriented components (and thinking) that may be alien to the fabric's qualities, such as soldering wires, using hard PCBs, or solderless breadboards. These mismatches limit the prototyping of e-textile designs where iteration, debugging, and circuit layout must adapt to the constraints and affordances of textiles [74].

To address this gap, we adopted a Research through Design (RtD) approach to develop FabricBoards: a set of fully fabric-based prototyping boards for e-textile LED circuits. As an RtD project, our contribution is not a technical solution, but rather the process-level knowledge generated through iterative making (i.e., how textile structures can be rethought as a prototyping substrate), using this mode of inquiry [77]. RtD values the design insights and material explorations [77, 100] that emerge from experimenting with different techniques and the conceptual reframing of electronics prototyping as a soft, craft-native, material-driven practice.

Building on prior work [40, 64, 71, 98], FabricBoards is inspired by solderless breadboards but reimagined for fabric, using sewable components alongside textile-friendly tools and methods. Our focus on e-textile LED circuits stems from their dominance in commercially available kits and introductory tutorials, making them the most common entry point for beginners. While expert users often develop their own specialized workflows, newcomers are typically introduced to bulky, fabric-unfriendly tools like alligator clips. Therefore, our motivation is to create intuitive textile-native alternatives that better support this widespread use case. Through iterative prototyping and design research, we present three key contributions:

1. **Re-imagining the breadboard** to be compatible with sewable/wearable components and challenging (using RtD) what it looks like, what it's made of, and how it's used.
2. **Introducing textile crafts** (such as machine sewing, felting, crochet, knitting, weaving, embroidery) to expand the design space of breadboards and to welcome underrepresented makers in electronics, such as women.
3. **Gaining insights** from 18 textile/electronics practitioners (70% women) through group workshops and individual interviews to better understand beginners experience with e-textiles using FabricBoards.

2 Related Work

2.1 Unconventional Breadboards in HCI

Breadboards have long been a central focus in HCI research as tools for rapid prototyping, with studies ranging from software-based environments [66, 67] to physical and hybrid reimaginings [9, 24, 27, 56, 57, 62, 72, 86, 91, 98]. Tools like the ToastBoard [27] support visual debugging, Ellustrate [66] and AutoFritz [67] support early ideation and simulation in digital spaces, while others, such as JellyBoard [86], CurveBoard [98], and LeatherBoard [64] introduce new physical form factors like silicone, wearable, or curved surfaces. Accessibility-focused tools like AccessibleCircuits [17] and SkinKit [60] tailor breadboard-like platforms to users with low vision or to on-skin interfaces, respectively. These examples all share the core goal of adapting breadboard functionality to new materials, bodies, and contexts.

The educational value of solderless breadboards has also led to new designs aimed at reducing complexity and increasing transparency. EdBoard [92] exposes internal connections with a transparent body and magnetic parts to support young learners, while BitBlox [24] modularizes connections into snap-together blocks to make circuits more legible. These approaches address common issues such as the hidden internal structure of traditional breadboards, a challenge noted in both BitBlox [24] and ThreadBoard [40]. However, standard plastic breadboards (whether rigid or flexible) remain largely incompatible with the soft, foldable nature of textiles [11, 40]. While some e-textile toolkits attempt to adapt these platforms, they often fall short in flexibility, adaptability, or accessibility. Responding to Posch et al.'s call for tools that "*bring e-textile artefacts into being*" in a fragmented landscape [74], our work explores a materially grounded alternative that reflects the tactile and structural qualities of textile craft.

2.2 E-Textile Prototyping Tools and Inclusivity of Kits

The field of e-textiles has introduced a range of construction kits designed to support the integration of electronics into textiles for users of varying expertise [3, 10, 12, 49, 75]. The LilyPad Arduino [12] played a foundational role by making sewable electronic components accessible to educators, hobbyists, and designers, inspiring a wave of follow-up toolkits [6, 46, 47, 49]. For instance, Wearable Bits enables ideation of e-textile applications using low and mid-fidelity swatches [49] but does not support placing or testing off-the-shelf electronic components. More recent tools like the

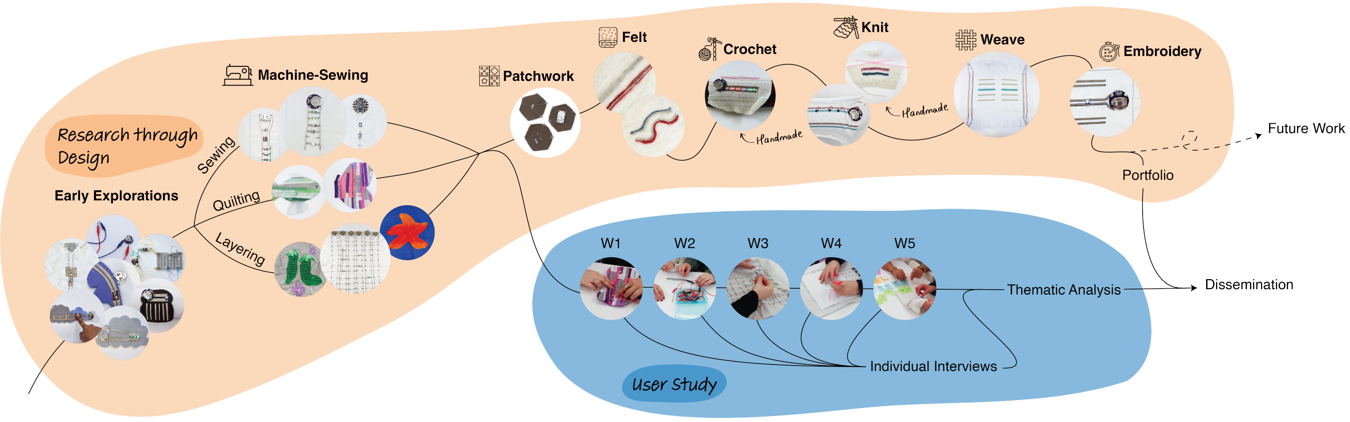

Figure 2: Diagram illustrating our RtD journey of iterative fabric-friendly breadboard designs for e-textile circuit prototyping using different textile crafts alongside a qualitative user study exploring how users (especially women) experience their usage through a series of hands-on group workshops and individual interviews.[1]

ThreadBoard [40] and TeeBoard [71] attempt to bring rapid prototyping principles into e-textile crafting by introducing connector platforms (such as magnets and snaps) but these often rely on rigid or component-specific modifications [85], which can limit reusability, hinder seamless fabric integration, and introduce risks of component damage.

Most related work on e-textile toolkits has either taken a perspective centered on able-bodied and, often, male-privileged groups [35, 81] or has focused primarily on children [78]. For example, Rode et al. examined gender considerations in computational making with the BBC Micro:bit, comparing how boys and girls engaged with e-textiles [78] including: aesthetics, creativity, constructing, visualizing, and materiality. Some prior work has investigated "why women are not interested in technology" [61], with preliminary findings suggesting the potential of engaging mothers and daughters in making activities. Only limited work has broadened the demographic of e-textile design by including Blind and Visually Impaired makers [35]. HCI literature has also explicitly sought to engage women in e-textile making [50], yet little of this work addresses the design of the prototyping tools or breadboards themselves. Other work argues that gender equality, aesthetic expression, and individualism are desirable values in making and DIY crafting [81]. However, re-imagining breadboards through new materialities to make them inviting and accessible to broader user groups remains largely unexplored.

2.3 Hybrid Textile Crafts

Hybrid crafts represent the integration of interactive components seamlessly within, or inspired by, traditional crafts. Sewing e-textiles is a form of hybrid craft for developing physical prototypes [65], including wearables [37, 59, 82, 93] and non-wearables [45, 59, 69, 70]. Sewing circuits can be done entirely by hand [68] with numerous resources including books [15, 53], tutorials [21, 43, 44], and kits [10, 12] aimed particularly at beginners and students. While hand-stitching [68, 89] remains the most wide-spread method for e-textile practice, education [13] and learning [73], recent research has begun to explore machine-sewing as a promising hybrid craft [30, 41, 42]. Machine-sewing offers an accessible and potentially more consistent approach for fabric-based breadboards, but many other textile crafts also warrant investigation in this context. For example, punch-needling has been used to create e-textile circuits [52], and other hybrid crafts such as goldwork embroidery [48] and bobbin-lace [51] have also been explored, although not in the context of breadboards. Crocheting [38], knitting [63], felting [28], and weaving [1, 26] are additional underexplored textile practices with potential for constructing textile breadboards. In this work, we examine these modalities and evaluate their applicability and material characteristics for producing fabric-friendly breadboards.

3 Iterative Prototyping and Design

3.1 Research through Design (RtD) Methodology

We adopted a Research through Design (RtD) approach [100] and an iterative design process to explore the conflicting needs between e-textile crafting and electronics prototyping. Zimmerman et al. describe RtD as a model of interaction design research, where researchers engage a 'wicked problem' through an active process of ideation, iteration, and critique [100]. The result of this process, among other things, is a set of research artefacts, which can range from physical prototypes to models and documentation. They articulate that the value of RtD comes from its ability to address wicked problems, which are not easy to address through 'scientism' [32] and engineering methods [77] because the elements of the problem have conflicting needs. RtD is well-suited for studies where knowledge is generated through making, evaluating, and articulating material qualities [74, 90, 96]. In our work, our design research engages in the wicked problem of the conflicting needs of textile making and electronics prototyping when combined in their hybrid form, as described in Section 1.

Furthermore, our work resulted in an annotated portfolio [7, 22, 39], provided in the supplementary documents, that presents

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[1] Icons in the illustration are courtesy of Flaticon.com, made by Good Ware, Freepik, Becros, and ToZ Icon.

"proposals" and sites for reflection, not "representations" [2]. The annotated portfolio is a design-led research approach that uses all the outcomes of design research to represent the insights made throughout the RtD process [33]. Although our design work unfolded along multiple parallel and interwoven paths, we present it sequentially for clarity in Figure 2, following prior RtD work [55]. Design explorations that were conducted in parallel-to or after the user study were driven by our curiosity to further our RtD in a diverse set of textile craft contexts, but may also have subconscious incorporations of participant feedback from the user study.

We demonstrate the elements of RtD in our design research by documenting our iterative design process and reflecting on our outcomes. We developed a collection of fabric-based breadboards (FabricBoards, which we abbreviate as 'FB' throughout this paper) as research artefacts to investigate diverse form factors, materials, and textile-based fabrication methods. To mitigate bias from our own e-textile expertise, we collaborated with Author 3, a female textile crafter new to electronics. Her fresh-eyed perspective informed decisions aimed at designing for underrepresented beginners to e-textile prototyping with breadboards.

3.2 Computational Making Framework

Following prior visions on evolving from computational thinking to computational making [78, 80] for e-textiles, we aimed to design artefacts that embody the skills and qualities in best practice. We used the five aspects of the Computational Making Framework [80] as a set of design dimensions (Table 1) to identify and address the research gap in existing e-textile prototyping boards and extend related work accordingly. We note that the subjective description of each dimension is meant as an operationalized prompt rather than a performance measure.

- **Aesthetics (D1).** The board should have aesthetic qualities to support beginners and underrepresented users who can feel overwhelmed or intimidated by connections that are too messy or too hidden to be intuitive. We ask here, *"Is the board aesthetically pleasing, pretty, cute [29], or welcoming? Or, is it purely functional or aesthetically messy?"*
- **Creativity (D2).** The board could be used as a tool for free expression, allowing users to change their circuit design and component placement easily to customize their projects with interpretive flexibility. We ask, *"Can it be created to support playful flexible designs? Or, is it constricted in a rigid grid?"*
- **Constructing (D3).** The board should be relatively easy to construct from the perspectives of both the maker and the user (in case they are different). We ask, *"Is it easy to make and replicate? Is it easy to construct circuits with reliable and robust connections using off-the-shelf components as-is (i.e. plug and play)? Or, does it require alterations (e.g., gluing magnets or soldering snaps to sewable pins)?"*
- **Visual Clarity (D4).** The board should support visualizing different representations in a way that is organized and intuitive to identify component placement, electric flow, and for troubleshooting circuits. We ask, *"Can the board visualize different representations with clarity?"*
- **Materiality (D5).** The materials used to construct the board should be native to textile crafts and support placement on/with fabrics using the textile makers' skills. We ask, *"Are the materials fabric-friendly or 'textile-native'? Or, does it rely on non-textile-native materials (e.g., plastic, silicone, etc.)?"*

3.3 Early Iterations: Experimenting with Connections

To enable rapid prototyping, early iterations of our fabric-based breadboards drew on 'cut and glue' crafts [28, 97], using stacked felt sheets and strips of conductive fabric tape. For component connections, we experimented with previously established e-textile methods (in conjunction with conductive fabric tape [16, 95]), including alligator clips, magnets, conductive Velcro [16, 88], and metal snap fasteners [6, 49, 71] (Figure 3). Our initial layout replicated a standard breadboard in a $12cm \times 9cm$ rectangular format (Figure 3a), but this quickly proved to be cluttered (D4) and incompatible with sewable components (D3). Although functional, alligator clips introduced visual clutter and distorted the fabric by twisting and/or damaging it with its sharp teeth (D5). We simplified the layout to two main paths (power and ground) and integrated the battery holder directly using conductive tape, improving both portability and clarity (D4). However, conductive tape alone was unreliable due to its unstable conductivity (D3), adhesive insulation, and poor mechanical durability as it does not survive flexing and repeated handling. Therefore, we used magnets to secure connections on either side of the fabric (Figure 3b), which introduced additional weight (D5) and often snapped together unintentionally, complicating precise placement (D3). We also tested machine-stitched conductive thread (Figure 3c), which proved insufficient on its own due to the limited contact area (D3). Conductive Velcro (Figure 3d) enabled a compact latch onto LED sewing holes with its 'hook and loop', but lacked robustness (D3). Snap fasteners (Figure 3e) supported customizable layouts but requires component customization (D3) to be used as a connection mechanism.

Although these approaches did not meet our standard for robustness in D3, they led to further exploration of sewing notions such as hooks and eyes, earring posts and clutches, sewing clips, release knots, and ironing cushions with sewing pins (Figure 4). Ironing cushions provided a soft, supportive base for using sewing pins to secure components along connection paths (Figure 4a). Earring posts and clutches were also effective for anchoring components on loosely structured textile surfaces (Figure 4b). Release knots (easily undone) enabled a flexible method for tying components into circuits using loose yarn ends or fringed textiles (Figure 4e). Additionally, we leveraged standard sewing clips ($2.7cm \times 1cm$), seen in Figure 4b, combined with silicone wires, to create a more fabric-compatible alternative to alligator clips and multimeter probes, avoiding twisting or damage to the textile (Figure 5). The hooking mechanism showed particular promise, motivating further exploration of hooks and eyes (Figure 4d) as familiar and readily-available fasteners for garment construction.

3.4 Machine-Sewn FabricBoards

Machine-Sewing with Hooks. Inspired by recent research [30, 42], we explored machine-sewing as an accessible method for crafting prototyping boards that allow users to test components (D3) and visualize layouts (D4). Our first iteration, FB1.1 (Figure 6a), included

Table 1: Situating previous work in comparison to FabricBoards across dimensions of the Computational Making Framework [80]. Legend: ● denotes the design fully aligns with the dimension; ❍ denotes the design partially aligns with the dimension; an empty cell denotes that the design does not align with the parameter.

	Aesthetics (D1)		Creativity (D2)		Constructing (D3)		Visualizing (D4)		Materiality (D5)
	Is it purely functional or aesthetically noisy?	Is it pretty, cute/welcoming, or pleasing?	Is it constricted in a rigid grid?	Does it support playful flexible designs?	Is it easily made and replicated?	Is it easily used (i.e. plug & play?)	Is it visually ambiguous, cluttered, or entangled?	Can it visualize different representations with clarity?	Are materials fabric-friendly or textile native?
Alligator clips [15, 30]	●					❍	●		
CurveBoards [98]	●		❍			●		●	
ThreadBoard [40]	●			❍		●		❍	
TeeBoard [71]	●		●			●	❍		●
LeatherBoard [64]	●		●		❍		●		●
Cut and glue FBs		❍		●	●	●		●	●
Machine-sewn FBs		●		●	❍	●		●	●
PatchBoard		❍		●	❍	●		❍	●
FeltBoard		●		●	❍			●	●
CrochetBoard		●	●		❍	●		●	●
KnitBoard		●	●		●	●		●	●
WovenBoard		●	●		❍	●		●	●
EmbroideredBoard		●		●	●	●		●	●

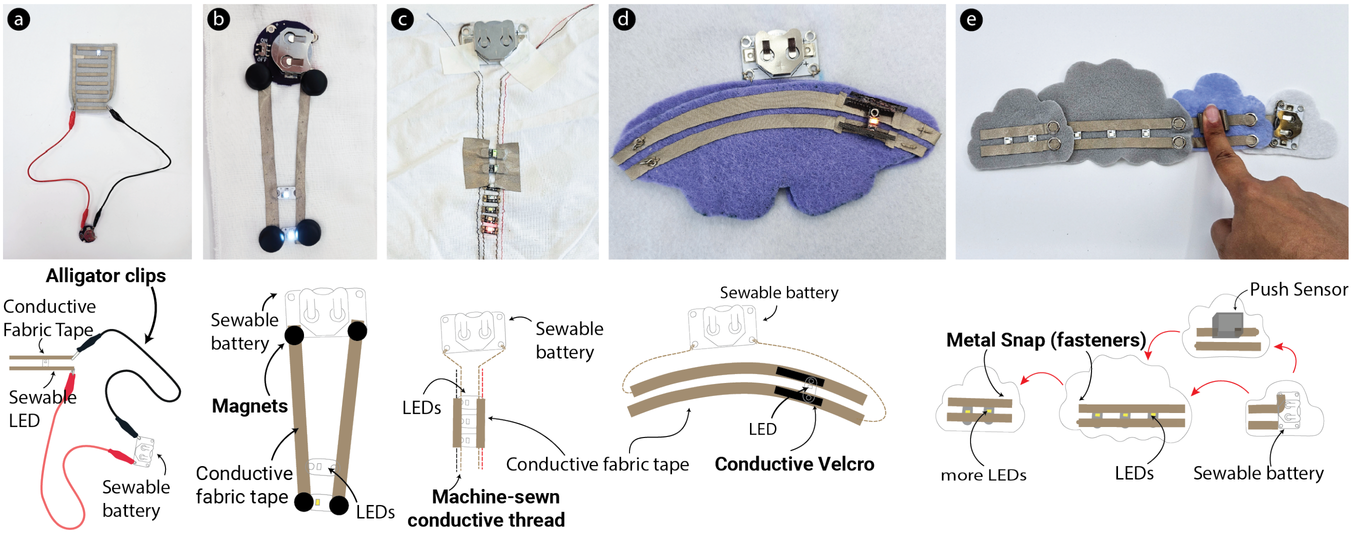

Figure 3: Early iterations in the RtD process using different connection mechanisms: a) alligator wires, b) magnets, c) machine-sewn conductive thread, d) conductive Velcro, and e) metal snap fasteners.

a coin cell battery holder, switch, three LEDs, and five pairs of conductive hooks all machine-sewn onto cotton fabric with serged edges (D1, D5). We then added colour-coded seams (red for power and black for ground) to guide component placement and improve visual clarity (D4). However, FB1.1 revealed two key issues: the hooks needed to be spaced further apart to create tension with the LEDs for stable connections (D3), and the extra machine-sewn LEDs consumed unnecessary power, causing any additional hooked LEDs to be dimmed.

The second iteration, FB1.2, addressed these issues by using a switchable battery holder and increasing the hook spacing. The soft flexible base fabric (D5) allowed users to manipulate the board to align hooks with various LED sizes (Figure 6b), including small LED sequins. This version demonstrated a wide coverage of the design dimensions (Table 1) as it used accessible fabric-friendly materials (D5), with a neat and welcoming finish (D1), offering quick connections in a creative way (D2) with high visual clarity (D4), and required no customization of electronic components (D3).

In the third iteration, FB1.3, we integrated a sewable microcontroller (Adafruit Circuit Playground Express) and RGB addressable LEDs (NeoPixels), commonly used in e-textile projects [5, 84, 87]. NeoPixels are typically used with headers or alligator wires, both unsuitable for fabric (D5), so we machine-sewed conductive threads to connect the microcontroller to three NeoPixels using hook terminals (Figure 6c). Although the setup was functional and programmable, the closely spaced NeoPixel pinholes made placement

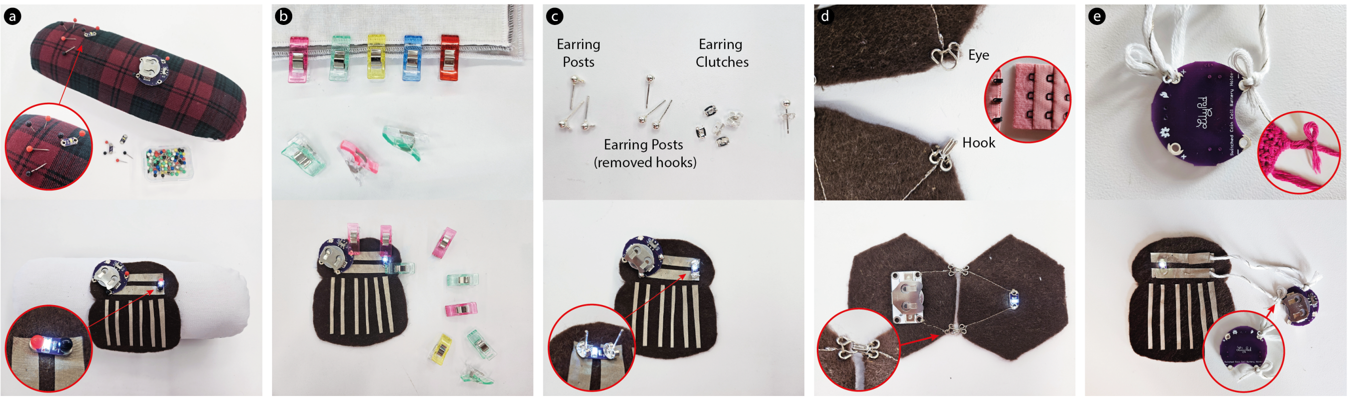

Figure 4: Experimenting with connection methods that are fabric-friendly, including: (a) pins on ironing cushions, (b) sewing clips, (c) earring posts and studs, (d) hooks and eyes, and (e) release knots.

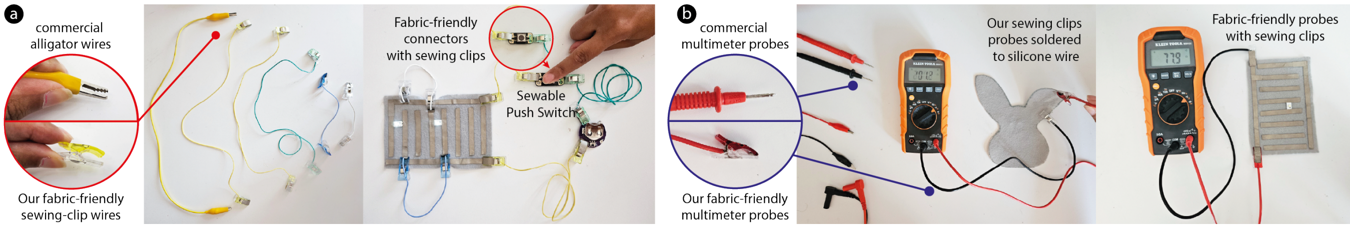

Figure 5: Designing fabric-friendly (a) male-male connection wires and (b) multimeter probes. Our novel connectors replace alligator wires that damage textiles (with sharp teeth, weight, and tensile force) using standard sewing clips soldered to soft silicone wire.

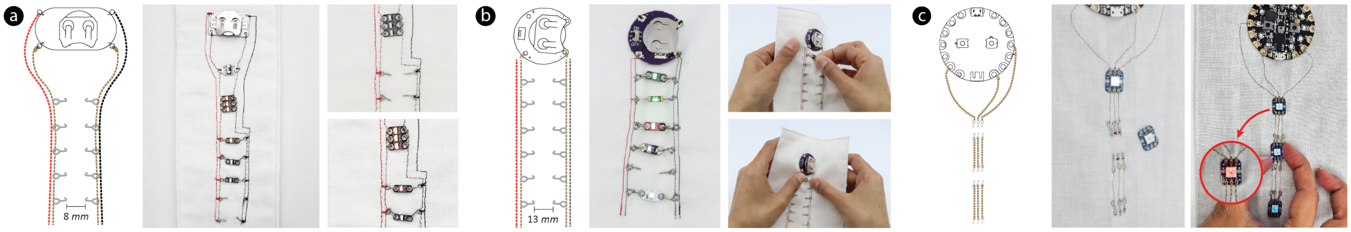

Figure 6: Machine-sewn FabricBoards: (a) FB1.1 with a switch, sewn LEDs and other hooked LEDs; b) FB1.2 with a cleaner design and wider range of motion; c) FB1.3 supports RGB LEDs through a microcontroller.

difficult and prone to shorting (D3). Additionally, the microcontroller was now semi-permanently stitched to the fabric, limiting reusability and increasing potential material waste.

3.4.1 *Quilting: FishBoard and ButterflyBoard.*

The earlier FBs (1.1–1.3) featured a flat, uniform appearance, prompting us to explore how aesthetic and textured elements (D1, D5), common in textile craft, could be integrated into fabric-based prototyping. Drawing inspiration from quilting techniques, we extended FabricBoards and designed expressive forms and textures to create two quilted boards: the FishBoard and the ButterflyBoard (D2), shown in Figure 7 and 8. Constructed like quilts, each board consists of three layers: a top appliquéd fabric layer using scrap materials, a middle insulating batting layer, and a backing fabric. The use of scrap and recycled materials in this approach contributes to the growing body of HCI research on sustainable textiles [31, 99]. Decorative and functional stitching (D1) was used to secure the layers and integrate pairs of conductive seams (see electrical resistance in Table B.1) with hooks and eyes, along with a switchable battery stitched to the back. These added layers and textures introduce partial dimensionality, leading us to describe them as 2.5D FabricBoards.

3.4.2 *Layering: GridBoard.*

This technique draws on ‘fabric layering’ practices (D5), wherein a semi-transparent overlay is combined with a functional base layer to create a composite textile with both visual appeal (in the overlay) and structural complexity or functional utility (in the underlay) (D3). While our earlier versions supported parallel LED circuits in a single straight line, many e-textile applications require two-dimensional layouts (D2) to illuminate specific shapes or visual elements [4, 11, 18, 101]. Inspired by this

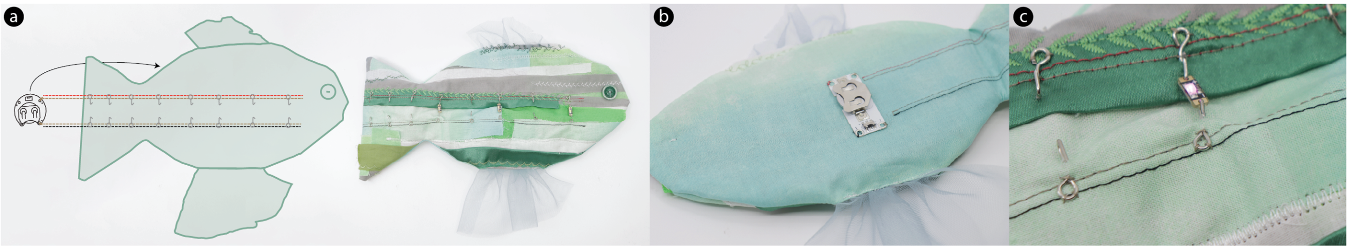

Figure 7: FishBoard (FB2.1): a) Front view with circuit diagram illustration, b) Back view, c) Close-up of a hooked LED.

Figure 8: ButterflyBoard (FB2.2): a) Front view with circuit diagram illustration, b) Back view, c) Close-up of a hooked LED.

need, we developed the GridBoard (FB3), an extension to the approach of FB1.2, as a horizontal expansion of the circuit layout, featuring 13 pairs of hooks repeated six times to form a 13 × 6 grid (Figure 9a), enabling up to 78 LED positions. Each column is powered by its own sewable battery holder, allowing independent circuit control. To complement this structure and support creative flexibility, we designed themed overlays (D1) such as 'Peas in a Pod' (Figure 9b–c) and 'Starfish' (Figure 9d–e), which conceal the circuit layout and guide complex LED placement. These overlays allow makers to prototype, plan, and visually test (D3) engaging 2D designs, offering a level of spatial interaction not supported by other research or commercially available e-textile kits.

3.5 FabricBoards in Diverse Textile Fabrication Methods

We explored alternative form factors and crafting techniques for FabricBoards. These experiments were conducted in parallel-to and after the workshops, guided in-part by participants' feedback and reflections, allowing us to further investigate the design potential of fabric-based breadboards through a range of textile crafts. While not all prototypes were equally robust, they enrich our design portfolio [2, 7, 22, 39] and demonstrate a continued commitment to material exploration beyond the user study. Therefore, these are not solutions meant to answer questions, but experimental vehicles for materializing questions [23].

PatchBoard. Inspired by prior work on modular e-textile prototyping in Wearable Bits [49], we explored ways to create a modular FabricBoard. The PatchBoard consists of a number of felt fabric pieces (D5) in the same hexagonal shape that forms a tessellation, fitting together like a jigsaw puzzle (D2, D3), each with a different combination of hooks, eyes, and sewable components. Bringing a battery hexagon to an LED hexagon (Figure 10b) forms a connection through the hooks when they are engaged (Figure 10c). This modularity can be beneficial for quickly replacing damaged components, rather than reconstructing the entire circuit. However, this simple concept quickly adds complexity and limitations to the design process as considerations needed to be made on which hexagons receive hooks and which ones receive eyes (D3), similar to +/- poles of magnetic connections in LittleBits®[2] and ThreadBoard [40].

FeltBoard. We experimented with needle felting as a fabrication method [28] for creating a textile breadboard, using 100% Merino wool (carded and combed) for the base layered on a 9" × 12" white 100% polyester Tailor craft felt sheet for stability (D5). For the connection paths, we used Merinox conductive fibre (80% wool, 20% extra fine micro steel fibers, coarse micron Merino + Inox steel), see electrical resistance in Table B.2. Two parallel paths were felted to serve as power and ground, with red fibre added to mark the power line (D4), as seen in Figure 11. Note that, short circuits can occur due to the nature of the material as felted conductive fibres are prone to friction with felting needles and tend to interlock, catch, and bridge unintentionally (D3), unlike twisted or plied yarns that contain stray filaments. Their loose, directional, and entangled structure may cause them to fan out and latch onto adjacent paths, especially under motion, compression, or friction. This intrinsic microstructure gives the felt its softness and flexibility (D5), but also introduces unpredictability in this electronic application. However, our experiments revealed three effective ways to mitigate these construction issues. First, twisting the conductive fibres before felting helps them stay cohesive and reduces fraying or bridging.

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[2] LittleBits is a registered trademark of Sphero, Inc.

Figure 9: (a) GridBoard (FB3): showing some of the designs e.g., the "Peas in a Pod" and "Starfish" (b,d) with fabric overlays placed on top of the GridBoard (c, e), using 8 and 6 LEDs hooked on, respectively.

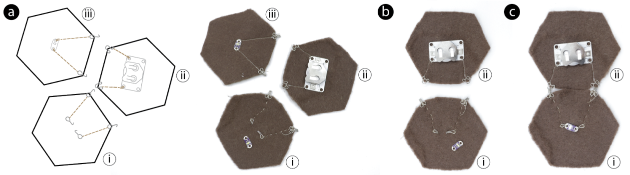

Figure 10: PatchBoard (FB4.1): (a) Patch piece (i) comprises four hooks, (ii) two eyes and a battery, and (iii) two hooks and an LED. (b) patch pieces i and ii can be paired and (c) connected, forming a closed circuit.

Second, holding the fibre bundle in hand (rather than placing it directly on the felt) limits stray fibres that can accumulate into short circuits. Third, keeping the felted sheet on the sponge while working, rather than lifting or shifting it, prevents backside fibres from merging. With these precautions, we achieved reliable results on layouts with aesthetic richness (D1) and playful creativity (D2), expanding the expressive potential for underrepresented makers who may appreciate these material qualities while maintaining visual clarity (D4), see Figure 11f.

CrochetBoard. To explore hand crochet as a fabrication method, we used a 2*mm* crochet hook and soft yarn (Estilo: 60% acrylic, 40% polyamide) to crochet a FabricBoard of three pairs of 10*cm* long connection paths with single crochet stitches, each using a different combination of conductive strands (D1, D5), see Figure 12. The full CrochetBoard took over 12 hours to complete (D3), with frequent rest breaks due to moderate wrist fatigue. Samples 1 and 3 were quick and easy to connect to, while Sample 2 (using conductive fancy yarn [41]) was unreliable due to the conductive thread being embedded and difficult to access (D3). Sample 1 offered the most reliable and convenient connection due to a larger conductive surface area, though it consumed more conductive thread. Sample 3 used less conductive material, making it more eco-friendly and visually integrated with the base fabric (D4) than the metallic appearance of Sample 1 (1Ω), but with double the electric resistance at 2.2Ω (see Table B.3). On the crocheted textile, both sewing pins and earring studs worked well with sewable components such as LEDs, sensors, and coin-cell battery holders.

KnitBoard. We experimented with both hand-knitting and machine-knitting approaches. For hand-knitting, we used 4*mm* needles and thick polyester yarn, creating two conductive connection paths over a length of 10*cm* with a garter stitch (Figure 13a–c). Sample 1, utilizing a hand-spun conductive fibre (50-50 blue Merino wool) selected for its matching weight (D1), proved unreliable due to inconsistent surface exposure of the conductive fibres (D3). Sample 2 combined non-conductive red yarn with conductive thread, which was difficult to knit and similarly unreliable (D3), as the thin conductive thread made securing components challenging. These limitations prompted us to explore machine knitting for tighter, more consistent results (see Figure 13e). However, inlay techniques (e.g., fair isle or jacquard) were found to be unsuitable for functional breadboard layouts because the machine layers the yarns. Instead, we designed edge-to-edge connection paths on the KnitBoard, using a size 6 front-bed stitch on a Kniterate machine with TAMM Estilo yarn (60% acrylic, 40% nylon) and Madeira HC12 conductive thread (see resistance in Table B.4). After additional experimentation, we refined the method using the plating technique, which improved conductivity by bringing the conductive yarn directly to the fabric's surface (D3, D4) where connections were secured using sewing pins on an ironing cushion (D2). While the hand-knitted board took over 3 hours to create, all machine-knitted samples were completed in approximately 30 minutes.

WovenBoard. We explored digital weaving as a fabrication method for creating a woven breadboard, the WovenBoard (Figure 14). Using AdaCAD [26], we designed a weaving draft for a computational Jacquard loom that mimics a traditional solderless breadboard layout (D3) using 2/20 cotton yarn for both warp and weft (D5). The design included four vertical conductive columns and two horizontal double-layer weft inlay traces (based on our recent work [1]), repeated five times and varied by weaving structure (tabby, twill, satin, shaded satin) and conductive material (Madeira HC12, HC40, or textured sperged yarn [41]), as seen in Figure 14. The vertical paths used a colour-coded supplementary warp (red for power, black for ground) with alternating coloured and conductive threads (D4). After weaving, the fabric ends were finished with a decorative fringe (D1), allowing the four vertical conductive paths to serve as attachment points for power and ground (D2). Electrical performance was strong across the ten inlay paths ($0.18 - 0.36\Omega/cm$), except for sample 3 ($8.62\Omega/cm$) where the supplementary warp paths showed higher resistance ($6.2\Omega/cm$) due to partial insulation from the shuttle weft (Table B.5). Despite this, the vertical power and ground paths supported up to 8 LEDs (secured with sewing

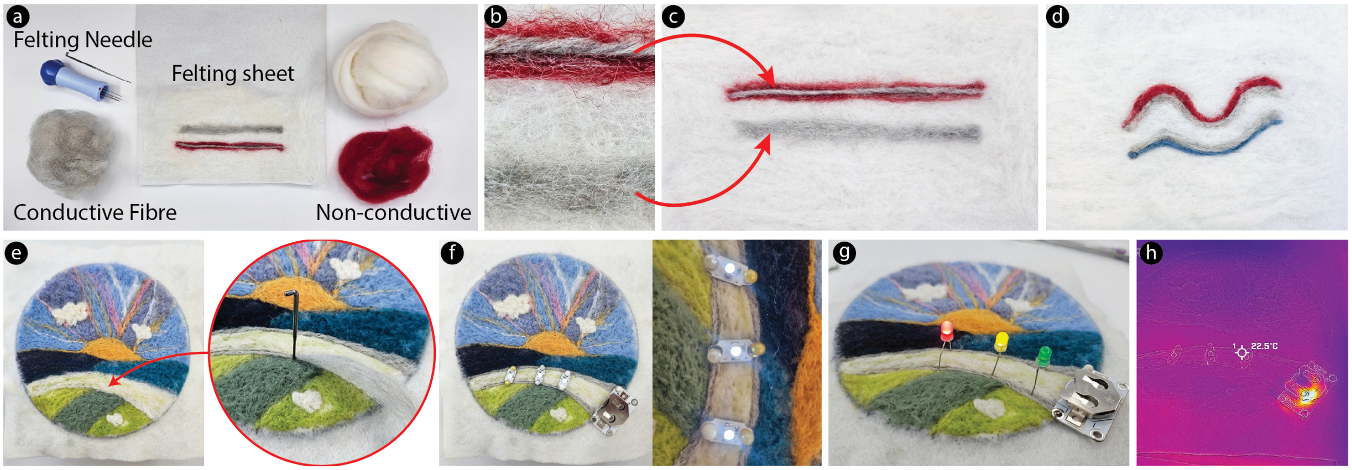

Figure 11: Designing the FeltBoard: (a) with needles and Marino wool (b) to felt 4 connection paths as 2 pairs of colour-coded power/ground lines (c) where two are straight lines and (d) two others are curved in parallel organic lines. e) adding conductive fibre as curved connection traces to a felted landscape extends the aesthetic possibilities where (f) sewable LEDs can be secured with sewing pins or (g) pinhole LEDs can be used easily and safely (h) as seen in thermal imaging.

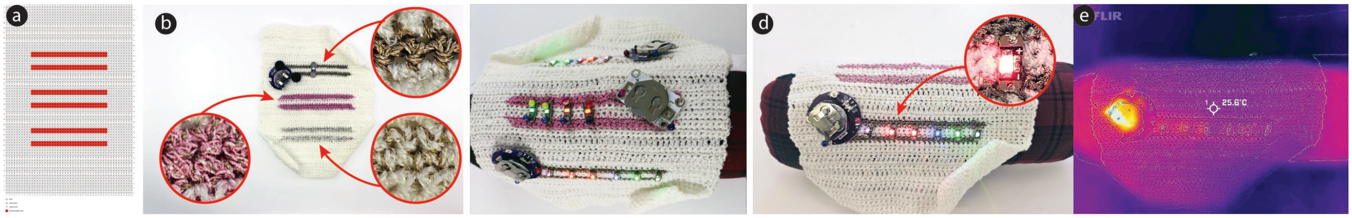

Figure 12: Designing the CrochetBoard: (a) on a digital stitch software (b) with 6 connection paths as 3 pairs of power/ground lines (c) that act as connection paths for up to (6x3) 18 LEDs (d) connected with magnets or sewing pins on an ironing cushion. (e) Thermal imaging shows the heatmap while powered by a 3V battery.

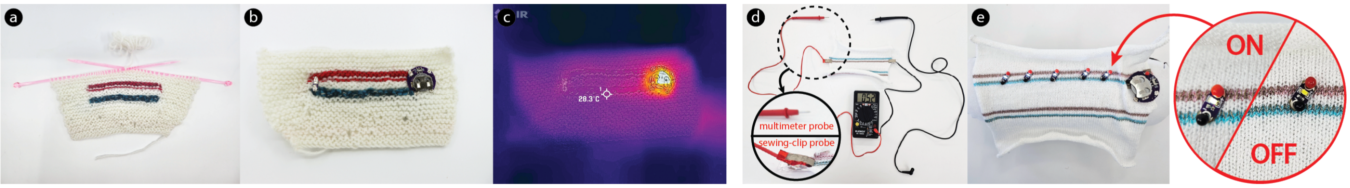

Figure 13: Designing the KnitBoard (a) using hand-knitting (b) with 2 connection paths as a pair of power/ground lines exhibits unstable performance as shown in (c) thermal imaging. Machine-knitting proved more reliable, (d) as shown when connected to our invented fabric-friendly multimeter probes, where (e) each connection path powers up to 6 LEDs with a 3V battery.

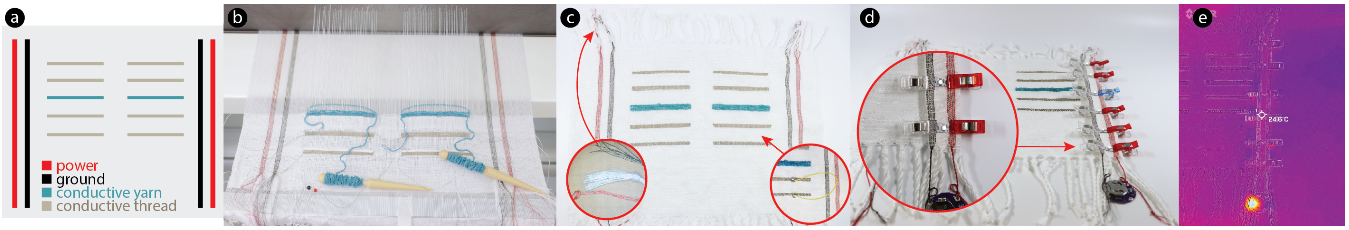

Figure 14: Weaving the WovenBoard: (a) as a digital draft, (b) on a computational loom, (c) resulted in conductive supplementary warp power/ground lines and inlay wefts, (d) that act as connection paths for 6+ LEDs powered by a 3V battery connected with a release knot to the functional fringes. (e) Thermal imaging shows the heat induced from the circuit.

clips) using a 3V coin cell battery, secured with release knots at the tassels (D1).

EmbroideredBoard. Digital embroidery has previously been used by HCI researchers to design and build circuit components [54, 76] using conductive thread. We applied this method with a ZSK embroidery machine to design a cotton fabric breadboard (D5) featuring three pairs of connection paths (Figure 15) outlined with a running stitch for visual clarity (D4) to colour-code power (red) and ground (black). The entire board was completely embroidered and replicable in under 3 minutes (D3). We used Madeira HC40 conductive thread and tested three $10cm$ samples with different stitches: Sample 1 used a default satin stitch ($0.45mm$ density), Sample 2 a tighter satin stitch ($0.2mm$), and Sample 3 a horizontal step stitch ($0.55mm$), as seen in Table B.6. Sample 3 outperformed both Sample 1 and 2 in terms of electrical conductivity, measuring at $1\Omega/cm$ compared to $2.2-2.5\Omega/cm$, while also using less conductive material and, thus, generating less e-waste. We used those results in further designs that expand the aesthetic possibilities (D1) of embroidery, freeing paths from the grid layout of straight lines into creative curved shapes (D2) and clear visual outlines colour-coding power/ground (D4) as a *SnailBoard*, see Figure 15e–h. For electrical contact, sequin pins ($13mm$, $0.5mm$ shaft, size 8) worked well with Adafruit LED Sequins, and regular sewing pins provided stable connections for other components. Embroidered stitches demonstrated superior structural integrity, appearing tighter, more uniform, and mechanically stable than the looser knit, compressible crochet, or lower-density woven paths (D5).

4 User Study

Our RtD explored how FabricBoards can support rapid early prototyping with wearable electronic components for testing and troubleshooting before committing to permanent stitching. The primary intended users of FabricBoards are e-textiles hobbyists, makers, and practitioners, as well as STEM learners ranging from school-aged children to graduate students and members of the general public, including women and other groups that are often underrepresented in electronics. Accordingly, we conducted a user study with university students who identify as makers, hobbyists, or practitioners (of textile craft, electronics, or both) and who reflected diverse gender identities, with women forming the majority. We conducted the study in the form of group workshops to understand the perceptions of FabricBoards and facilitate inter-participant ideation of their own fabric-based prototyping tools and e-textile applications. We conducted follow-up individual interviews to gather more insights that may not arise in a group setting. During the study, we collected qualitative data through audio recordings. Each workshop lasted 1.5 hours and was immediately followed by individual interviews lasting approximately 20 minutes per participant.

4.1 Participant Recruitment

Participants of the study were recruited through campus-wide recruitment posters and emails. Interested individuals were required to complete an online form providing demographic details (Table A.1) and indicating the practice they are most familiar with: either electronics, textile crafts, or both. A total of 18 participants were recruited, leading to the formation of five group workshop sessions. Each workshop was designed to include four participants, with an even distribution of two individuals identifying with textile crafts and two with electronics. Our final workshop had only two participants while still maintaining the 1:1 practice ratio. While our aim was to be broadly inclusive rather than target a single gender group, our sample organically consisted of 13 women (72%), three men, and two non-binary participants. This distribution aligns with prior work [61, 81] on how textile craft practices can be inviting of more women to physical computing. Notably, the only three men who enrolled were also the only participants who identified exclusively with electronics rather than any form of textile craft.

4.2 Group Workshop Setup and Study Procedure

The workshop was held in our lab's conference room and structured into three key activities: prototyping with current kits, i.e. using alligator clips (Activity 1), prototyping with our FabricBoards (Activity 2), and ideation of new prototyping tools (Activity 3). We started with an introduction to e-textiles and standard electronics prototyping tools (e.g., breadboards and alligator clips), followed by a demonstration of an LED circuit on a breadboard (Figure 16a). Participants were also shown how sewable components differ from through-hole ones due to their circular connectors pads. Each workshop concluded with a group discussion, where participants reflected on their experiences, challenges, and design suggestions.

Activity 1: Prototyping with Standard Tools. participants were paired (one with textile experience, one with electronics) and given a kit containing alligator clips, a sewable LED, and a coin cell battery holder (Figure 16b). Their task was to build a basic LED circuit (Figure 17a), then incrementally add two more LEDs. After completing all three connections, each pair reflected on their experience in a group discussion.

Activity 2: Prototyping with FabricBoards. Participants explored machine-sewn FBs in three stages. First, with FB1.2, each participant took turns attaching an LED and discussed the experience compared to Activity 1 (Figure 17b). Second, they worked in pairs with the QuiltedBoards, attaching four LEDs and reflecting on differences from FB1.2 (Figure 17c). Finally, in the GridBoard stage, participants collaboratively placed LEDs and traced their layout using paper overlays, simulating fabric-based design planning (Figure 18).

Activity 3: Ideation of Prototyping Tools. Participants engaged in a structured ideation exercise using five categories of prompt cards (Setting, Shape, Dimension, Connections, and Textile Craft), see Figure 16d. Each pair selected one card from each category as constraints to design a new FabricBoard or application concept. To support ideation, they received a sampler of materials representing each design element (Figure 16c). Pairs sketched, refined, and presented their ideas to the group (Figure 19).

4.3 Follow-Up Individual Interviews

After each workshop, individual interviews were conducted to gather further insights while the experience was still fresh. These interviews lasted approximately 20 minutes per participant and provided additional qualitative data for analysis. Questions were centred around interactions with the Fabricboards, and the user

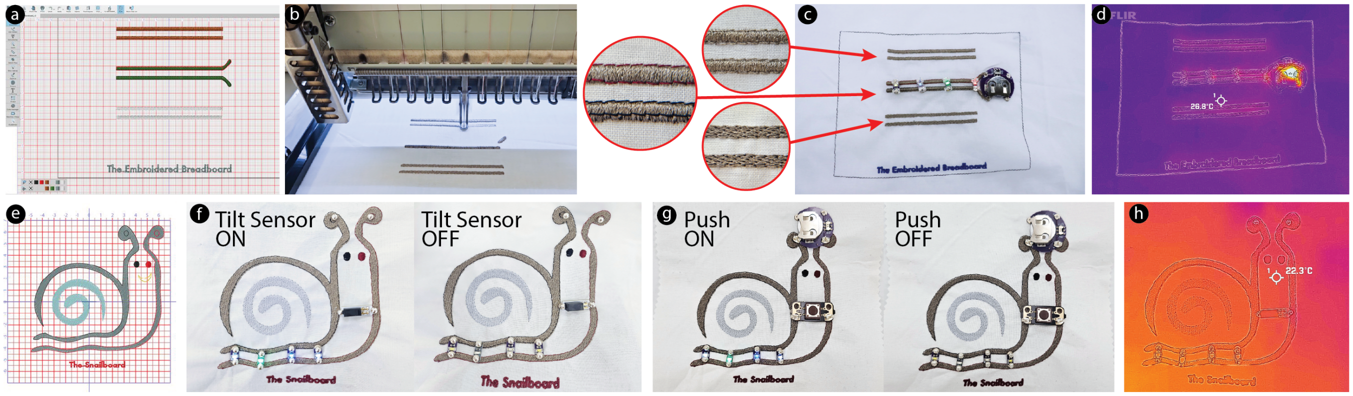

Figure 15: Designing the EmbroideredBoard: (a) on a stitch digitizing software, (b) with a multi-needle digital embroidery machine, (c) to create 6 connection paths as 3 pairs of power/ground lines where LEDs can be connected with silver-plated earring studs. Best stitch results were used to (e) design a freeform playful circuit, (f) with a tilt sensor, or (g) with a push button switch. (d,h) Thermal imaging shows the heatmaps while powered by a 3V battery.

Figure 16: Workshop materials: a) LED circuit demo using a regular breadboard; b) Activity 1 kit (alligator wires and sewable components); c) Activity 2 kit (e-textile tools and samples), and d) Activity 3 ideation prompt cards.

Figure 17: Participants engaging in: (a) Activity 1, using alligator clips to create an e-textile LED circuit; (b,c) Activity 2, using the three FabricBoard variations, and (d) Activity 3, ideating their own fabric-based prototyping tools or application.

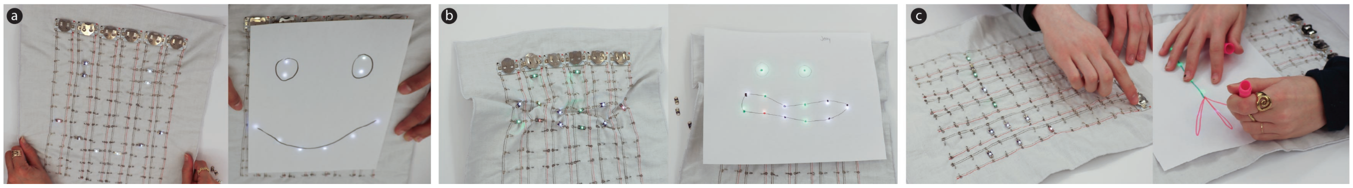

Figure 18: Participant GridBoard designs (Activity 2): a) smiley face (W1), b) "Jerry" (W3), and c) tulip flower (W4).

experience in comparison with current methods (i.e. the use of alligator wires) for forming the same circuit.

4.4 Data Collection and Thematic Analysis

Qualitative data was collected throughout the study via audio recordings of workshop discussions and interviews. These recordings were later transcribed and analyzed using Braun and Clarke's reflexive thematic analysis [8, 19, 20]. The transcripts of both workshops and interviews were analyzed together, with no distinction on whether quotes came from either component of the user study. Photographs were also taken during the workshop to document participant engagement, ideas, and interaction with the materials and artefacts (Figure 17).

5 Findings

Herein, we present findings from the thematic analysis of workshops and interview data, offering insights into participants' experiences and perceptions of FabricBoards across four key themes.

5.1 Theme #1: Designing for intuitiveness and ease-of-use

5.1.1 Familiarity impacts the ease of interaction and task framing. Participants had varied responses to the physical interaction required to hook components onto FabricBoards, depending on their backgrounds. Because stable connections required creating tension between hook pairs, users often manipulated the fabric by bringing the hook to the LED rather than the other way around. Textile craft participants found this motion intuitive, describing it as *"familiar"* (P14) and likening it to actions such as *"zipping up a dress"* (P13), *"hook[ing] a bra"* (P8, P12), or using a crochet hook (P8). P7 added, *"If you were a craftsperson or a seamstress, [...] then this would be very easy compared [to threading a needle]."* In contrast, electronics participants described the interaction as *"tedious"* (P5), *"frustrating"* (P16), and a *"repetitive gesture"* (P9), though still *"easier than alligator clips"* (P16, P13). Regardless of background, several participants described the hook-to-LED motion as instinctive; P15 explained, *"because you can't do that with a breadboard"* and P10 noted, *"The action is natural."* These reflections suggest that familiarity with textile crafts shaped participants' comfort and intuition with the FabricBoards interaction style.

5.1.2 Material properties support prototyping and shape user engagement. For women, participants' experiences with FabricBoards were strongly influenced by their tactile and flexible material qualities. P6 noted that fabric was *"a lot more flexible than a plastic breadboard"*, enabling them to bend it into *"certain positions"* while placing components, and said *"oh wait, I can fold the fabric [...] I can move [it] in any such way."* Several participants (N=5) described this flexibility as particularly helpful for e-textile prototyping. At the same time, participants pointed out that fabric thickness and surface texture impacted usability: P5 found the thicker 2.5D boards harder to bend, while P14 preferred a thinner material *"like a thin cotton or something instead [...] it could lay flatter."* Smoothness also mattered, with P1 emphasizing that *"the flat surface is probably best for connections with different sizes"* and P14 critiquing the *"fraying edges"* of textured boards as *"distracting"*. These reflections show that material properties like flexibility and texture actively shaped how women improvised, adjusted, and worked with the boards during prototyping.

5.1.3 Visual layout supports clarity and creativity. Participants emphasized that the visual layout of FabricBoards strongly influenced their understanding and approach to circuit design. Colour-coded threads were described as "*indicative*" (P6) and helped participants "*figure out where [they're] supposed to place things*" (P13), while the neat arrangement kept components visible and stable, unlike alligator clips, which were seen as "*messy*" (P8), "*tangled*" (P17), and caused LEDs to be "*flipped*" (P8) or "*lost in translation*" (P12). Participants with electronic experiences appreciated how the layout was "*straightforward*" (P4) and supported both novices and different prototyping stages. P3 noted it would be "*very convenient for demonstration or proof of concept*" while others saw it as a "*preview of the final product*" (P16) or "*a better representation of what it would look like*" (P16). However, issues arose when hook spacing did not match component sizes, especially on the GridBoard, leading to confusion and short circuits; P6 asked, "*The hooks were so far apart. How am I going to get these together?*" To improve clarity, participants suggested bringing hooks "*a little bit closer together*" (P7) and adding shaded placement zones, like "*a grey band where you can put the LED*" (P8). These reflections show that layout shaped not just usage but how participants reasoned about circuits and envisioned their final designs.

5.2 Theme #2: FabricBoard evokes curiosity and engagement

5.2.1 Ideation sparked by the FabricBoard. Participants' speculative ideas were directly shaped by their hands-on engagement with the FabricBoards, leading to a wide range of imagined applications in education, wearables, and games. Their concepts reflected the textures, layouts, and connection types introduced during the workshop. For example, P17 and P18 envisioned an interactive 3D fabric globe where Velcro-connected flags triggered audio, *"when they touch the country… there's a sound, say that the capital is X"* (P17), while others proposed wall-mounted tapestry boards (P13, P16), wearable LED bracelets (P9, P12), and soft interactive books for young children (P1, P4), see Table 2. Despite being limited to a few LEDs during Activity 1, participants in Activity 3 designed complex circuits with 10+ LEDs, enabled by the FabricBoard's flexible layout. P3 proposed a programmable 3D Rubik's cube in a fabric form with RGB LEDs on each face, *"to replicate the actual Rubik's cube movement."* Most participants framed their ideas as finished products rather than prototyping tools, with only 2 of 9 teams exploring iterative uses. As P4 noted, *"education... seems like a boring field, so we wanted to incorporate joy into learning"* while others (P5, P6) focused on accessibility for elderly users with low vision. These imagined uses reflected how participants interpreted the FabricBoards' potential through their material and formal cues, projecting their affordances into diverse real-world contexts.

5.2.2 Physical and verbal exploration of form and layout. Despite limited exposure to the design process, participants engaged in rich ideation around new interaction possibilities, often extending beyond the provided prompt cards. Textile craft participants considered how alternative base fabrics might affect usability, suggesting options like crochet, stretchy knits, or *"double knit fabric"* (P11); P6 asked, *"If I was able to pull it in all sorts of different ways, how would that do it?"*, while P9 argued, *"Knitting is better over crochet… it would be more efficient."* Participants also proposed alternative connectors including snaps (P1, P15), magnets (P7, P10), necklace clasps (P11, P14), pins (P12), Velcro (P6, P13), and conductive ink (P7). P17 suggested *"just have wire circles on the board… it*

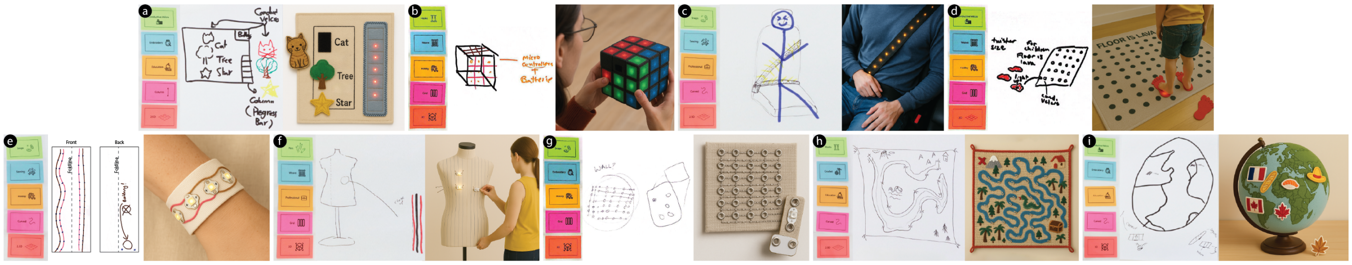

Figure 19: Participants' ideation sketches (Activity 3): (left) Selected ideation cards; (middle) Participants' sketches; (right) AI-generated rendering (by the authors after the workshops) based on the participants' ideas and sketches, using ChatGPT-4o.

Table 2: Participants' ideas from user study ideation activity (activity 3).

Idea	Participants	Dimension	Connection	Shape	Craft	Purpose
Animal Book (Fig.19a)	W1: P1, P4	2.5D	Velcro	Column	Embroidery	Educational game for kids
Rubrik's Cube (Fig.19b)	W1: P2, P3	3D	Hooks	Grid	Weaving	Educational game for kids
Seatbelt (Fig.19c)	W2: P5, P6	2.5D	Snaps	Curve	Sewing	Low vision assistance for elderly
Play Rug (Fig.19d)	W2: P7, P8	2D	Velcro	Grid	Weaving	Game for kids
Bracelet (Fig.19e)	W3: P9, P12	2.5D	Snaps	Column	Sewing	Leisure and fun
Mannequin (Fig.19f)	W3: P10, P11	3D	Pins	Grid	Weaving	Prototyping for garment making
Huge GridBoard (Fig.19g)	W4: P14, P15	3D	Snaps	Grid	Embroidery	Prototyping wall
Fantasy Map (Fig.19h)	W4: P13, P16	2.5D	Hooks	Curve	Crochet	Educational game for kids
Globe (Fig.19i)	W5: P17, P18	3D	Velcro	Curve	Embroidery	Educational game for kids

would be flatter," while P13 preferred using sewing pins or: *"something conductive to pin the LEDs in place."* Electronics participants focused more on layout and logic, with P16 encouraging *"mov[ing] away from the linear breadboard design"* and others experimenting with diagonal connections, which surprised some: *"I didn't expect the diagonal thing to work"* (P5). These reflections show how participants, regardless of technical background, treated the FabricBoard as a platform for modification and exploration, not just usage. FabricBoard prompted participants to become designers of the tool itself, acting as a provocation for exploratory, creative, and interpretive mode of engagement.

5.2.3 Emotional engagement and creative expression. FabricBoards, especially the GridBoard, served as platforms for expressive and creative exploration, with participants instinctively forming designs like light-up flowers and smiley faces (N=6). Participants described the GridBoard as a *"canvas"* (P13) that *"offers more space to try different things"* (P17), enabling freedom to experiment. P6 shared, *"It would occupy me for the longest amount of time... So many different possibilities I could do."* Rather than treating the activity as technical assembly, participants framed it as artistic play, using terms like *"decorating"* (P4, P14), *"freedom"* (P17), and *"playing"* (P13), with P5 noting, *"When you put the different patterns on top of the lights... that was very pretty."* The format encouraged visual expression by removing complexity; as P16 explained, *"When I think of an idea for an e-textile, I can just build it... I can just get to it"* and P8 added, *"The attention was taken away from making the circuit to adding the components... everything [else] was pre-done for you"*. Participants imagined wearable or artistic uses, including a light-up shirt (P5), a scarf (P8), or a *"starry sky"* inspired by Van Gogh (P1), revealing how FabricBoards supported not only prototyping but expressive and emotional designs.

5.3 Theme #3: Rethinking and adapting components for textile compatibility

5.3.1 Adapting component form factors for soft, wearable integration. Participants frequently described traditional electronic components (especially alligator clips and rigid LEDs) as incompatible with textile-based prototyping. Alligator clips were seen as *"clunky"* (P16), *"messy"* (P8), *"tangled"* (P13, P17), and *"bulky"* (P13) due to *"all the extra wiring"* (P8), making circuits visually confusing and hard to debug. Connections were also described as *"delicate"* (P13), *"finicky"* (P12), and *"fiddly"* (P11), often disconnecting during testing; P10 noted, *"You have to backtrack... if something's not working, then you have to follow the wires"* and P15 called them *"kind of a nightmare always"*. The weight and rigidity of current alligator clips caused instability, with LEDs that *"were flipping over... they move every way"* (P5), and these issues escalated with more components: *"We don't have space!"* (P18), *"This probably would not work with four LEDs"* (P13). Even some of our FabricBoards introduced slight rigidity; P16 observed, *"The more components you add, the more rigid [the FabricBoard] would get"* while others noted the boards became *"heavy"* (P2) and compromised *"the way the fabric feels and how everything flows together"* (P12), making it *"a bit more stunted."* Although hooks improved alignment with textile workflows, they still added stiffness. These reflections highlight the need to consider not only connectivity but also how components affect the softness, flow, and usability of textile-based breadboards.

5.3.2 Designing for diverse abilities and inclusive access. Among our participants, women raised accessibility concerns while using commercially-available e-textile prototyping kits. Sewable LEDs were described as *"so small"* (P5) and *"hard to pick up"* (P7). P5 noting, *"I do have sweaty hands... trying to clip the circuits on the alligator clips, it was a little bit difficult because it kept slipping"* and P7 adding, *"Maybe if I had like arthritis or something"* the components would be too difficult to use. P9 pointed out that handling and attaching components is *"a little harder if you're not as dexterous"* and P11 noted that it was already challenging *"with long nails"*. Participants also encountered issues with visual clarity of sequin LEDs; P6 explained, *"If I wasn't wearing my glasses, I know I would struggle to see which one was the positive side and which one was the negative"* and P2 described polarity labels as *"the challenge"* because *"they're pretty small"*. P9 emphasized that colour-blind users *"aren't going to know what this is"* referring to the low contrast of mixed fabric colours on 2.5D quilted boards, and recommended adding *"like a little colour marker"* for polarity. These reflections point to how women were thoughtful in thinking about other needs, not just their own, and the need for inclusive components design that prioritizes larger, more graspable, and visually clear elements to support women and users with limited dexterity, vision impairments, or other accessibility needs.

5.4 Theme #4: Balancing simplicity and scalability

5.4.1 Supporting novice users without limiting learning potential. Participants emphasized that prototyping tools should feel simple, practical, and unintimidating, especially for beginners. FabricBoards were described as *"quick, practical, and foolproof"* (P1), with FB1.2 preferred for early prototyping due to its reduced visual distractions and lower cognitive load: *"this one is more easier to use"* (P3). P7 agreed that a cleaner board would better support complex tasks by avoiding distraction, while more decorative boards like the ButterflyBoard were seen as *"pretty"* (P10), *"cute"* (P1, P8), and *"like a Picasso"* (P12). Participants viewed those quilted ones as creative outlets than practical prototyping tools. P2 explained, *"apart from being creative, would I use this one? No, I still prefer the first one"*. Simpler tools helped participants (especially those with less electronics experience) build confidence through constraints, enabling them to *"test what works [and] what doesn't"* (P1) with clear visibility, as P5 noted: *"easy to use"* and components *"wouldn't get lost"*. However, participants also cautioned that simplicity alone is insufficient e.g., P15 pointed out limitations in scalability: *"you're limited to how many hooks you have"* and P17 added that without support for *"more complicated circuits, like with sensors"*, the FabricBoard could limit deeper experimentation.

5.4.2 Scalability and flexibility for advanced prototyping. While participants valued the clarity and ease of using FabricBoards for simple tasks, many expressed a need for greater flexibility in layout and compatibility with a wider range of components. Several noted that while the hooks worked well for LEDs, they were not suited for sensors or switches. As P7 explained, *"the hooks are great for the LEDs specifically… but if you wanted to use other electronics… you'd have to make a new connection"*. P14 described the setup as *"a little limiting"* and P15 added, *"it just wouldn't work… if you're trying to connect something bigger"*. Participants highlighted that more complex circuits can be difficult to prototype with the current form, with P17 noting that testing *"sensors or maybe something that had to connect to a processor"* was challenging, and P6 observing, *"with breadboards, you can put things really close together… with the FabricBoard, I don't know how I would incorporate buttons and switches and sensors"*. Modifying existing setups was also difficult, as P15 pointed out, *"you'd have to almost custom make it for each thing"* which conflicted with the iterative nature of prototyping. These reflections point to a key design tension between preserving the simplicity that supports early exploration, as seen in most commercially available e-textile kits, and enabling users to expand and adapt their circuits as they increase in complexity.

6 Discussion

Across our study, participants engaged with FabricBoards not as passive users, but as active interpreters drawing from their own backgrounds in electronics and/or textiles to reframe what the FabricBoards were, and what they could be. Notably, many of these makers were women, underscoring how fabric-based prototyping can attract groups historically underrepresented in electronics. Building on both our design research and our study findings, we discuss design implications and introduce new opportunities for fabric-based breadboards from the lens of the Computational Making Framework [80].

6.1 Aesthetics

Although 'aesthetics' was defined as the first integral component of computational making [80], it is often overlooked in the design of new breadboards and prototyping tools. Whether through playful arrangements of components or decorative choices, our findings show how participants treated the FabricBoards not just as functional tools, but as aesthetic canvases. We argue that aesthetics is not merely adorning but central to welcoming beginners, yet it is frequently dismissed due to unconscious biases embedded in tools designed by (and for) historically privileged groups [81]. Recognizing that the visual and material conventions of breadboards, jumper wires, and alligator clips emerged within a male-dominated field is essential for understanding why our participants find them visually cluttered, intimidating, or inaccessible. Notably, most related prototyping boards (including ThreadBoard [40], TeeBoard [71], and LeatherBoard [64]) were designed primarily by men and were not evaluated with participants of diverse genders, further reinforcing narrow assumptions about who these tools are for. An inclusive (re)design of breadboards should therefore consider diverse needs and prioritize clarity, legibility, and material appeal to actively invite broader participation, particularly from groups historically underrepresented in electronics. The long-standing popularity of sewable microcontrollers alongside the absence of compatible, craft-aligned prototyping boards further illustrates the gap between the needs of diverse makers and the tools currently available.

6.2 Creativity

Our work opens new avenues for conceptualizing and constructing breadboards beyond the traditional rigid grid layout. The drapability of our fabric-based breadboards enabled use on curved or soft surfaces (such as ironing cushions, pin cushions, mannequins, or directly on the body) supporting forms of in-situ e-textile circuit design that are not possible with existing methods such as alligator clips [15] or stitching conductive thread [30]. Building on prior work that scaffolds user ideation of e-textile applications [49], our approach supports not only ideation but also prototyping and testing of circuits in more creative, situated, and materially responsive ways. Participants designed smiley faces, flowers, discovered unexpected ways of using the FabricBoards (e.g., "diagonal connections"), and ideated applications such as wearable concert bracelets and sound-interactive LED maps, illustrating the value of tools that enable playful, expressive, and narrative interactions alongside technical function. Our experimentation further contributed an understanding of which textile crafts are most suitable for constructing breadboards that support creativity. Knitting, crochet, and weaving naturally maintain a grid-like structure, while needle felting and embroidery allow for curved or freeform alignments that better match real-world placements of components on garments and soft surfaces.

6.3 Constructing

Our goal was not only to design breadboards that are easy to use, but also easy to construct and replicate. We advocate for accessible fabrication methods (whether hand-made or machine-produced) that democratize breadboard design, lower barriers for new makers, and resist obsolescence [81]. While previous re-imagined breadboards often required modifying commercial kits (for example, gluing magnets [40] or soldering snaps [71]), we relied on off-the-shelf components as-is to support beginners and easily integrate into existing workflows. Participants compared standard alligator wires with our FabricBoards when prototyping identical circuits and consistently found FabricBoards to be more intuitive and compatible with small sewable components. Anecdotally, they also noted that FabricBoards were considerably more robust and less finicky than alligator clips, providing stable connections that reduced frustration and confusion during prototyping. Some designs, such as the GridBoard and PatchBoard, further supported modularity by allowing layers and components to be rearranged and reorganized fluidly.

6.4 Visual Clarity

Previous HCI literature has emphasized the importance of visualizing multiple representations in computational making [78, 80], particularly through encouraging sketching and visualizing ideas on paper first. Building on this, we not only explored how FabricBoards can directly support visual thinking during early design, but also extended prior prototyping boards [40, 64, 71, 98] by prioritizing visual clarity in the boards themselves. Our designs made connection traces explicit and unambiguous, reducing cognitive load during circuit assembly.

Where possible, we incorporated colour-coding for power and ground, that participants appreciated for preventing polarity-related confusion. To achieve this clarity, we employed craft-based techniques that embed visual cues directly into the material. For example, using twin-needle machine stitching to lay conductive thread alongside red/black thread, adding supplementary red/black warps when weaving conductive paths, using colourful sperged yarn [41] for connection weft inlays, plating conductive thread with coloured wool simultaneously when knitting connection courses/rows, and outlining machine-embroidered conductive areas with black/red running stitches. These techniques ensured that circuits remained legible and visually clear at a glance. We, therefore, call for wearable electronic components (particularly small sewable LEDs and sequins) to adopt clearer polarity markings as well, so that visual legibility is supported throughout the ecosystem.

6.5 Materiality

Our work expands HCI research on alternative breadboards (whether made from plastic [40, 98], t-shirts [71, 97], or leather membranes [64]) by exploring a broader range of textile crafts and their material possibilities. This shift requires embracing qualities such as flexibility, softness, layering, and the development of textile-native or fabric-friendly connection mechanisms [74]. Rather than serving as neutral backdrops, the materiality of FabricBoards actively shaped the circuits and ideas users imagined. This reflects Giaccardi's notion of materials experience, in which materials influence perception, decision-making, and engagement [34]. Participants responded to specific material qualities, contrasting the fraying edges of FishBoard and ButterflyBoard with the clean serged seams of FB1.1–1.3 and GridBoard. These insights align with hybrid craft research that positions materials as collaborators rather than constraints [36, 79], and echo findings from systems such as CurveBoards [98] and Hybrid Artisans [102], where material and spatial configurations guide users' thinking across both technical and expressive dimensions. Material choices in FabricBoards are therefore not merely aesthetic considerations but are strategic design elements that shape how users interpret, construct, and iterate on circuits.

6.6 Inclusivity

Although inclusivity is not one of the five original dimensions of the Computational Making Framework [80], Rode et al. explicitly call for broadening its scope, and we build on this by proposing inclusivity as an essential dimension for future work. While some prior research has engaged non-privileged groups in e-textile prototyping, such as children [61, 78] and people with vision impairment [35], our work contributes by engaging participants beyond the dominant demographic. Our findings suggest that textile crafts do not simply offer new construction methods for prototyping boards but they also invite broader and more inclusive user groups, shaping how people explore and imagine what breadboards could look like and how they should function.

Accessibility also emerged as a central concern in participants' critiques of traditional electronics tools (particularly in dexterity challenges, long nails, and difficulty reading polarity markings) most of which are issues that disproportionately affect beginners. These insights align with calls to rethink components through tactile and perceptual affordances [74, 89]. Participants suggested practical improvements such as colour-coding polarity on components and increasing the size and grip of LEDs, echoing inclusive design approaches in e-textiles [14]. These adjustments signal a broader shift toward treating visual, tactile, and ergonomic accessibility as integral to tool design rather than secondary considerations.

As Devendorf et al. argue, hybrid systems must centre users' embodied experiences, particularly when bridging technical and craft practices [25]. Our findings extend this position by demonstrating that accessibility and inclusivity are not add-ons but foundational principles for designing future fabric-based prototyping boards.

6.7 Sustainability

Although sustainable practice is not part of the five original dimensions of the Computational Making Framework [80], we argue that it should be considered a crucial addition for future work. Across our design research, FabricBoards consistently supported more sustainable prototyping practices. Extending approaches that rely on loose strands of conductive thread [1, 40] or stitched conductive-thread circuits [41, 42], which require cutting and disposal during troubleshooting and therefore generate e-waste, FabricBoards eliminate the need to use conductive thread during ideation, prototyping, or testing circuits. Instead, they enable plug-and-play use of components in their original form, without altering, damaging, or discarding materials. Once constructed, a FabricBoard can be reused repeatedly with a wide range of off-the-shelf components. We also report experiments' results that decreased conductive material use while constructing the FabricBoards (such as less stitch in-fill), thereby reducing e-waste. These approaches aligns with prior work encouraging the sustainable (re-)use of conductive materials [52], and contributes to the growing body of HCI research on sustainable textiles [31, 99]. By incorporating scrap fabrics and recycled materials, we extend these conversations into the domain of electronics prototyping. Together, these insights highlight the need for HCI researchers to reconsider the dominance of alligator wires and to explore new fabric-based prototyping tools that better support sewable components while addressing the sustainability challenges of e-textile development.

7 Limitations

While the RtD was 15 months long, the user study was conducted in a short-term workshop setting, offering valuable insights into early-stage engagement but not into long-term use, where factors like material durability, user appropriation, and repetitive usage may surface different challenges. Anecdotally, the FabricBoards demonstrated remarkable longevity and robustness, enduring repeated use by our five research team members for over a year, alongside their deployment in a user study where 18 participants handled them multiple times, though this durability was not formally quantified or measured. In future work, we plan to investigate the lifespan of fabric-based breadboards and their performance under daily conditions with repeated bending and folding.

Most participants were students or hobbyists, with a limited number ($N = 5$) having experience in both electronics and textile crafts, meaning the findings may largely reflect the experiences of non-expert users. We acknowledge our positionality as a research team composed mostly of women, which may have shaped the insights and sensitivities we bring to this area, and we recognize this as a limitation as well as a contextual influence. While the novelty of the tools and structured activities may have influenced participants' engagement, further research is needed to explore how professional e-textile designers or expert hybrid practitioners might use such boards.

Prototyping simple LED circuits is the dominant entry point for beginners in e-textiles, and thus, the primary use case focus of our research. Consequently, our findings may not fully capture the challenges of prototyping more complex e-textile circuits that involve intricate, non-trivial electrical designs. While our design explorations did include integrating components like microcontrollers (Figure 6) and sensors (Figure 3), further research is needed to investigate how fabric-based breadboards can be adapted to support advanced prototyping, specifically by exploring designs with power handling capabilities, expanded component compatibility, and layouts that are more suited to facilitate the integration and testing of sophisticated e-textile systems.

8 Conclusion

We documented the evolution of FabricBoards, a set of fabric-based breadboards used as a vehicle to explore the design space of e-textile prototyping kits through Research through Design and iterative development. From early experiments with everyday craft materials to a refined suite of diverse boards, each iteration surfaced new insights into how materials and construction methods can support circuit prototyping in soft, accessible, and visually coherent ways. Hooks emerged as a suitable connection method in our design research, though materials like conductive Velcro and snaps also revealed unique affordances and constraints that shaped interaction. Rather than optimizing for a single 'best' solution, our work highlights the importance of materiality as a contextual design decision. Alongside the machine-sewn FabricBoards, we explored a range of alternative form factors inspired by textile crafts, including crochet, hand and machine knitting, machine weaving, and digital embroidery. The experiments demonstrated that while needle felting was unreliable due to fraying and short circuits, digital embroidery offered the best results, outperforming weaving, knitting, and crochet in conductivity, reliability, and structural integrity.

Our user study with 18 participants showed that practice familiarity, material properties, and visual layout contributed to intuitive interaction, with users describing FabricBoards as easy and engaging to use for both creative and functional prototyping. The study attracted a majority of women and non-binary participants, suggesting that textile craft approaches can broaden engagement in electronics for groups historically underrepresented in breadboard prototyping. This highlights the potential of FabricBoards to support more inclusive pathways into circuit prototyping by aligning with the craft practices and material aesthetic qualities that resonate with these communities.

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A User Study Participants’ Demographics

Table A.1: Participants’ demographics over 5 workshops, including self-identified practice and the associated number of years of experience (YoE).

Workshop #	ID	Age	Gender	Practice	YoE: Electronics	YoE: Textiles	Textile Craft Practice
1	P1	27	W	Electronics	8	0.5	Sewing
1	P2	39	W	Textile Crafts	0	4	Sewing
1	P3	27	M	Electronics	4	0	—
1	P4	30	W	Both	5	12	Knitting, Sewing
2	P5	20	W	Electronics	0.5	3	Knitting
2	P6	20	W	Both	6	11	Crochet, Knitting, Sewing, Embroidery
2	P7	22	W	Both	3	5	Crochet, Sewing, Embroidery
2	P8	21	W	Electronics	4	0.5	Crochet, Sewing
3	P9	22	W	Both	4	3	Crochet, Knitting, Sewing
3	P10	22	W	Textile Crafts	0	5	Crochet, Felting
3	P11	28	W	Both	1	20	Knitting, Sewing
3	P12	20	NB	Textile Crafts	0	8	Knitting, Sewing
4	P13	18	W	Textile Crafts	0.5	3	Sewing
4	P14	20	W	Textile Crafts	0	10	Crochet, Knitting
4	P15	20	NB	Electronics	4	6	Knitting
4	P16	19	M	Electronics	2	0	—
5	P17	23	W	Textile Crafts	1	7	Sewing
5	P18	27	M	Electronics	3	0	—

B FabricBoard Resistance Experiments

Table B.1: Electrical resistance of the machine-sewn FabricBoards.

FabricBoard	Stitch Type	Conductive Material	Path Dimension ($L \times W$)	Resistance (Ω/cm)
ButterflyBoard	straight stitch	Madeira HC40	$32cm \times 1mm$	$11.80(\pm 4.06)$
FishBoard	straight stitch	Madeira HC40	$38cm \times 1mm$	$8.35(\pm 2.64)$
GridBoard	straight stitch	Madeira HC40	$28cm \times 1mm$	$7.10(\pm 1.33)$

Table B.2: Electrical resistance of the FeltBoard

FabricBoard	Stitch Type	Conductive Material	Path Dimension ($L \times W$)	Resistance (Ω/cm)
Sample #1 (on top)	—	Bart & Francis Merinox fibre	$12.5cm \times 3mm$	$3.22(\pm 0.52)$
Sample #2 (full)	—	Bart & Francis Merinox fibre	$12.5cm \times 1cm$	$5.40(\pm 1.27)$
Sample #3 (beside)	—	Bart & Francis Merinox fibre	$8cm \times 4mm$	$2.29(\pm 0.11)$

Table B.3: Electrical resistance of the CrochetBoard

FabricBoard	Stitch Type	Conductive Material	Path Dimension ($L \times W$)	Resistance (Ω/cm)
Sample #1 (grey)	Single crochet stitch	Madeira HC40, 1 strand	$9cm \times 5mm$	$1.08(\pm 0.07)$
Sample #2 (pink)	Single crochet stitch	HC40+Polyester serging thread	$10cm \times 7mm$	$2.57(\pm 0.31)$
Sample #3 (black)	Single crochet stitch	Madeira HC40, 4 strands	$9cm \times 5mm$	$2.27(\pm 0.16)$

Table B.4: Electrical resistance of KnitBoards

FabricBoard	Stitch Type	Conductive Material	Path Dimension ($L \times W$)	Resistance (Ω/cm)
Sample #1 (hand-made)	garter stitch	Madeira HC12	$11cm \times 9mm$	$1.03(\pm0.06)$
Sample #2 (hand-made)	garter stitch	Custom hand-spun	$11cm \times 7mm$	$31.55(\pm1.43)$
Sample #3 (machine-knitting)	front-bed stitch	Madeira HC12	$19cm \times 4mm$	$3.375(\pm0.43)$
Sample #4 (machine-knitting with plating)	front-bed stitch	Madeira HC12	$19cm \times 4mm$	$5.95(\pm2.00)$

Table B.5: Electrical resistance of WovenBoard

FabricBoard	Weaving Structure	Conductive Material	Path Dimension ($L \times W$)	Resistance (Ω/cm)
#1 Weft Inlay	Tabby	Madeira HC40, 1 strand	$8cm \times 4mm$	$0.36(\pm0.02)$
#2 Weft Inlay	Tabby	Madeira HC40, 2 strands	$8cm \times 8mm$	$0.33(\pm0.04)$
#3 Weft Inlay	Tabby	Madeira HC12, 1 strand sperged yarn	$8cm \times 8mm$	$8.62(\pm2.7)$
#4 Weft Inlay	Tabby	Madeira HC12, 2 strands	$8cm \times 5mm$	$0.18(\pm0.02)$
#5 Weft Inlay	Satin	Madeira HC12, 3 strands	$8cm \times 4mm$	$0.18(\pm0.01)$
#6 Complementary Warp	Tabby	Madeira HC40	$12cm \times 5mm$	$6.26(\pm1.34)$

Table B.6: Electrical resistance of the EmbroideredBoard

FabricBoard	Stitch Type	Conductive Material	Path Dimension ($L \times W$)	Resistance (Ω/cm)
Sample #1 (top)	satin (density: $0.45mm$)	Madeira HC40	$8cm \times 3mm$	$2.27(\pm0.16)$
Sample #2 (middle)	satin (density: $0.2mm$)	Madeira HC40	$8cm \times 3mm$	$2.57(\pm0.31)$
Sample #3 (bottom)	step stitch (density: $0.55mm$)	Madeira HC40	$8cm \times 3mm$	$1.08(\pm0.07)$