Integrating Textile Materials with Electronic Making: Creating New Tools and Practices

Irene Posch
TU Wien
Vienna, Austria
irene.posch@tuwien.ac.at

Geraldine Fitzpatrick
TU Wien
Vienna, Austria
geraldine.fitzpatrick@tuwien.ac.at

ABSTRACT
We introduce and discuss the design and use of new tools for electronic textile making. Electronic textiles, or eTextiles, are increasingly produced and used in experimental interfaces, wearables, interior design, as well as in the education and maker cultures. However, the field relies on tools specific to either the textile or the electronic domain, neglecting the distinct requirements, and potentials, of their intersection. To address this gap, we explored the design of new tools, targeted at specific needs and use cases of electronic textile making and the materials used. Three resulting prototypes have been evaluated through use in both our own practice and among a group of experts in the field. Our findings show the importance of specialized tools for routines essential to the field eTextiles, their role for the emergence of new practices, as well as for the understanding of the discipline.

Author Keywords
Crafts, Design, DIY, eTextiles, Making Cultures, Maker, Textiles, Tools, Wearables

ACM Classification Keywords
• **Human-centered computing~User studies** • *Human-centered computing~Systems and tools for interaction design* • *Human-centered computing~Ubiquitous and mobile computing*

INTRODUCTION
Recent years have been dominated by the spread of computational technologies and computer mediated interactions beyond the screen into the physical world, into growing areas of everyday life. This also includes the field of electronic textiles [3, 13, 15, 18]. Advanced technological developments [8, 19, 20] as well as educational and DIY kits [4, 22] have made electronic components accessible to the integration with textiles, fostering the expansion of computational technologies into textile domains. However, their development has been mostly discussed from a perspective of technological achievement, neglecting the processes and interactions that bring the electronic textile artefacts into being. Even the explorations of craft approaches in the domain of electronic textiles [5, 7, 16, 17] have largely been made using legacy electronic or textile crafting tools. The experiment undertaken here is to design new tools that account for both textile and electronic requirements when working on eTextiles [23]. We especially want to design for a textile making practice including electronic functionalities, rather than electronics that also incorporate some textiles. The purpose is to intervene in the existing tool space, and inquire about potential new routines, possibilities, and values within the domain.

TEI '18, March 18–21, 2018, Stockholm, Sweden

ACM ISBN 978-1-4503-5568-1/18/03…$15.00
https://doi.org/10.1145/3173225.3173255

BACKGROUND AND MOTIVATION
Electronic textiles, or eTextiles, describe textiles or fabrics that enable digital and electronic functionalities to be embedded in them. The use of textiles for electronic and computational applications has been explored through the crafting of conductive and resistive threads in specific patterns to hold electronic functions [16, 17] and the combination of textile materials with custom electronics and circuit boards [5], among them the commercially available Arduino Lilypad [12] and the Adafruit Flora [22].

Discourse and developments in the field of eTextile kits have mostly focused on making electronic components connectable on and with textiles with the goal to incorporate the qualities inherent to the textile material - its softness, flexibility, and aesthetics - into new uses and interaction scenarios. Studies of the use of such kits have shown their potential to attract a different user group to computational technologies [4, 6]. Current instructions and kits include conductive thread and a needle for sewing conductive thread, and use the same tools electronics use for decades for electric measuring and connecting tasks [8, 22]. They propagate novel outputs combining textiles and electronics, however, they do not reference the changed production possibilities of an integrated electronic textile practice.

The design of new tools is motivated by the wish to account for the specific needs when working with electronic textiles. Tools cannot be considered neutral. Their form, function and cultural embedding explicitly or implicitly include or exclude specific experiences, insights, and goals

[14]. Examining the tools allows us to look outside the work itself, the conditions that make it possible in the first place [1]. Tools are not just important to functionally complete tasks, but often also take on a role to figuratively stand for a practice. Historically established stereotypes surface, suggesting who uses the tool, in what domain it is used, and what artefacts it brings into being [2]. In a research through design process we want to explore what tools specific to a practice of electronic textile crafts might look like? What would the availability of targeted tools mean for the practice of eTextiles?

METHODOLOGY

We approached the task giving high importance to the pondering of material cultures, aesthetics, and context of use in the design process in order to create tools that reflect the functional as well as formal needs of the practice.

The research presented here discusses the genesis, design, and evaluation of three versions of measurement/power tools, that we named *eTextile Tape*, *Travel Tester*, and *eTextile Tester*. We engaged in this work from the position of reflective practitioners in the field, using personal practice as the first point of investigation. Observation and reflection on the practice, tools, and routines regularly used by the first author over the duration of two months marked the starting point of the design process.

Within the design process, all three tools underwent several design iterations to reach the level of elaborated prototypes usable in everyday making. We base our explorations on the use of these prototypes within established eTextile practices to understand the role of specific tools.

The *eTextile Tape* and *Travel Tester* were informally tested through their integration in the personal practice of the first author. The experiences gained from this consequently informed the design of the third tool, the *eTextile Tester*. This tool was given to a group of 28 practitioners in the field with a follow-up questionnaire one year later. To probe the unbiased integration and usage of the tool into their practices, we did not announce that we might ask in the future about their experiences with the tool. The online questionnaire asked quantitative and qualitative questions about their experiences, and probed the role of the tool for the practices of this group of experts. The thematic analysis of their feedback is the basis for the discussion of our findings.

EXPLORING FORM AND FUNCTION

Reflecting on the experiences of the first author in their own making practices, we identified making contact to the textile material to measure electric continuity and to apply power as essential key routines in the making of textile electronic artefacts. In conventional electronics applications, testing continuity is done with a multimeter. Multimeters are used for testing a wide array of industrial and household devices. They have multiple measurement functions, such as electric current, voltage and resistance, to select from, and are designed to withstand high currents and rough working environments. To take the measurement, two multimeter probes are put in contact with the device under test, and the result is displayed on the meter. Electrical continuity is usually indicated through a beeping sound. Standard multimeters do not supply power.

Working in the domain of electronic textiles, creating a circuit poses different challenges than working with conventional hardware electronics. Applications are in a low-power range and the materials are soft and often delicate to handle. Conductive threads are used to construct connections rather than insulated cables. Mostly realizing custom designs, connections have to be designed and realized from scratch, including connecting hardware parts to textile elements where no standard solutions exist. Consequently, there is an increased need for testing the actual functionality of established connections, as well as to test for potential short circuits of the conductive textile materials. Applying power allows testing the circuit, or parts of it, before it is finally connected. It allows probing the functionality of electronic components that are about to be used. Integrating components in eTextile projects is often more labour intensive than in conventional electronic projects, hence knowing the component functions is especially helpful. In the following, we describe our explorations of tools to address these challenges.

Design 1: From Textile Tool to eTextile Tool

In our approach to look at eTextiles as electronic textile crafts, we turned towards textile cultures, skills, and techniques for inspiration. Studying the textile tool space we noticed the tailor’s tape as omnipresent in textile craft studios to measure lengths, one of the main measuring tasks in textile making. This led us to explore interaction scenarios towards one of the main measuring tasks of electronics: electric conductivity; And so to make an *eTextiler’s Tape*.

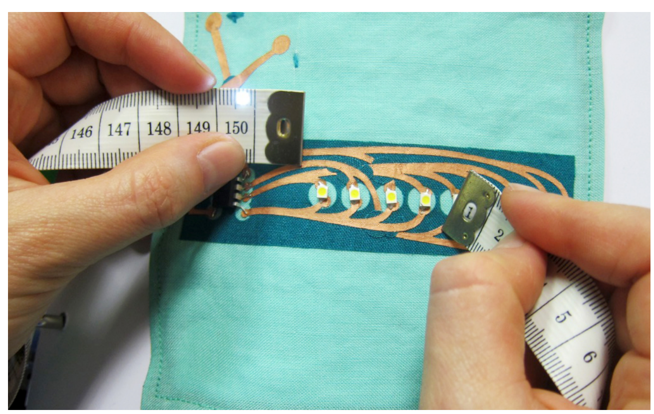

Figure 1. Testing scenario with the eTextiler’s Tape. The ends of the tape touch the material under test, essentially working as a switch to the circuit. If the material is conductive the circuit closes, the LED lights up to indicate the conductivity.

The tape measure or tailor's tape is part of the standard equipment of sewing baskets. It is essentially a flexible ruler, usually 1,5 meters (or 60 inches) long and between 0,7 and 1,5 cm wide with the cm or inch measurements printed along the length. It is made of durable but flexible and light material. It most commonly features metal handles at its ends, probably to prevent fraying of the material and to clearly mark the endpoints. Since its introduction in the 19th century, it has become a ubiquitously used and iconic textile tool. Tailors often 'wear' the tape around their neck, the tape being always within fast reach of the hand even when wandering around the studio or moving around a client to take measurements.

To appropriate the tailor's tape as an eTextile tool, we used the metal fastenings at the end to make electrical contact to conductive materials. We scratched the surface for increased conductivity and connected the ends with conductive thread to form an electric circuit including an LED and a 3V coin cell integrated into the tape. The LED is mounted close to the end, lighting up when the circuit is closed – when both metal ends touch a continuously conductive material. A tool very commonly used for measuring tasks in textile practices now becomes a tool for one of the essential measuring needs of electronic work: a tool to measure the length as well as the conductivity of a textile (Figure 1).

An additional switch allows switching between two modes: testing continuity and applying 3V power. When switched to the power mode, the ends connect the device under test to the positive and negative terminal of the coin cell, applying power when the circle is closed. When switched to the testing mode, the LED lights up when there is an electrically conductive connection between the two ends.

Our own reflective usage of the tool over a year highlighted a few points worth noting: The tool fulfilled the practical expectations: We could get feedback about the conductivity of a material through the LED and apply 3V to circuits or components. The interaction with the tool was very close to interaction scenarios known from tailoring. Worn around the neck, the ends to probe the material were conveniently within reach of our hands. However, while the metal ends of the tape could be used as a connecting probe, they did not allow for high precision. Also, the tool design needed the probes to always be held manually during the measuring, as there is no possibility to fix it to the material.

Apart from these practical experiences, we also received interesting reactions from people whenever we showed the tool in workshops or presentations to audiences of makers and novices in the field. The iconic form and handling of the tool clearly placed it into the context of textile crafts. The use of the tool, making the LED light up through electric conductivity, bridged the textile context with an electronic circuit. This straightforward combination of textile aesthetics and electronic functionality embedded in the tool, prompted immediate ideas about the production space of electronic textiles.

Design 2: Adapting to New Material Contexts

The goal of the second tooling experiment was to design a 'ready at hand' tool to detect conductive materials for potential inclusion within an eTextile practice. The *Travel Tester* is a tool to always take along when on the look out for new materials that fulfil aesthetic and haptic qualities, as well as hold desired conductive properties.

Metallic materials have been produced and used in textile crafts for centuries, with early written mentions dating back to the Old Testament [10]. A variety of wires and threads spun out of gold, silver or copper, and also beads and jewellery elements, traditionally appreciated for ornamental reasons, are of potential interest for eTextile practices for their conductive properties [18]. Today these materials are a rare find. Lurex is often used as a replacement, mimicking the metallic appearance without possessing its material properties. Our experience showed, that sellers often do not know about the composition of the materials they are selling. As electric conductivity is not a prime concern for them or their customers, the materials are not sorted according to their conductivity, and sellers are not prepared or able to answer related questions.

To make it easier to find these materials and so make them accessible to the field of eTextiles, we developed a prototype consisting of a black ribbon with conductive ends. If the points touch a continuous conductive material a circuit is closed and the LED lights up (Figure 2a and 2b). Folded up it fits easily in a bag or pocket.

Figure 2a and 2b. A small travel tool in use at a market in Turkey (2a, top) and India (2b, bottom), looking for local materials of potential for electronic textile practices.

Our experiences of bringing the tool to shops to test different materials have been very positive. Often the sellers were as interested as we were to learn if a material was conductive or not, and to learn what we would do with this information. Motivated by seeing the LED light up, sellers started looking for more materials and artefacts we could test for their conductive properties. In presenting them to us and waiting for the LED to light up, they would often also talk about the 'original' use context of a specific material, or the specific purpose of an artefact we were looking at.

The *eTextiler's Tape* was an experiment to translate electronic functionality onto an existing textile tool. The *Travel Tester* aimed at making a tool for detecting conductive materials as portable as possible. Building on these two distinct approaches, the motivation for the third tool was to design a portable tool that lives within a studio practice of eTextiles.

Design 3: Designing for New Practices

The *eTextile Tester* allows for continuity testing and supplying of 3V, but in a different form than the tape tool we previously introduced. Again inspired by materials and routines of textile crafts, it uses pins to connect to the device under test. Pins have been used to fastening diverse objects or soft material together for centuries, but have an especially strong connotation of being sewing equipment, often seen symbiotically with the practice [2]. Pins, made out of thin, sharpened metal wire, are pierced through the material to hold it together or place a mark. They are a precise, firm and temporary way to connect (to) textile material. Being metal, they are also conductive. In the design of the *eTextile Tester* these formal and functional properties of a pin are repurposed: they become the probe to electrically connect to the textile material (Figure 3).

The design of the *eTextile Tester* is primarily driven by practical considerations to create a small and flexible electronic tool that integrates well with the materials and routines of textile crafts: The body of the *eTextile Tester* is a small almond shaped 3D print, holding the coin cell and the switch to choose between the two modes, with labels indicating which mode is selected. Each side of the body extends to a cord that ends with a pin. To integrate well with textile practices, the connecting cord consists of a flexible conductive core coated with a braided textile cord, producing a thin and flexible insulated textile conductor. They are long enough so that the tool can be worn around the neck, similar to the tailor's tape. The connection of the pin to the cord is covered with a 3D printed handle, enlarging the area to grasp the pin. The handles are of different size and colour, and labelled to differentiate between the anode and cathode of the coin cell. An LED, lighting up if electric continuity is detected, is integrated within the bigger, yellow pinhead. When not in use, the pins can be stuck into the felt cover of the almond shape body (Figure 4a-d).

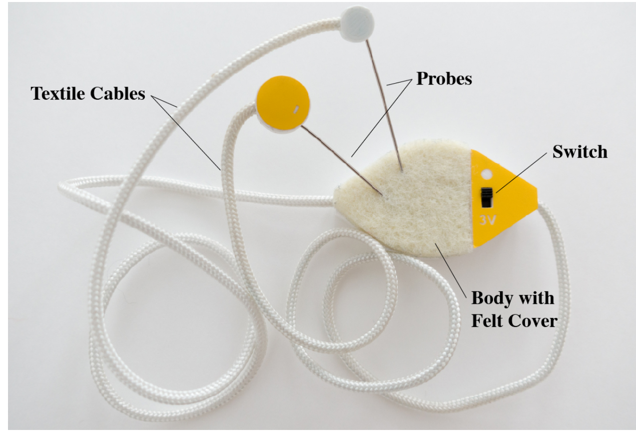

Figure 3. The eTextile Tester tool: Pins are used as probes to electrically connect to the textile material. They are connected to the battery in the body of the tool through a textile cable. A switch enables selecting between supplying 3V or measuring electric continuity. The LED indicating continuity is included in the yellow handle of the tool. When the pins are not in use they can be stuck into the felt cover.

USING AND EVALUATING THE ETEXTILE TESTER

The evaluation of the *eTextile Tester* focused on its integration within the existing practices of eTextile practitioners. The hypothesis was that, as active makers, they were the target audience.

Participants were accessed via an annual eTextile workshop meeting of practitioners in the field. Each participant was invited to contribute physical work samples to an eTextile Swatchbook in exchange for other participant's swatches [11]. The *eTextile Tester* in the form shown above was included as one such swatch, given to 28 participants. The tool was mounted in the book in a way that it could easily be taken out to use and was complemented by a brief description [9]. A practical demonstration of how to use the tool was given during the workshop. The group of recipients was predominantly female (five male participants). They came from three different continents and were of diverse ages, the majority of the group being between 30 and 40 years. They had individual backgrounds in the fields of design, textile, fashion, and engineering, but all had an established eTextile practice of their own.

The survey we sent them via email after a year included a total of ten quantitative and qualitative questions about the adoption of the tool into their routines, and the role the tool took within their practice.

Out of the 28 recipients, 16 completed the survey (P1-P16). Out of the 16, two said they never used the tool: One said they did not do any practical work in the field of electronic textiles over the past year (P1), the other one said they wanted to keep the tool in its original form within the Swatchbook (P16). Three people said they tried it but did not usually use it when working on eTextile projects because they preferred using a multimeter (P13, P15) or did not remember it at the right moment (P14).

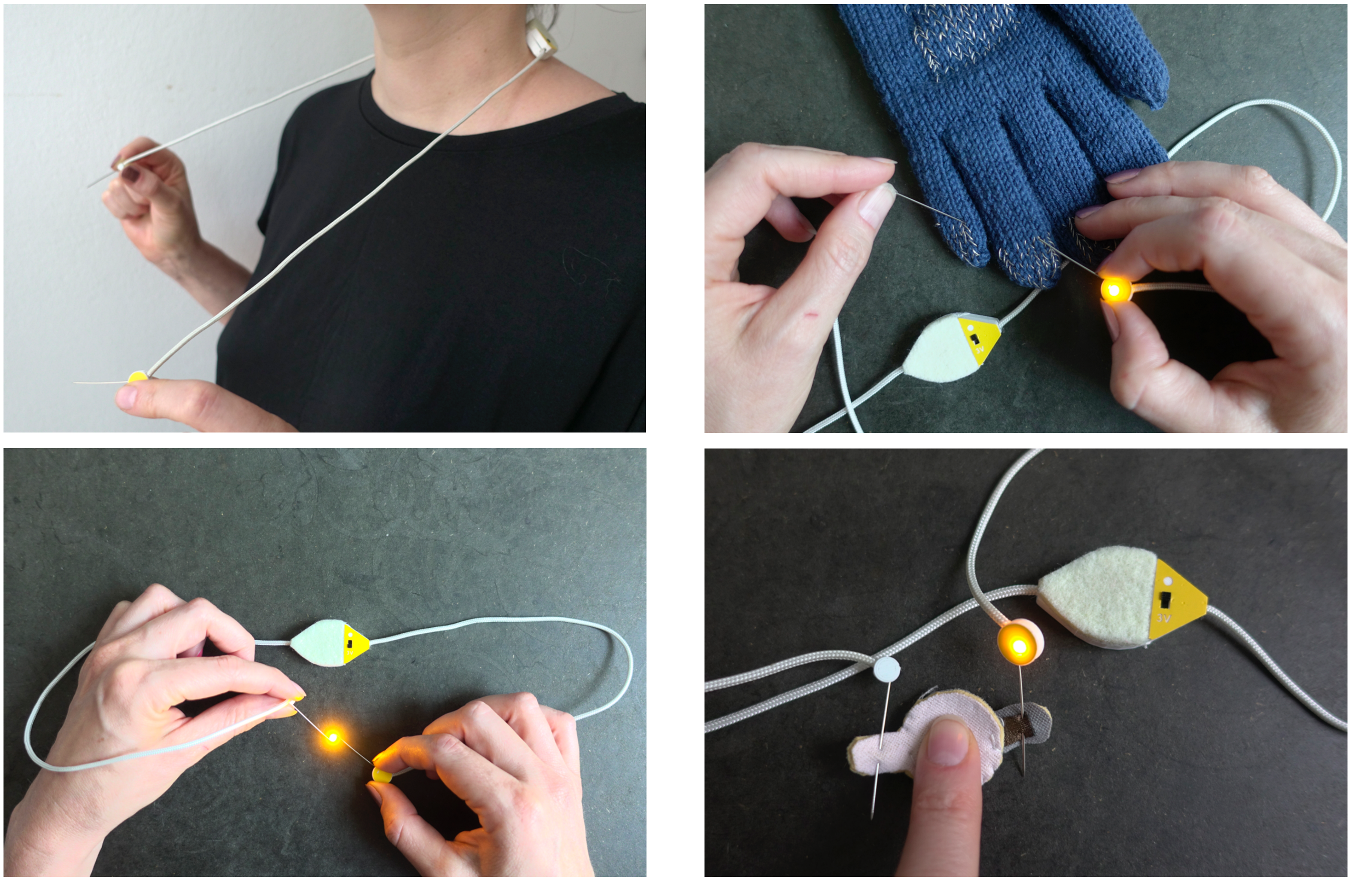

Figure 4a,b,c,d. Example scenarios of the eTextile Tester in use: interacting with the tool, testing and applying power to electronic textile projects. Top left, 4a: "Wearing" the tool around the neck, ready to use. Top right, 4b: Testing connections in a knitted circuit in touching the yarn with the pins. Bottom left, 4c: Applying 3V to test the functionality of a small LED. Bottom right, 4d: Pinning the probes to a textile artefact (here, a textile button) to test if contact is established.

The remaining 11 participants used it to various degrees: Three people said they used the tool, but mainly to demonstrate the other swatches in the book (e.g. applying power to other swatches or demonstrating conductive materials). Seven people said they used the tool on some of their eTextile projects, one said they used it on half of their projects (P5). They described using the tool with diverse conductive fibre and thread based techniques and materials: knitting, crocheting, weaving, felting, embroidering, and sewing in the making of textile sensors, circuits, and fabric circuit boards. Extending the textile domain, two of them stated they also used it on materials other than textiles (P3, P6), the small and light weight size of the tool being *"convenient for situations where [the multimeter] is too big or heavy"* (P3).

"something easy and effective to use!"

12 out of 16 participants stated the tool being beneficial to their work with eTextiles. Participants who used the tool most mentioned its small and light design (P3, P6, P9, P10, P11) and the *"handy"* (P6, P9, P11) form as most beneficial for their practice. Participants commented on its form as *"friendly to use"* (P4), *"attractive"* (P7), *"aesthetic"* (P9), and "*Nice Design!"* (P2). It was most contrasted to the multimeter, with several participants describing it as *"easy"* or *"easier"* (P7, P8, P11, 12,) for *"fast basic testing"* (P4). The additional function to supply power was positively received: *"I normally would have to put a battery in a battery holder and attach crocodile clips to it - this makes it easier!"* (P8). Users described the pins as *"pointy probes"* that they could *"securely attach to textile, but not damaging it the way alligator clips can"* (P15). This made it possible to *"pin the tester into the circuit and leave it there to test continuity over time, especially in actively moving or interactive e-textile projects. I can see how the connectivity behaves through the LED, while my hands are busy with the interaction"* (P12). The light output as feedback for connectivity was also mentioned positively: *"if you get annoyed by the beep short circuit tester [the continuity signal of the multimeter] […] it illuminates the spot where you measure"* (P3). One participant summarized the main benefit for their practice as providing *"a sense of immediacy: it allows to quickly test sensors and debug traces, etc."* (P5).

Participants gave explicit descriptions of the scenarios of use of the tester tool in supplying 3V: testing the polarity of small LEDs (P6), testing if an LED or buzzer motor works

(P3, P9) testing specific custom made components (P7), as well as powering circuits (P3, P8). They were even more precise in providing accounts of using the continuity-testing mode within their practice: checking the connections between textile and electronic components (P9) or the continuity between two conductive lines or in complex traces (P3, P5, P9). One mentioned using the brightness of the LED as a visual indicator for the resistance (P5). Other users (P10, P11) noted they used specifically when working with (very) thin yarns. Unlike with conventional multimeter probes, they would *"pin it straight into the combined materials"*, or *"wind the pin end directly into the threads"* (P11). One said that they would pin the *eTextile Tester* to the textile artefact to have their hands free when testing the interaction of an artefact: The LED light indicates if a switch was closed properly and as reliably as intended (P12).

The analysis shows that the majority used both functions of the tool. Among those using only one function, the group using it to test continuity was slightly bigger than those using it to apply 3V. Among those who reported using the tool at least sometimes, four participants said the tool (partially) replaced the multimeter. Six people said it replaced custom constructions to apply 3V for testing components or circuits. For others, it did not replace a specific tool but was an extension to the toolkit they were already using.

The questionnaire also asked about the problems people faced when working with the tool. Most problems concerned the physical realization of the tool: the LED having a loose contact or being broken (P3, P9), the coin cell being drained (P4, P7), or the top of the body coming loose from time to time (P2, 12). One participant mentioned that the probes were too small to be grabbed quickly (P6), while another observed that the probes were not suitable to be pinned to coated materials as they left a hole there (P11). While the *"thin and pointy"* probes were predominantly mentioned as a positive feature of the tool, one person said that this shape made it hard to make good contact on certain threads or surfaces (P12). Rather a suggestion than a complaint, some participants wished for wider functionality, either the tool itself incorporating more elements of a multimeter (P4, P5) or a modular way to integrate it into a multimeter (P2, P5, P15).

"the tester is much more textile"

The questionnaire also asked about new or altered practices potentially enabled by the tool. One person specifically mentioned the portability of the tool as relevant to their practice (P6). Other descriptions focused on how the pin probes allowed for new ways to make contact with the material. Participants mentioned how the pins allowed for a *"much better"*, connection as the usually used *"crocodile clips are too clumsy"* (P11). They also mentioned being able to make contact to material *"where even small multimeter clips try to cramp"* (P11), and being able to *"place the needles more precise at the testing area"* (P9). This made the tool being perceived as "*much more textile in its use*" (P11). Another user mentioned how it influenced their actual making routine *"I use the multimeter often in a sequential manner (first make, then measure, make a change, then measure again). With the eTextile Tester, it became easier to work in a simultaneous manner (measure while making)"* (P12). On a more abstract level, another participant stated: *"It galvanized me to brainstorm and explore designing other customized tools to support my practice"* (P5). The participant further stated that being introduced to research on making of new tools for the practice of eTextiles had *"a profound impact on how I think about, describe, and approach eTextiles/eCraft as a field. Not only are they extremely helpful, but they provide a tangible provocation to discuss and problematize the space. These tool mashups embody the intersection of the fields we pull from and ground eTextiles as a separate, discrete field"* (P5).

DISCUSSION

The goals of our approach of designing and then using new tools for an emerging eTextile practice have been both to explore tools that highlight the textile material and cultures within electronic textile making practices, as well as how the availability of targeted tools influences the practice. Our user study specifically focused on the last prototype, the *eTextile Tester*, collecting feedback from a group of eTextile practitioners about its use and role. In the following we discuss the results, focusing on the themes of design, practice, and adoption in relation to a new tool.

Tools Matter

A dominant part of the feedback from participants was concerned with new possibilities to contact to textile fabrics and threads. The pointy and thin shape of the pin allowed for precision in selecting the point of contact and in piercing through the fabric for temporary, minimally invasive, hands-free connection to the textile material. It physically extended the reach to textile materials that otherwise could not, or not as easily without damage, be electrically connected. It also extended the reach of the pin, a tool strongly associated with textile crafts, into the field of electronics, becoming both literally and figuratively the point of connection between textiles and electronics, embodying the integration of textile and electronic fields.

Our goal was to value the practice and materials of the craft, a decision we see validated in the participants' feedback. They could use the tool as intended and appreciated the functionalities introduced. The approach of referencing established textile tools in the design, and functionally mapping their tasks to the field of electronics, while drawing on familiar routines, proved suitable in this endeavour. The users' feedback also reinforced our assumption that a tool is not just a physical artefact for manipulation or measuring, but also an object of identification; the availability of specific tools potentially contributing to the grounding of the practice as discrete discipline.

New Material Interactions

Apart from describing how established routines could be improved to fit the textile context, participants also described how the use of the *eTextile Tester* allowed for new routines to be included in their practice. Measuring electric continuity is foreign to textile craft, as is a continuous, physical, aesthetic driven design process to electronics. Using existing tools from either domain thus inherently ignores essential aspects of electronic textile making processes.

What one participant called "*measure while making*" points to the potential transformation tools can have on a discipline. *eTextile Tester* now render an essential quality of the artefact, electric conductivity, perceivable to the maker. This additional information enables new routines for exercising judgment, dexterity, and care in the making, essential qualities of crafting processes [21]. Not only aesthetic decisions influence the next step to be taken, but also electrical aspects not per se visible to the human eye.

Adopting New Tools

Although the feedback points to relevant contributions to the practice of those who used it, attracting new users proved more challenging than we expected. Including the tool in the eTextile Swatchbook seemed a good way to reach a target group active and interested in the field of electronic textiles as they would be able to judge the potential improvement within their practice. However, some considered the Swatchbook a precious collection they wanted to preserve and thus did not remove the tool to use it. Also worth noting is that all recipients had already an established practice, meaning they had to actively remember the new tool and change their previous routines to include it. We interpret the fact that still half of the people answering our survey did adopt the tool and adapt their practices to its use as proof of its potential to fill a gap in eTextile making routines but are also aware that changing routines can be difficult.

The tools presented here are experiments towards a practice that integrates electronics and textiles in the making. They illustrate the statement: *"Designing for the post digital does not mean blindly embracing nostalgia or turning away from technology – it means demystifying the digital through the design process and encouraging designs that equalize the status of digital and analogue, both in the materials and the practices"* [24]. Our research to date suggests that tools matter toward reaching this goal. Their design influences how we interact with the electronic and material properties in the making. They are a physical argument for an integrated practice inclusive of both textile and electronic properties. Even at the state of functional prototypes, they shaped the processes and the self-understanding of a discipline among the groups of experts that used them.

CONCLUSION

The research discussed covers the genesis and application of a new tool instantiated in three designs combining electronic functionality with traditional textile craft tools: the *eTextilers Tape* building on an established textile tool to perform eTextile measurements, the *Travel Tester* as a portable tool to easily test the conductivity of newly found materials in situ, and the *eTextile Tester* repurposing pins to not only connect materials but also electrically connect to them.

The study investigated the usage of the tool among eTextile practitioners over the duration of a year. The tool was well received by the participants. They provided positive feedback about the design and use of the tool and valuable insights into the tools new form and functional possibilities easing routines or allowing for new ways of working, as well as thinking about, in the field of eTextiles. It also pointed at possible improvements in a next design iteration, addressing parts becoming loose or breaking over time.

Future research will look at a wider set of tools relevant to the practice. While in this study we focused on practitioners, we are also specifically interested to explore how tools influence the access and understanding of a discipline among novice users, what role they play in framing the potentials and possibilities of a discipline. Directing what tools are used - how things are made - might eventually also influence what is being made, and by whom.

ACKNOWLEDGEMENTS

This research was supported by the project Stitching Worlds (www.stitchingworlds.net) funded by the Austrian Science Fund (FWF): AR 284-G21, initially developed as part of a workshop by Ebru Kurbak, Hannah Perner-Wilson, Irene Posch and Mika Satomi. We would like to thank all the participants of our study, as well as our colleagues and reviewers for helpful comments.

REFERENCES

1. Glenn Adamson. 2013. *The Invention of Craft.* Bloomsbury Academic.
2. Mary C. Beaudry. 2006. Findings: the material culture of needlework and sewing. Yale University Press.
3. Joanna Berzowska. 2005. Electronic Textiles: Wearable Computers, Reactive Fashion, and Soft Computation. *TEXTILE* 3, 1 (May 2005), 58 - 75.
4. Leah Buechley, Mike Eisenberg, Jaime Catchen, and Ali Crockett. 2008. The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '08). 423-432. https://doi.org/10.1145/1357054.1357123
5. Leah Buechley and Michael Eisenberg. 2009. Fabric PCBs, electronic sequins, and socket buttons: techniques for e-textile craft. *Personal Ubiquitous*

Computing. 13, 2 (February 2009), 133-150. http://dx.doi.org/10.1007/s00779-007-0181-0

6. Leah Buechley and Benjamin Mako Hill. 2010. LilyPad in the wild: how hardware's long tail is supporting new engineering and design communities. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (DIS '10). ACM, New York, NY, USA, 199-207. DOI:http://doi.acm.org/10.1145/1858171.1858206
7. Leah Buechley and Hannah Perner-Wilson. 2012. Crafting technology: Reimagining the processes, materials, and cultures of electronics. *ACM Trans. Comput.-Hum. Interact.* 19, 3, Article 21 (October 2012), 21 pages. DOI: https://doi.org/10.1145/2362364.2362369
8. Laura Devendorf, Joanne Lo, Noura Howell, Jung Lin Lee, Nan-Wei Gong, M. Emre Karagozler, Shiho Fukuhara, Ivan Poupyrev, Eric Paulos, and Kimiko Ryokai. 2016. "I don't Want to Wear a Screen": Probing Perceptions of and Possibilities for Dynamic Displays on Clothing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16). ACM, New York, NY, USA, 6028-6039. https://doi.org/10.1145/2858036.2858192
9. eTextile Tester. 2015. In *eTextile Swatchbook 2015.* Retrieved June 23 2017 from http://etextile-summercamp.org/swatch-exchange/etextiles-tester/
10. Sophie Fürnkranz. 2005. Metallstickerei im Außereuropäischen Raum: Beispiele aus der Sammlung des Weltmuseums Wien. In *Technologische Studien, Kunsthistorisches Museum: Konservierung - Restaurierung - Forschung – Technologie. Band 2.* Wilfried Seipel (ed.). KHM-Museumsverband, Wien, AT, 10 - 49.
11. Anja Hertenberger, Barbro Scholz, Beam Contrechoc, Becky Stewart, Ebru Kurbak, Hannah Perner-Wilson, Irene Posch, Isabel Cabral, Jie Qi, Katharina Childs, Kristi Kuusk, Lynsey Calder, Marina Toeters, Marta Kisand, Martijn ten Bhömer, Maurin Donneaud, Meg Grant, Melissa Coleman, Mika Satomi, Mili Tharakan, Pauline Vierne, Sara Robertson, Sarah Taylor, and Troy Robert Nachtigall. 2014. 2013 e-textile swatchbook exchange: the importance of sharing physical work. In *Proceedings of the 2014 ACM International Symposium on Wearable Computers: Adjunct Program* (ISWC '14 Adjunct). ACM, New York, NY, USA, 77-81. http://dx.doi.org/10.1145/2641248.2641276
12. LilyPad Arduino Main Board. Retreived June 30 2017 from https://www.arduino.cc/en/Main/ArduinoBoardLilyPad
13. Diana Marculescu, Radu Marculescu, Nicholas H. Zamora, Philipp Stanley-Marbell, Pradeep K. Khosla, Sungmee Park, Sundaresan Jayaraman, Stefan Jung, Christl Lauterbach, Werner Weber, Tünde Kirstein, Didies Cottet, Janusz Grzyb, Gerhard Tröster, Mark Jones, Tom Martin, Zahi Nakad. 2003. Electronic textiles: A platform for pervasive computing. *Proceedings of the IEEE*, 91, 12, (December 2003), 1995-2018.
14. Cara McCarty and Matilda McQuaid (eds.). 2015. *Tools: Extending our Reach.* Cooper Hewitt, Smithsonian Design Museum, New York, NY.
15. Kylie Peppler. 2016. A review of e-textiles in education and society. In *Handbook of research on the societal impact of digital media, Barbara Guzzetti and Mellinee Lesley (eds.).* IGI Global, Hershey, PA, 219-241.
16. Hannah Perner-Wilson, Leah Buechley, and Mika Satomi. 2010. Handcrafting textile interfaces from a kit-of-no-parts. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction* (TEI '11). ACM, New York, NY, USA, 61-68. http://dx.doi.org/10.1145/1935701.1935715
17. Irene Posch and Ebru Kurbak. 2016. CRAFTED LOGIC Towards Hand-Crafting a Computer. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (CHI EA '16). ACM, New York, NY, USA, 3881-3884. https://doi.org/10.1145/2851581.2891101
18. E. Rehmi Post and Margaret Orth. 1997. Smart Fabric, or "Wearable Clothing". In *Proceedings of the 1st IEEE International Symposium on Wearable Computers* (ISWC '97), 167-168.
19. E. Rehmi Post, Margaret Orth, Peter R. Russo, and Neil Gershenfeld. 2000. E-broidery: design and fabrication of textile-based computing. *IBM Systems Journal,* 39, 3.4 (July 2000), 840-860. http://dx.doi.org/10.1147/sj.393.0840
20. Ivan Poupyrev, Nan-Wei Gong, Shiho Fukuhara, Mustafa Emre Karagozler, Carsten Schwesig, and Karen E. Robinson. 2016. Project Jacquard: Interactive Digital Textiles at Scale. *In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16). ACM, New York, NY, USA, 4216-4227. https://doi.org/10.1145/2858036.2858176
21. David Pye. 1968. *The nature and art of workmanship*. Cambium Press.
22. Becky Stern and Tyler Cooper. 2015. *Getting started with Adafruit FLORA*. Maker Media Inc.
23. Stitching Worlds - Connected Research: Kobakant. 2014. Retrieved Dec 6 2017 from http://www.stitchingworlds.net/experimentation/connected-research-kobakant/
24. TEI 2018 - Twelfth International Conference on Tangible, Embedded and Embodied Interactions. Retrieved July 22, 2017 from http://tei.acm.org/2018/

<ccs2012>
<concept>
<concept_id>10003120.10003121.10003122.10003334</concept_id>
<concept_desc>Human-centered computing~User studies</concept_desc>
<concept_significance>500</concept_significance>
</concept>
<concept>
<concept_id>10003120.10003123.10011760</concept_id>
<concept_desc>Human-centered computing~Systems and tools for interaction design</concept_desc>
<concept_significance>300</concept_significance>
</concept>
<concept>
<concept_id>10003120.10003138</concept_id>
<concept_desc>Human-centered computing~Ubiquitous and mobile computing</concept_desc>
<concept_significance>300</concept_significance>
</concept>
</ccs2012>