“The Fabric of our Lives”: Exploring the Future of Interactive E-Textiles

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ABSTRACT

E-textiles, or "smart" textiles incorporating electrical components, have the potential to transform our interactions with material and technology. However, the adoption of e-textiles in commercial products has been slower than their development in academic research. In this paper, we report on e-textile modules we developed as well as an affinity diagramming workshop we conducted with textile and design industry professionals to identify challenges and opportunities of interactive e-textiles. The workshop’s results offer insight into the current state of e-textile technology and directions for future development.

KEYWORDS

Interactive e-textiles; e-textiles workshop; affinity diagramming; soft e-textiles; e-textiles in industry; tangible technology

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INTRODUCTION

Textiles are a pervasive presence in our daily lives, comprising many of the objects with which we interact, including clothing, home furnishings, industrial and medical products, and sports and military gear. In recent decades, some textiles have undergone a transformation by being imbued with electrical components, resulting in "smarter" textiles referred to as e-textiles. Despite this progress, the incorporation of e-textiles in commercial products has lagged behind their development and implementation in academic research.

1.1 Interactive E-Textiles

Interactive e-textiles are fabrics that have been embedded with sensors and/or actuators to enable interactions beyond traditional textiles' capabilities. They are generally created using traditional fabrication techniques such as yarn, weaving, knitting, embroidery, screen printing, and layering fabric. Sensors are used to collect input based on changes in the state of the textile's surroundings, which can be triggered by a person, the textile's environment, or another object. For example, bending a knee clad in e-textiles (an event) causes the fabric to stretch (a stimulus); the stretch is then sensed and inputted by the fabric (a sensor). The "Electrodermis" stretchable electronic adhesive bandage achieves this particular interaction using sensors for pressure and stretch to get collect biofeedback from the wearer [6]. The "ambienBeat" also senses pressure, though along with heart rate, in a wrist-worn biofeedback device [13]. Other types of input for sensors include proximity [14], tilt, light, temperature, and more. Actuators, on the other hand, produce feedback or output in response to an external trigger. For example, an electrical current (external trigger) can activate an electromagnet (actuator), which produces sound (response), as used by Sonoflex, a flexible textile -based speaker [12]. Other types of responses by actuators include haptics, shape change, color change, heat, texture, and volume. E-textiles can include sensors, actuators, or both, and some even have the ability to use machine learning to sense changes, produce feedback, and analyze input. In "E-textile Microinteractions: Augmenting Twist with Flick, Slide and Grasp Gestures for Soft Electronics," Alex Olwal et al. applied the I/O Braid sensing architecture [7] to recognize gestures and found that it was able to recognize them with a high degree of accuracy [8].

1.2 E-Textiles Industry Adoption

E-textiles have indeed been implemented in a number of industry products, including wearables, smart clothing, and other electronic devices. Yet despite the abundance of technology and prototypes borne of the research and development conducted in academic spaces, they have not materialized in industry products widely used in day-to-day interactions. In her 2016 work, "A Review of E-Textiles in Education and Society," Kylie Peppler envisioned the future potential of e-textiles to support education and learning, in particular in STEM fields, and even to promote gender and cultural inclusivity [9]. Her prediction that e-textiles may go so far as to promote gender equality in greater society could only come to fruition if it might rest on e-textile's widespread use and ubiquity in our lives, something that evidently has yet to happen. A more recent study by Irene Posch et al. identifies a lack of accessible tools as a reason for the dearth in e-textile applications in the industry. They propose that the form and function of e-textile tools are essential to promoting more widespread development and introduce a set of newer, more accessible tools [11]. Emily Lovell et al.'s "The LilyTiny: A Case Study in Expanding Access to Electronic Textiles "reached a similar conclusion, as the authors reflected on the decade since they released LilyTiny, a microcontroller developed to make e-textiles more accessible. While they found that their product's partial success lied in its simplicity free supplemental resources, and community outreach, there is still room for improvement on educating non-technical designers on the programming requirements necessary for development (Lovell). We were inspired by the many calls for further research to understand this gap on a deeper level.

MODULE DEVELOPMENT

To provide workshop participants with a hands-on experience that demonstrates the full potential and functionality of e-textile technology, we developed three interactive e-textile modules - a shape-changing actuator, a thermochromic actuator, and a capacitive sensor. We fabricated, iterated, and test a variety of modules; to select which would be included in the workshop, we considered three main criteria: they had to be soft and fabric-based, consume little power, and be easy to implement and understand for participants. These criteria guided us towards creating e-textiles that were practical, user-friendly, and engaging.

During our fabrication process, we sought to find different types of thermochromic paints that would respond to heat at a temperature of 31 degrees, so that it could both react to body heat and change color in a visible way. To achieve this, we experimented with conductive materials such as copper, threads, and tape to create designs that we tested for temperature, shape, pattern, current, heat spread, and cooling rate, as well as the overall user experience. After many experiments and iterations, we chose three modules that answered our original criteria and operated best. The first module, a shape-changing actuator, was made with two pieces of fabric layered on top of one another, attached at the ends and ending in a flap-like shape. The top layer was embroidered with conductive thread; once an electric current is run through the thread, it uses opposite magnetic force to lift the flap, in reaction to the input it receives through the current (Fig. 1). The second module, a thermochromic actuator, is an embroidered fabric dyed with thermochromic ink. One side of the fabric was embroidered with conductive thread, while the other side was embroidered with regular thread. Once exposed to heat, via an electric current run through the thread, the fabric changes color in the area with the pattern embroidered on it. (Fig. 2). The third module, a capacitive sensor, was made with conductive fabric that could sense proximity and transfer that data onwards. (Fig. 3). When used in conjunction with the other two modules, the sensor served as a trigger for the shape-changing actuator and thermochromic actuator, based on the input it received and processed. Thus, it could be used separately or together with the other two modules. This allowed workshop participants to experience first-hand how sensors and actuators can both operate separately as well as work in conjunction with one another in various combinations, to grasp the full range of capabilities that e-textiles offer.

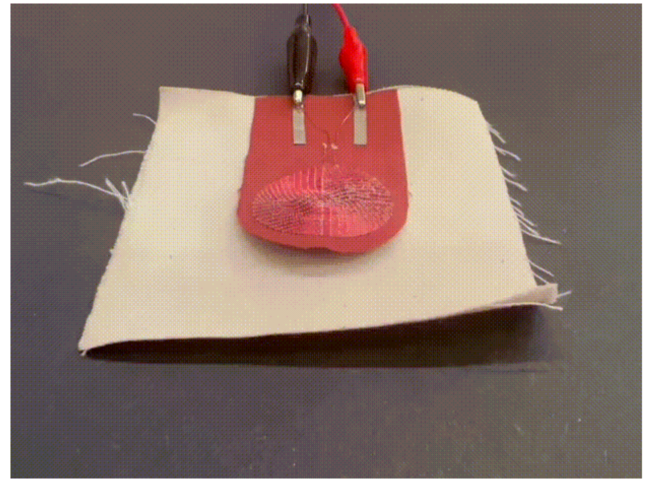

Figure 1: Shape-changing actuator

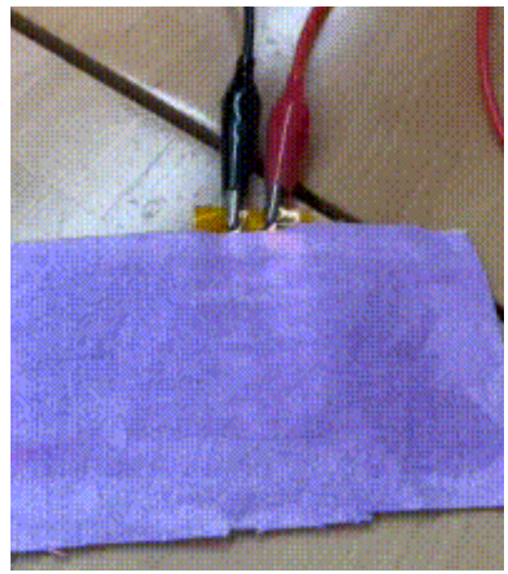

Figure 2: Thermochromic actuator

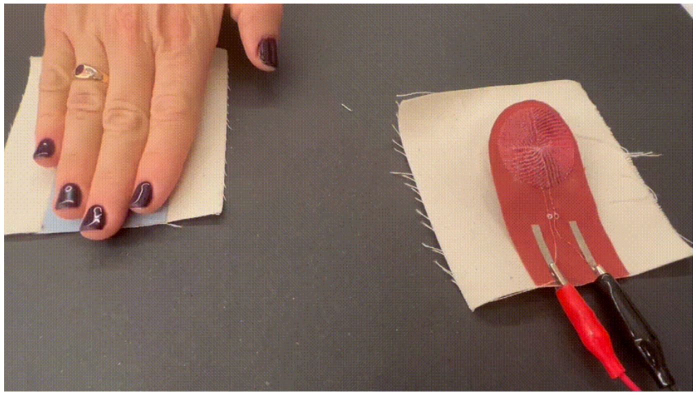

Figure 3: Capacitive sensor (on left), when pressed, activates the shape-changing actuator and prompts it to lift

WORKSHOP

The goal of our workshop was to explore the gap between academic e-textile developments and their practical applications in industry. It consisted of an introduction to e-textiles, hands-on experience with our developed modules, then an individual brainstorming and affinity diagramming session. Through this process, we aimed to understand the reasons and forces behind the gap between academic and industrial e-textile use, and identify challenges and opportunities for e-textile incorporation into industry products. We were inspired by e-textile workshops such as Lee Jones's "Wearable Bits,' in which the authors present a toolkit designed to enable co-design of wearable e-textile prototypes with non-expert users. They incorporated brainstorming techniques into the process [4], which was ultimately our workshop's central feature.

3.1 Participants

To attract participants for our workshop, we advertised it among industry professionals in Israel (where the workshop took place) through various professional channels (online and word of mouth). All applicants responded to a questionnaire that screened for professional backgrounds, demographics, and familiarity with e-textiles. We invited professionals from the industry, as opposed to people with academic backgrounds, in order to better understand where the gaps lie in the design and textile fields. Of the 40 people who responded to our open call, we invited 11, out of which 6 people ultimately joined the workshop. The participants' ages varied from 24 to 55; four of the six were women. All held at least a bachelor's degree, and three also held masters degrees. The participants' academic backgrounds included three with degrees in industrial engineering, one in technology, one in civil engineering, and one in fashion design. Their current fields of practice included: textile development in the defense sector, two digital user experience designers with prior experience in textile design, one NFT-embedded fabric designer, and one industrial designer who specialized in 3D printing in the health sector. This range of expertise fostered lively, well-rounded discussions throughout the workshop. Although the participants had substantive experience with different types of textiles, they had limited experience with e-textiles; when asked to rate their familiarity with e-textiles on a scale of 1-5, their average answer was 2.3. This gap between their own levels Their mix of familiarity and unfamiliarity with e-textiles allowed for balanced perspectives during the discussion.

To attract a diverse group of participants with a range of expertise and experiences to our workshop, we advertised the event among industry professionals in Israel and screened applicants based on professional backgrounds, demographics, and familiarity with e-textiles. We specifically invited professionals with industry backgrounds rather than from academia, to better understand the gap between academic e-textile developments and their practical applications in industry, based on participants' real-life experience. Of the 40 applicants, we invited 11, of which 6 ultimately participated in the workshop. These participants represented a range of academic backgrounds, including industrial engineering, technology, civil engineering, and fashion design, and worked in fields such as textile development, digital user experience design, NFT-embedded fabric design, and industrial design. The average level of familiarity with e-textiles among the participants was 2.3 on a scale of 1-5, providing a mix of familiarity and unfamiliarity that contributed to balanced discussions during the workshop.

3.2 Setting

The workshop room was set up with a table featuring samples of the e-textile modules that we developed. There were also white boards available for group brainstorming exercises using affinity diagramming. The participants sat around a table together to work and discuss, fostering a collaborative and interactive atmosphere. The arrangement of the workshop room encouraged hands-on exploration and facilitated group discussion and problem-solving.

3.3 Presentation and tactile experience

The workshop began with some brief mingling and time for participants to introduce themselves, followed by an introduction to interactive e-textiles, detailing much of what was discussed in the first section of this paper. The introduction session was supported by a slideshow listing main points and featuring images and videos. The presentation's content and style were varied and multi-disciplinary, with plenty of examples from academia and the industry, demonstrating each type of material and interaction. The goal was to encourage broad-reaching brainstorming based on a technical understanding of the technology. Following the presentation, participants were invited to engage directly with the e-textile modules we developed, which were laid out on a table (Figs. 4-5). Some were connected to electricity and fully functional, while others were static yet still available for exploration. We also included several pieces of raw material to depict the steps in the fabrication process. Participants were encouraged to touch, play with, and inquire further about the various modules developed. Facilitators answered questions and guided the participants, to assure that they understood the technology's principles and functionality through firsthand tactile experience.

Incorporating tactile experience was significant since e-textiles offer new and unique sensory experiences. These can be best appreciated through hands-on interaction. Participants can get "a feel" (no pun intended) for the materials and technologies, and based on their understanding - brainstorm e-textiles' potential applications and limitations. In their study on textile game controllers, Kate Hartman et al. incorporated tactile experience and "play" in their non-expert fabrication workshops to evaluate the potential for fabric-based game controllers [3].

Figure 4: E-textile modules on display for workshop participants to engage in tactile experience

Figure 5: Participant interacts with modules, guided by a facilitator

3.4 Brainstorming and affinity diagramming

Afterward, participants were instructed to brainstorm, then sketch or write down concepts, thoughts, use cases, or ideas that reflected on the challenges and opportunities of e-textiles. To help inspire their thinking, participants were shown a series of questions geared toward identifying these challenges and opportunities. They were provided with tools such as index cards, sticky notes, and pens or markers to record their ideas however they felt most comfortable. This stage of brainstorming was individual; each participant worked on their own (Fig. 6). Once the individual brainstorming was complete, we moved on to affinity diagramming, a collaborative method for organizing and categorizing ideas and forming a singular output. We drew inspiration from the use of affinity diagramming by Nathalie Bressa et al. in “Sketching and Ideation Activities for Situated Visualization Design”; which reports on the use of design workshops to prototype new situated visualizations [1], as well as in Inbal Deutsch et al.’s exploration of the opportunities and concerns of home robotic devices for older adults using the same brainstorming technique [2].

In this affinity diagramming exercise, the facilitator guided the participants through the process of categorizing their ideas in a collaborative and reflective manner. Initially, all of the participants placed their cards on the board. The facilitator began by reading out the first card: "How can we successfully weave traditional and electronic fibers together?" He then challenged the participant who proposed the idea to clarify the underlying problem and why they saw it as a challenge. Through this process, the facilitator and participant were able to create and name a category titled "Clash between electronics and material; ethics and culture," which became a major focus of the group discussion later on. This process was repeated for several other cards, after which the participants were invited to move their own cards into those categories or create new ones as they saw fit. This provided an opportunity for the participants to actively engage with the process and consider how their ideas might fit together with others. The process became increasingly iterative, as participants reflected on the motivations, importance, and broader themes of their ideas. The facilitator asked reflective questions and provided guidance and support, but also gave the participants space and independence to engage with the process and come to their own conclusions, individually and collaboratively (Figs. 7).

A number of themes emerged from the discussion. These included concerns about the compatibility (or lack thereof) of technology and textiles, the challenges of washing e-textiles, the potential for e-textiles to create a "wow effect" in art and fashion, the possibility of reducing the amount of fast fashion and making the production of fabrics more environmentally friendly, and the possible ability of e-textiles to gather intimate knowledge about the wearer's body and physiological state. Participants also raised uses such as temperature control (for example, clothing that could automatically adjust the amount of heat it emits), shape-changing clothing (for example, to create a statement garment or to ward off attackers), and color-changing textiles (for example, that might reflect changes in physiological state). In addition, there were concerns raised about the potential loss of control over e-textiles and the data they could collect. To help focus the discussion, the facilitator separated these use cases into "uses" and "types of innovative effects." This discussion arose during the categorization process, as the cards were reviewed and placed into categories that slowly formed.

Figure 6: Individual brainstorming

Figure 7: Participants organize and categorize cards in affinity diagramming exercise

3.5 Affinity diagramming results

Once all of the cards were assigned categories, the participants voted on the categories that they found most relevant and important; each was allotted three stickers with which they could mark categories as they wished. The most popular categories included "Physiological connection and tracking," "IoT; device-to-device," "Practical usages based on external triggers," "Clash between electronics and material; ethics and culture," and "UI; interacting/interfacing with the technology," each receiving three votes. "Sustainability and industry barriers" and "Privacy concerns and challenges" received two votes and one vote, respectively. These categories were all related to people's relationships with their bodies and ethical issues surrounding the topic of e-textiles. The facilitator summarized the results of the voting, stating that it reflected the perspective of the specific group gathered: "We are more individualistic than we are societal, yet we still value culture and ethics." Interestingly, the "fashion" category did not receive any votes - despite how closely tied traditionally fashion is to textiles. Some participants thought that this may have been because fashion is viewed as frivolous and not important enough to be considered a major challenge or opportunity; furthermore, it could be that since fashion is constantly evolving according to trends, the participants struggled to identify its practicality as integrated with technology. Other categories that did not receive any votes included "data usage," "data ownership," "social interaction," and "emotional and medical usages." It was surprising that the social interaction categories were not popular, as they were expressive and would have fit in with the popular categories. The lack of votes for the data-related categories and "innovative types of output" may have been due to the futility of concerns about data privacy and the perceived technical nature of the topic, respectively. At this point, a participant opted to add another category - “Urban/scale,” since she identified that all the categories were preoccupied with the individual and less with the collective. In other words, she wondered how e-textiles might be useful in an urban setting that affected many people, as opposed to just one individual. A full reproduction of the completed board, including the voting results, can be viewed [here](#) (Fig. 8).

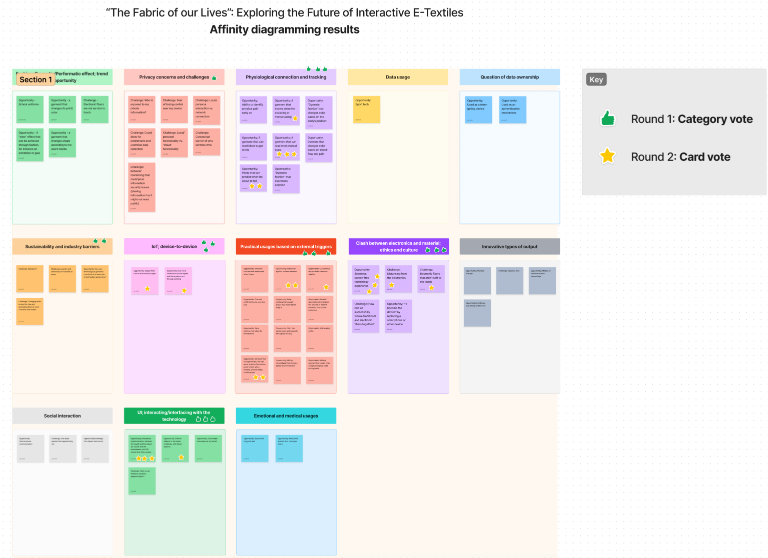

Figure 8: **Reproduction of the completed affinity diagramming board**

RESULTS AND DISCUSSION

The facilitator summarized the results of the workshop at its close; he reported that the results were clear in terms of the overarching themes that arose throughout the discussion. The facilitator noted that the participants expressed, through their ideas and categorizations, that people feel overwhelmed by technology and want to create a more intimate connection with their bodies and materials. They want to retain the cultural and historical significance of materials, but also find practical uses for them that are not already being addressed by existing technologies. This includes things like communication with others, privacy, and fashion, which may be losing some of their importance or meaning due to technology. There is a desire to find new and innovative ways to connect with our bodies and materials that do not currently exist, which makes it an exciting and interesting area to explore further. Their choices expressed people's desire for technology to be more integrated and natural in their lives, rather than something shallow and disconnected. They want technology to adapt to their intuitive way of being (rather than vice versa) and be less reliant on screens and data. It seems to be clear to people what we need from technology; however, technology is not yet meeting those needs. Furthermore, the participants relayed the desire for our technologies to feel more "organic" - made of materials and fibers that are more traditional and innately familiar to humans. A lot of the discussion revolved around clothing, leading to much discussion about bodies and our relationship with them. It appears that the discrepancy between academic research and industry development may lie in the fact that current e-textiles technologies do not answer that inherent need to the extent that would lead to widespread adoption.

LIMITATIONS

During our research, we encountered a few limitations. One of the main limitations was technological, as the modules needed to be kept small and simple for the sake of understanding. We also struggled to find the perfect patterns to incorporate into our textile modules, and had difficulty working with conductive threads. Additionally, we had some issues with participant attendance, as a few scheduled participants did not show up and we had to call in replacements. Another issue we faced was a lack of fully developed and integrated technology to use as a basis for our research. Our research and development also revealed the need for further investigation into the materials we worked with; there is not yet a mature enough understanding of the materials and their functionality in order to easily achieve properly working modules that meet our criteria.

NEXT STEPS

As a next step, we plan to build upon the main insight we gained from the workshop, which is the desire for a more intimate connection with our bodies and materials through innovative technologies. To do this, we plan on organizing a more hands-on workshop where we can use the insight as the foundation for an e-textiles toolkit. Participants will be able to use this toolkit to create their own e-textiles that address the need for a closer relationship with materials and fabrics through technology. This will allow us to further explore and develop this insight in a more concrete and practical way, with tangible, material-based outputs. In preparation for this workshop, we need to fine-tune the patterns, materials, and fabrication methods that we have been working with, to reach better results.

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