Integrating Interactive Technology Concepts With Material Expertise in Textile Design Disciplines

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ABSTRACT

Textile and fashion designers are increasingly interested in integrating interactive technologies into their practice. However, traditional design education typically lacks support for them to develop technical digital and electronics skills alongside their expertise in materials. Reflecting on outputs from an e-textile design workshop and 8-week design projects with four textile design students using an e-textile toolkit, and follow-up data collection with the students one year after the projects, we argue that starting technical explorations with raw materials results in a better understanding and more flexible use of technical knowledge. We also argue that this newly acquired knowledge is then more fully integrated with their pre-existing material knowledge as it is applied to physical interface design. The results contribute to the development of tools and approaches in supporting designers with material expertise to learn tangible interaction design skills.

CCS CONCEPTS

• **Human-centered computing → Interface design prototyping**.

KEYWORDS

Design education, Design process, Textiles, Interface Design, Electronic textiles, Tangible Interaction

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1 INTRODUCTION

Electronic textiles (e-textiles) are fabrics integrated with electronic elements, offering textures and flexibility that cannot be achieved with traditional electronics such as printed circuit boards. The emergence of e-textiles has engaged a diverse group of people with electronics[5, 29]. Increasingly, textile and fashion designers are exploring tangible interaction design, including e-textiles, to help them to achieve interactive functionality with materials, enhance design concepts, and engage people with their designs. However, there is a lack of support for these designers to build a holistic design process where the aesthetics and functionality of their designs are developed together.

Research on how to better support makers to achieve interactive functionality in materials designs includes offering specific tools to achieve pre-determined functions [7, 16, 31, 35], encouraging open-ended design that is centred around material [22], or supporting interdisciplinary collaborations through tools as boundary objects [13, 25, 33, 36–38]. However, some ready-to-use e-textile toolkits limit users to predetermined functions [3, 6, 12, 14, 15, 20, 28, 32, 34], whereas open-ended solutions, on the other hand, require a level of technical knowledge that may be inaccessible for textile designers [22].

Textile designers are specialised in materials and textile construction techniques, valuing aesthetics, comfort or functionality. With regards to interactive technology, they value aesthetic aims alongside functional ones, and their motivations are not driven by general hobby interests as typified by many maker toolkits. Given the gap between textile designers' interest in intertwining interaction in their designs and the current support for designers to engage with technology (see sections 2.1 and 2.2) our work explores the following questions: i) How do textile designers perceive interactive technology knowledge? ii) How do textile designers apply and appropriate sensors in their practice? iii) How do textile designers integrate a flexible use of technological knowledge in their material expertise?

This paper reports on an exploration of how to support designers to design tangible interaction with e-textiles and to enable self-driven technical explorations. First we review related work in textile design discipline and e-textiles toolkits. We then report our exploratory study which included a survey of designers' current interests and difficulties when designing with interactive technology, the design of our e-textile toolkit, its use and coaching approach in workshops with designers, its longitudinal use and coaching approach in 8-week design projects, and follow-up data collection a year later about ongoing use of technology in design. We conclude with a discussion about how material expertise can be integrated with technology concepts in design practices.

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2 RELATED WORK

2.1 Interdisciplinarity in Smart Clothing Development

The fields of smart textiles and clothing have been growing, innovating the traditionally material-oriented disciplines with programming and electronics. The digital era of textile and clothing design features digital production, personalized design process, and end user programming [2]. Smart textile and clothing projects embedded with interactive systems require a better integration between materials, electronics, circuitry design, material construction methods, and on-body deployment [1, 9]. These often require closer collaborations between technologists and designers, but the role of the textile designer is often marginalised [30]. Researchers have explored approaches to addressing this issue. For example, Mannequette is a prototyping tool for avant-garde fashion-tech garments and it was found valuable in facilitating and supporting communication cross disciplines in teams [25]. Zeagler et al. designed an e-textile swatch book that contains a variety of e-textile interfaces to support collaboration between technologists and fashion designers [36]. Zeagler et al. also used this swatch book as a boundary object [27] to support a collaborative design process for a wearable music instrument [37]. Jones et al. created a toolkit for prototyping wearable e-textiles to support co-design of non-expert users and designers [12, 13]. Research has also explored the support for fashion designers through cross-disciplinary collaborations more broadly [10, 26, 36–38]. These collaborations have been found to be challenging as there is a lack of shared understanding between the different fields involved and poor communication cross disciplines [25, 36, 37]. Seyed and Tang found that cross-disciplinary communication is limited in such collaborations as designers have a lack of knowledge into what and how can the technology be deployed, so the opportunities in communication is lost [25]. Indeed, researchers emphasize the importance of building a shared language that allows a common understanding of design intention and visions – "tools that support articulation of creative ideas and allow for better exchange between different disciplines can eliminate some of the barriers in interdisciplinary collaboration." [17]

2.2 Existing E-textiles Construction Toolkits

E-textile toolkits play an important role in facilitating novices in hands-on learning electronics and programming. Modular blocks are most commonly found in these toolkits, as they reduce the complexity of circuits that users need to deal with. For example, the LilyPad Arduino kit is the first widely available e-textile toolkit [6] and the functional blocks are assembled on the round PCBs with petals for sewing electrical connection, enabling a more robust connection.

Patchwork [3] and Rewear [15] are e-textile toolkits developed for children, encouraging self-expression through functional modules and an easy-to-connect structure. Their modular structure and flexible connections make learning electronics easier for beginners and enable rapid iteration and experimentation. However, these toolkits have particular constraints on what people can achieve [22]. Furthermore, the predefined modules do not enable designers to focus on the material properties nor the aesthetics of interfaces.

In contrast, some toolkits are contextualised in material exploration, encouraging the personalisation of interfaces. Most notably, Kit-of-No-Parts is an approach encouraging people to craft personalized interfaces from a diverse palette of materials without predetermined functions [22]. Its open-endedness contributes to a deeper understanding of material properties and results in more aesthetic and expressive creations. Also using a crafting approach, Embelashed is a toolkit for prototyping embodied audio interfaces, providing paper templates and online image-led tutorials to guide crafting interfaces from paper [8].

The modular toolkits discussed above do not provide the aesthetics or functionality that satisfies material design requirements. As Posch et al. pointed out, the majority of e-textile toolkits are aimed at novices, and few are focused on developing expertise: "*In the context of a practice that is named and defined by material, it seems surprising that varied textile materials are not prominent elements of kits across all levels of expertise.*" [23]. The Kit-of-No-Parts[22] on the other hand emphasises personalisation of e-textile interface and values material property, but it requires pre-existing knowledge in e-textiles and electronics which makes it unsuitable for designers without such technical expertise.

There are also toolkits developed for fashion and textile designers. For example, Magnetform is a shape-change display toolkit made with robotic arms and magnets, enabling exploration on movement in soft materials for material-oriented designers [35]. Vahid and Jones developed shape changing fabric samples through origami fabric patterns, air compressors, balloons and tubes, with samples to help fashion designers to easily prototype movement related projects [31]. Ebb is a textile display technology which consists of conductive threads coated with thermochromic paints, it enables freely designing and constructing textile displays with such threads [7]. These toolkits are made for material experts providing a particular functional support, but none of them offer the ability to explore a broad spectrum of tangible interaction design.

2.3 The Nature of Textiles Design Discipline

To better understand how to support textile designers, we need to have insight into textile designers' perception. The nature of textiles design is traditionally taciturn [11]. In the textiles discipline, designers are accustomed to feeling and exploring material functions tangibly, and form their designs during the process, which is often tacit. Textile designers' knowledge is less able to be articulated, but it can be described as internal intelligence, "*awareness, intuition or tacit knowledge*" [11], and their exploration is driven by intuition and curiosity [18].

For textile innovation, designers need knowledge or assistance from other domains they are not familiar with to help with the designs [18]. Although the tacit knowledge can be implicitly communicated between textile practitioners, its unspoken nature makes it hard to communicate beyond the field [11]. Miller and Igoe suggested the tacit expertise and approach of textile designers needs to be externalized [11, 18]. However, in most cases, words are insufficient to describe implicit properties of materials, and the perceptions of the same subjective description may vary between individuals. So there is a need to translate between subjective description and objective knowledge [40]. Wilkes et al. used the same set of material samples to translate designers' subjective sensorial perception to material properties that scientists could appreciate. This work emphasised that the interdisciplinary communication related to materials benefits from the "*shared language of physical objects*" [33].

3 STUDY METHOD

The study reported in this paper comprised five parts undertaken over one year. Our study started with a survey (see section 4) into textile designers' design interests and concerns in interactive technology, whose results led to the understanding of how to facilitate support. We designed an e-textile toolkit (see section 5) and used it in a workshop (see section 6) with five textile students from a world-leading arts university, four of the five participants from the workshop further participated into an eight-week long-term design projects (see section 7). The study was conducted in the wild as part of the university's teaching curriculum. The workshop and eight-week project formed an elective module for the textile postgraduate program. Students were free in choosing this module among others based on their design interests. The participating students signed a consent form and were advised that they could stop participating in the study but still engage with the module at any time. We observed how students approach interactive knowledge and apply the knowledge into their design practice in an open-ended design process. A year after the project, we revisited the participants (see section 8), viewing their recent work and conducting interviews to learn how this project gave long-term impact on students' design practice.

4 SURVEY INTO DESIGNERS' INTERESTS IN DESIGNING WITH INTERACTIVE TECHNOLOGY

We created a questionnaire to find out about design students' previous experience with interactive technology and their design preference for projects which included interactive elements. The questionnaire helped us to better structure support for participants in later stages of this study. The main survey questions included:

- Q1. Describe the idea(s) of the interactive project you wish to achieve
- Q2. What kind of reaction (output) do you want to use in your interactive project?
- Q3. What kind of sensing do you want to use in your next interactive textile project?
- Q4. What kind of materials do you wish to design with?

This survey was targeted at textile design students who had no formal training in programming or electronic engineering, and we also included fashion students due to their common skills in textiles.

4.1 Results and Reflections

We received 18 responses to the survey: 12 from textile design students, three from fashion designer students, and three from students with both fashion and textiles education background. We used thematic analysis [4] to analyse the questionnaire responses. The data from each iteration were coded using a thematic coding system.

The purposes of using interactive technology (Q1) was classified into two types: achieving functionality for monitoring wearer's physiological information or energy storage (6); and design enhancements (8) which aim to enhance the interaction between the design and users/wearers, and to make designs more playful or aesthetically pleasing.

For Q2, movement (13), lighting (8) and sound (8) were the most popular outputs. For Q3, touch & proximity (16), pressure (15), and stretch (10) sensing were the most popular sensing interests. The results for Q4 suggested that yarn, knitted fabric, thread, metal and paint were materials of most interest to the respondents.

Ten participants mentioned the visibility of the electronic components and concerns over whether the scale is "small enough", and whether they can be "hidden" or "incorporated" into the materials and garments. The responses revealed the concern of whether the electronic electrical circuitry can be texturally or aesthetically applied to design. Table 1 summarizes the survey outcomes.

5 E-TEXTILE TOOLKIT DESIGN: THE INFINITE TOOLKIT

The questionnaire results in section 4.1 offer an insight into design students' interests and concerns about interactive technology. As none of the existing toolkits reviewed in section 2 facilitate both easy access (low requirement of programming or electronics knowledge) and an open design space (few embedded design constraints) we created an e-textile toolkit with the following goals: a) easy to access with limited programming or electronics experience; b) allow for rapid prototyping; and c) encourage personalising interactive elements in the context of textile design.

The toolkit consists of online how-to instructions of hardware assembling and software installation and four types of e-textile sensor tutorials, including pressure and bend sensors (derived from questionnaire Q3) as well as switches and potentiometers with a supplement of templates to assist learning. The sensors can be seen in Fig 1. We also explained the electronic sensor principles through graphics to assist with learning the underlying mechanisms. The toolkit includes basic code for achieving different interactions. Instructions are straight forward, pointing out which lines of code contain parameters that can be modified to achieve a different outcome.

The toolkit supports two output functions: movement and sound (derived from questionnaire Q2). With the soft PCB mainboard illustrated at the top of Fig 2, designers can easily build a digital or analog sensor circuit by snapping template or personalised e-textile sensors to the PCB. To support students with different textile construction skills, we provide a selection of conductive materials including thread, yarn, fabrics, and metal, etc [39].

6 WORKSHOP

To investigate how to better support textile designers in understanding interactive technology, we firstly conducted a two-day workshop with five textile postgraduate students. Students were expected to learn the basics of sensors and interaction design with

Table 1: Summary of the survey into participants' design interests with interactive technology

Questions	Responses
Purpose of designing with interactive technology	Design enhancement (44%), achieving functionality (33%)
Desired output functions	Movement (72%), lighting (44%), sound (44%), color (11%), video (6%)
Desired sensing functions	Touch & proximity sensing (89%), pressure (83%), stretch (56%), switch (39%), position (39%), temperature (11%), sound (6%)
Preferred design material	Yarn (78%), knitted fabric (67%), thread (67%), metal (67%), paint (61%), woven fabric (50%), foam (33%), wool (11%)
Aesthetic concerns	Visibility (56%), texture (22%), attachability (6%)

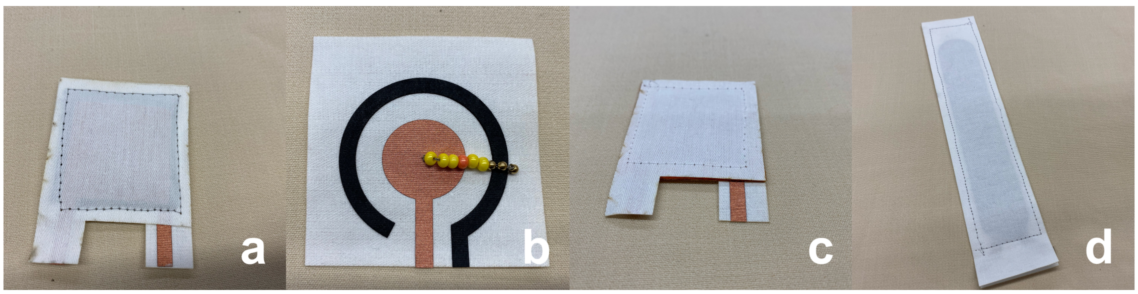

Figure 1: Sensors created from templates.(a) pressure sensor (b) potentiometer (c) pressure sensor (d) bend sensor

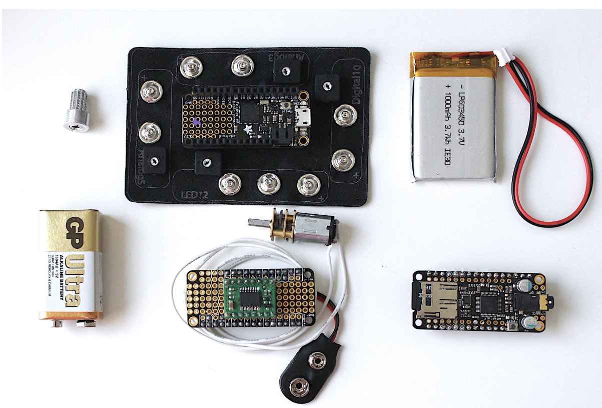

Figure 2: Core elements of the toolkit

the support of the toolkit which will be a fundamental to the following eight-week design process. The first author played the role of both facilitator and technologist. The workshop was facilitated by the MA Textiles course at the Royal College of Art (RCA), and this research project was integrated in their teaching modules.

Before the workshop, each participant filled a survey asking about their background. Table 4. describes participants' background information and the level of experience in electronics. In this paper, we refer to the participants as P1 for Participant 1, P2 for Participant 2 and so on.

6.1 Procedure

The workshop started with a short introductory lecture. The facilitator showed several videos of example e-textile and smart clothing projects, and invited students to discuss the interactive input and output in the projects. Students were then invited to make e-textile sensors with templates following the online sensor tutorials outlined in section 5. The facilitator then demonstrated how to use a multimeter to test material conductivity. Students then explored and tested conductivity from a range of design materials, including the conductive materials included in the toolkit and the usual design materials of their own practice, for example zippers, key rings, and a variety of thread, fabric and wire. This step was intended to raise participants' awareness that their usual design materials might have the ability to be used in interfaces, which may lead to a free exploration of e-textile interfaces. While testing, we encouraged students to think about the template sensors provided, and to brainstorm more personalised sensor designs with these materials. For the rest of the day students were asked to create sensors of their own.

On the second day, students downloaded the toolkit software environment following the step-by-step online instructions. They were then asked to create interactive prototypes in 3 hours. The limited time frame was intended to help to "*create a sense of urgency and also to sustain a high level of energy*" [19]. At the end of the workshop, participants were invited to demonstrate results and to fill in a questionnaire about their feedback on the toolkit and the workshop.

Participants were observed and interviewed during the workshop process, and the first author took field notes throughout the workshop. These offered insight into participants' learning processes and the level of engagement with the workshop and the toolkit.

Table 2: Participants' background

Part.	Program	Background	Experience
P1	1st-year MA Textiles (Knit)	Fashion design	None
P2	1st-year MA Textiles (Knit)	Textiles design	Limited, *"had a couple physical computing workshops that just touched on the basics of Arduino"*
P3	1st-year MA Textiles (Knit)	Textiles design	None
P4	1st-year MA Textiles (Mixed media)	Fashion/costume design	None
P5	(graduated) MA Textiles (Print)	Industrial design	Limited, *"have tried conductive ink, yarns and sensors to create functional textiles printing"*

6.2 Results and Reflections

Table 3 lists a selection of sensor creations which are pictured in Fig 3. We found that all students showed a strong interest in testing the conductivity of their own materials which in turn provided design inspiration and helped students to transfer sensor knowledge learned through the templates into material expertise. In the following sections we outline our observations of students' learning of e-textiles and how they used this knowledge in rapid design prototyping.

6.2.1 Relating technical knowledge to the textile construction process. We observed that students' first attempts at freestyle sensor creation highly resembled the template sensors. They followed the toolkit's sensor structures and replaced elements with different materials of similar electrical property with different construction techniques. For example, the dual purpose sensor by P2 and the pressure sensor by P1 imitated the sandwich structure of the pressure sensor template. P1 replaced the copper fabric layers with 2 layers of crochet in the shape of cross that was twisted with non-conductive and silver yarn.

6.2.2 Divergent sensor creation while interacting with materials. During the free sensor exploration, students typically intuitively interacted with materials without a clear target, and gradually formed design ideas as the hands-on work took shape. This allowed for unexpected creativity to happen. Crafting sensors with various materials helped students to build a deeper understanding and flexible use of the sensor principles. We observed three modes for this kind of exploration of sensors outlined below which suggest that learning happened during hands-on interaction with materials.

Combining materials. One popular way of forming e-textile sensors was for participants to combine their usual design materials with conductive materials. For example, P2 crocheted rafia yarn together with conductive thread to form the conductive layers of the dual purpose sensor. P1 twisted silvers thread with a piece of pink non-conductive yarn to construct conductive surfaces.

Shaping to form sensing functionality. Some students started by handling materials without a clear target of functions they were going to achieve. When the textile took shape, they sought sensing possibilities by shaping or playing with the textile itself. For example, P3 started by twining metal wire on a strip of chunky yarn, later she played with the yarn whilst sliding a metal key ring on it, realising the metal ring could close the circuit. She then formed the yarn into a ring that senses sliding. Squeeze switch by P4 was originally a knitted textile embedded with several strips of silver yarn. P4 then found this could be used as a switch circuit by pulling the threads which resulted in the conductive threads making contact through the tightened textile structure. P5's The Collar was inspired by planet and aircraft embroidered patches. P5 played with storytelling around an aircraft landing on a planet, resulting in her proposed interface that responds to the contact between the two embroidered patches. Students using this method usually started making intuitively, and then found unexpected sensing possibilities when the textile took shape, then processed it to complete the sensing functions.

Adding conductive elements after the textile is shaped. This method prioritised textile construction, and sensing functionality may be achieved by adding conductive elements once the textile is made. However, the interactive success of such a design was a result of sheer luck. P4 constructed a textile sample with a selection of design materials regardless of their electrical properties. When the sample was completed, P4 tried to fill some conductive wool between layers through the seam, and attempted to form a squeeze sensor, but it was not successfully achieved due to the incomplete electrical circuit. This method has limited feasibility as the circuit may be hard to build and fully embed into completed textiles.

7 EIGHT-WEEK EXPLORATION

Following the workshop, four students (P1, P2, P3, P4) took the toolkit home and started designing interactive textile projects over eight weeks. P5 chose not to continue in the study due to personal logistic conflicts. It was not mandatory to use the toolkit, and participants were free in choosing any electronic components. The first author met each student once a week to discuss their design process, provide technical support upon request, and keep field notes on project development. To capture longitudinal data throughout the design process, we asked students to keep a design diary [21, 24]. Students were interviewed at the end of the project discussing the project and their experience of the study.

7.1 Results and Reflections

Students went through three stages to complete their projects. The first stage was researching - starting by researching design concepts, colour scheme, materials, and interaction examples. Next is the experimenting stage in which students tested sensors and actuators while constructing textile samples, adjusting the physical design according to the technical affordances. In the final stage, students mostly implemented and finessed their projects independently.

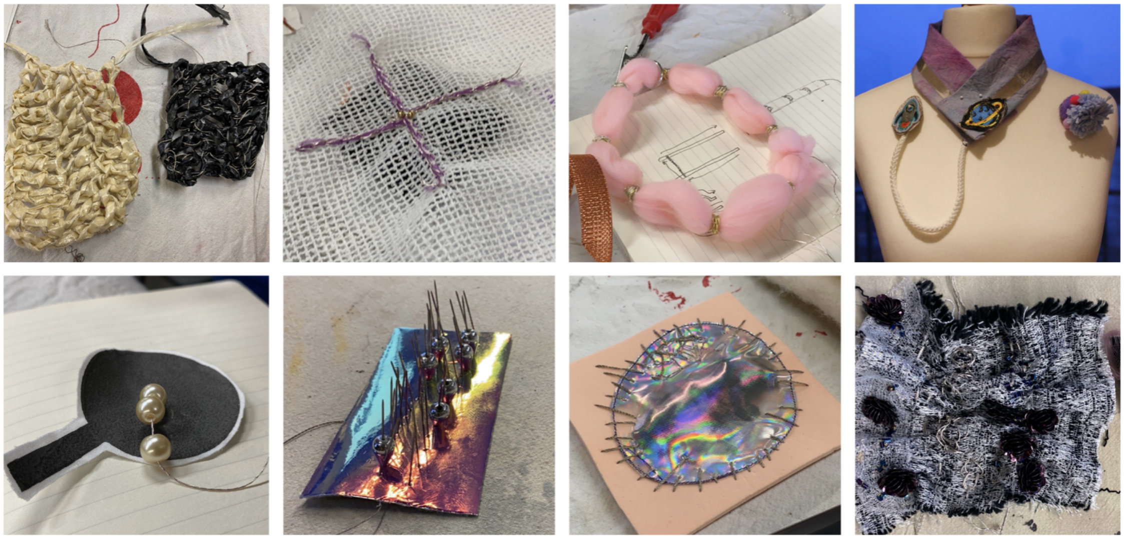

Figure 3: A selection of sensor creations. From top left to bottom right: dual purpose sensor by P2; the cross by P1; ring by P1; the collar by P5; pearl by P3; spikes by P2; pressure sensor by P4; squeeze switch by P4

Table 3: A selection of sensor creations

Sensor	Construction	Interaction
Dual purpose sensor by P2	Two separate layers of crocheted rafia yarn with the conductive thread	A pressure sensor if the anti-static foam is placed in between of the two crocheted layers, can also be a pressure switch without the foam
The Cross by P1	Two layers of mesh material both crocheted with the mix of a pink and silver threads, a piece of anti-static foam sandwiched in between	Can sense pressing or squeezing of the crocheted threads
Ring by P3	Twined the metal wire on the pink thread in about every 3cm, then chained a key ring on it	Can sense the key ring sliding on the pink thread
The Collar by P5	The collar was tie-dyed. Two strips of conductive fabric are placed through the collar, the end of each strip is connected with a embroidery patch and bonded with conductive fabric	Senses switching on and off when the two embroidery patches were in contact with each other
Pearl by P3 (incomplete)	The round-shape fabric was printed with conductive ink, pearls were strung onto the conductive thread	-
Spikes by P2	There are two stripes of conductive fabric glued on the back of the gold metallic fabric, there are a plenty of needles stuck through the fabric	Can sense stroking on needles
Pressure sensor by P4 (incomplete)	The conductive wool was stuck into the sewed layers of non-conductive material	-
Squeeze switch by P4	Two strips of silver threads and metal snaps were sewed randomly on the knitted non-conductive textile	Senses switching on and off when tightening or loosening the textile by the drawstrings

Table 4 shows a summary of the completed projects pictured in Fig 4. Note that we did not receive P2's authorization for publishing the visual project documentation, so there are only text descriptions of P2's project. In the following sections we outline our observations of how students used and appropriated the toolkit and sensors in their design projects drawing on data from interviews, field notes, and design diaries.

7.1.1 Browsing a gallery of interaction design stimulates creativity. It was reported that the videos of example interactive textile

Table 4: Results of long-term exploration

Project name	Design concept	Construction	Interaction
God Creation Project by P1	This project explores God Creation as a form of shelter and spiritual escapism. The action of God Creation can be considered a physiological stress response towards an unstable social and political environment.	A LDR is wrapped into the knitting object. The sculptural textile objects have different inner structures that achieve five different motions using a motor, and the movement causes bells embedded on textile to shake.	Lighting UV light on the LDR to activate motions operated by embedded motors.
Radiolarian by P2	Inspired by a single-celled aquatic animal Radiolarian, the project consists of sculptural structures that are associated with Trypophobia, creating an abnormal feeling of discomfort.	The crochet is made into a switch sensor of two conductive layers and a bio-plastic layer in between. The two conductive layers make contact through the holes on the bio-plastic layer when pressed.	Touching crochet to trigger unpleasant sound through the MP3 player.
Annoying Gum by P3	The project is about people's daily interaction with bubble gum. Building a scene of a person stepping on gum and trying to get rid of it, it shows the annoyance of the bubble gum in the form of a knitted puppet show.	Combining conductive yarn with a stretchy hollow material, a stretch sensor is knitted on the gloves. A puppet moves when the pulling thread is rolled by the motor	As fingers moving against each other, the movement of the knitted puppet is triggered.
The Forbidden Eden by P4	Inspired by the forms of jellyfish and how their organisms work together, P4 combined air inflation and silicone to achieve a level of softness and breathing, reflecting contemporary societal issues.	The silicon objects are hollow, and the reformed pump could pump air into the silicone.	Pressing the e-textile pressure sensor to trigger air inflation.

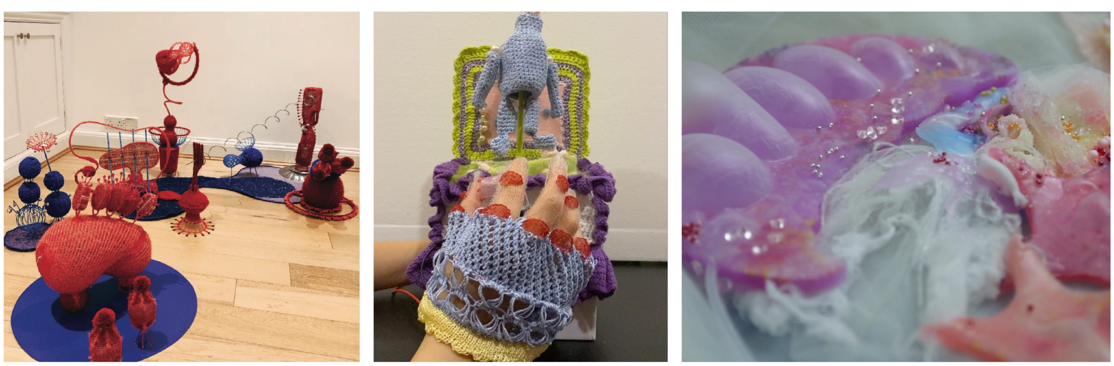

Figure 4: Results of long-term exploration. From left: God Creation Project by P1, Annoying Gum by P3, and The Forbidden Eden by P4

and garment projects in the introduction workshop were inspiring and built students' confidence in an unfamiliar area. Students also reported that through the workshop they became clearer about input and output relationships in interaction, and these understandings enabled them to research more interaction options beyond the toolkit. This learning also helped to support better communication with the facilitator when they needed technical support.

With the technical knowledge gained during the workshop, students browsed a variety of e-textile and smart garment examples in the research stage, and developed broad ideas about potential sensors and actuators based on those used in the examples. These resources became points of inspiration. Inspired by an exemplar soft robotics project, P4 decided to use a similar function of air-inflation and silicone to create her textile project. While browsing online resources, P1 expressed their intention to use light sensing as it better supported their project concept. Both P1 and P2 stated they wanted to try as many sensors as possible before making a decision, as it allowed them to identify design opportunities by observing different interactions.

7.1.2 Fast-prototyping toolkit boosts design efficiency. We observed that our toolkit's modularity saved design students' labor and time from making supporting circuitry and learning programming, helping to keep their focus on the physical interaction design. Students reported that they could easily achieve input and output functions in any stage of design. This helped to exemplify how specific input and output functions could be integrated into textile designs cases. For example, P1 decided to use movement in their work, so they spent the majority of their time in the experimenting stage exploring how to achieve different movement effects through a single rotating shaft, and developed five physical prototypes to simulate movements through motors (Fig 5). The fast-prototyping toolkit and ready to use functions saved P1's effort on learning programming and building electrical circuits, and allowed them to invest more time into design-related work. Also, it was reported that this helped P1 to understand the technical requirements of the movement structure, so that they could dig deeper into their specific design problem.

7.1.3 Design and technology are co-developed together. During the experimentation stage, students constructed and tested sensors while also undertaking textile construction. This co-development of sensors and textiles made the interactive textile more integrated. For example, P2 aimed to create a switch sensor and started with using conductive paint and applying this to crochet. As this approach was not robust P2 instead used a mix of conductive and cotton yarns to stitch together into two lattice style swatches , and then used bioplastic to fuse the two structures together, sandwiching a piece of hole punched non-conductive fabric in between. This formed a switch sensor. P2's process considered textile design and technical development as a whole, the interface was fully integrated into the textile construction. P1 found when the LDR is wrapped into yarns, it would be less sensitive to the room light but more sensitive to the UV light, therefore she knitted a shell to contain the LDR as well as controlling its sensitivity (Fig 5). Such evidence revealed students were able to adjust sensors in specific design scenario, and build up a flexible use of technology. P3 chose a hollow material for the puppet's glove, considering that this material is stretchy, she crocheted conductive yarn into a strip and inserted it into the hollow material to form a stretch sensor. In these cases, interactive systems were not presented as separate from the textile design and something added as a second process, instead they were integrated during the textile construction process and related closely to the material properties.

8 POST-STUDY REVISIT

Fourteen months after the study, we reached out the participants (P1, P3, P4) who continued eight-week design project to investigate whether they have been using interactive technology in design after the project, and what on-going impact the project had. Despite numerous attempts we failed to reach P2 after the end of the eight-week project - possibly the pandemic may have made contact difficult at the time. The students had graduated and so we examined the digital elements used in their graduate project. We also conducted an interview including the following topics:

- Q1. Have you explored more about interactive technology or other digital technology since the project? What did you explore?
- Q2. What on-going impact did the project give to your design practice? What was the most useful knowledge you gained through the project?
- Q3. What jobs have you been looking for? Do you think you will continue exploring interactive technology in your career?

8.1 Results and Reflections

All three students used digital elements in their final projects. P3 continued working with interactive technology, using movement related interaction to deliver a series of storytelling knitted textile installations. P4 constructed a color-changing costume using thermal-chromatic dye. P1 had been exploring different sensors and actuators with other commercially-available toolkits since the project, but she did not use interactive technology in the final project, instead she used VR photogrammetry and digital landscape building to create an immersive experience of knitted sculpture.

P1, P3 and P4 suggested that the basic knowledge and mapping of interaction is the most useful thing learned through the project. It helps them to no longer panic about interactive technology. As P1 stated, learning how to make sensors and knowing how everything worked was extremely interesting and inspiring to her : "*I did explore physical computing in my spare time...the project just opens the door for me and it sort of gravitated me to dive into it deeper.*" P3 reported that interactive technology is very powerful in enhancing the storytelling design concept.

P1 reported the impact of this project was to let her reach the interdisciplinary area of digital technology, she tried to connect her work with digital technology in her own way. P4 reported this project changed her design thinking and interactive technology became a part of her design process. Since the project, she started to consider whether interactive technology could be useful in a specific design case, and what sensors and actuators can help to enhance the design concept. Talking about P4's final project, P4 stated "*I always think interactive technology is a part of my final project, because from the beginning, when I structured this project, I considered interaction in it.*"

P1 joined a gallery as an artist to continue textile fine art exploration, she stated that she planned to use interactive technology in her next project, and as an artist, interactive technology is very important for her future work. P3 and P4 thought interactive technology might be not useful for their careers, but P3 stated that as a designer, she would continue designing with interactive technology in her spare time, because it has become a part of her personal interest.

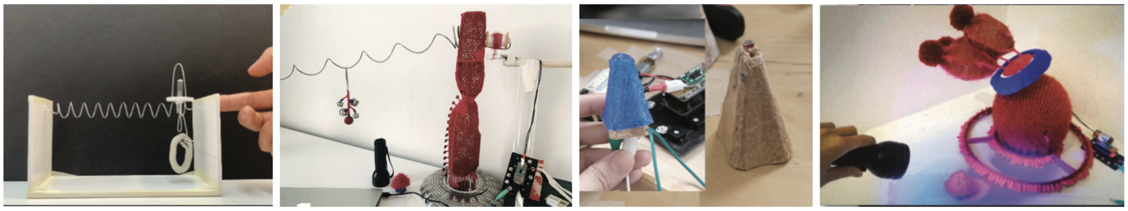

Figure 5: P1's design process to create movement with a single rotating motor.

9 APPROACH IMPLICATIONS AND CONCLUDING REMARKS

The open-ended approach and the toolkit mutually reinforced a flexible use of technology and resulted in a more integrated design. Demonstrating a variety of example interactive projects, sensors and actuators relating to textile and clothing design broadened students' design vision and helped to generate new concrete design ideas. The toolkit supported rapid hands-on tests and experiments between physical design and electronics, appealing to textile designs' tacit nature.

We suggest that our results contribute to the development of tools and approaches for textile design students and designers learning tangible interaction design skills and building flexible use of technical knowledge in their textile design process. Reflecting on our open-ended exploratory study we note that guiding textile designers to start technical exploration from familiar materials increased their enthusiasm and curiosity in technology. Knowing that everyday-use materials have potential in building interfaces helped our designers to better associate technical knowledge with their material expertise, and further contributed to integrated interface designs.

We suggest that it is important to explain some of the principles of electronics, as this is an entry point for personalisztion. However, it is more effective to deconstruct e-textile sensor principles at a material level. For example, we found students usually repeat the structure of template sensors with materials with similar electrical properties using different textile construction techniques. This reveals their process of digesting technical knowledge relates closely to material expertise. As P1 stated, the process of making sensors with the template gave her inspiration on how to associate technical knowledge with textile design.

We identified three ways of applying and integrating sensors in textile design process, including combining usual design materials with conductive materials, shaping to form sensing functionality as textile design took shape and adding conductive elements after the textile is constructed. The first method contributes to a more integrated interface design on textile as the textile layers of diverse materials can be featured with conductivity while it was constructed. The other methods are more intuitive, and the formation of sensors is usually random. However, there will be more unexpected creativity and sensing possibility explored during the textile construction process, and creative sensor design might be more informed by material properties.

9.1 Focusing on the Design Itself

In section 4, we reviewed a range of e-textile toolkits, the majority of those focused on supporting learning of electronics and programming and assisting interdisciplinary collaboration. Our toolkit aims to provide ready-to-use technical solutions to save students' time for the textile design itself. At our workshop, students quickly experienced two output functions through the toolkit, offering a concrete understanding of each function and how it might feel in textile application. The toolkit not only demonstrated the design space of different functions but also led students to understand the mapping of interaction which supported an interaction ideation process as well as expanding explorations beyond existing technical support.

We argue that it is more important to demonstrate the affordances and general principles of technical functions than explaining circuitry and programming mechanisms in detail. Rather than mechanically applying interactions on designs, the effort saved helped students to investigate how to better embed technology with textiles to achieve a harmonious result.

9.2 Intertwining Technical Explorations with Material Expertise

We suggest that the process of free sensor exploration with diverse materials during the workshop helped students to ground technical exploration in their textile design processes and 8-week project. Students might make technical decision based on the choice of materials, for example, P3's glove embedded stretch sensing to the stretchy hollow material and P4 found air inflation function for the silicone material to create levels of breathing effect. Also, students tested input and output functions according to the specific textile design scenario, for example, P1 found when enclosed in yarn, the LDR became less sensitive to ambient room light but more sensitive to UV light which she intended to use for creating environment atmosphere for the textile sculpture.

In addition, we found the role of the facilitator changed throughout the study, and the toolkit became a base point for communication with students. Students independently researched online and determined options of interaction that could fit their design, then they initiated consultation with the facilitator. In this stage, students were able use their emergent understanding of electronics to specify their technical intentions and lead the design process.

Longevity of our approach is suggested by the graduates who were revisited 14 months after the project who continued to explore interactive technology in their design practice, reporting that interactive technology opened more design possibilities, and had become a part of their design thinking.

9.3 Limitation and future work

The study was integrated into one of the RCA elective modules that recruited only students who were interested in the area, and so students' engagement with their module contributed to a high quality of participation. However, there were a small number of participants with only 4 students taking part in both the workshop and the long-term design project, and we lost touch with one student during the post-study revisit. Undertaking the follow-up interview a year after the study is important to understand the impact of the work, but also pragmatically difficult given the difficulty of reaching people who have already graduated. To better integrate interactive technology concepts into textile disciplines, it would be worth investigating ways of inspiring bigger groups of design students including those who were not previously aware of the benefits of designing with interactive technology.

The study results suggested that the communication between students and the facilitator was improved as students became familiar with the mapping of interaction and its design space. Future research could build on the approach applied in this study and further investigate how cross-disciplinary collaboration between designers and technologists could be improved.

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