E-Textiles in STEM Outreach and Education

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***Abstract*— Textiles, being both ubiquitous and familiar, provide an accessible medium for teaching electronics interactively. By integrating electronics into textiles, STEM education becomes more relatable and promotes inclusivity and gender diversity. This paper presents two primary resources: e-textile demonstrators and a learning kit for students aged 6 to 11, aligned with the Key Stage 2 science curriculum. The demonstrators—which include motion-detecting and light-up fabrics embedded with accelerometers, LEDs, and microcontrollers—are used to spark student interest prior to the main activity, highlighting real-world applications of electronics in familiar materials like textiles. The learning kit comprises filament electronics, laminated screen-printed e-textiles, conductive tape, and a battery pack. Students assemble these components to create a functional LED circuit on fabric in a straightforward, easy-to-grasp format. This hands-on experience not only reinforces students' understanding of basic electronics but also supports iterative learning and troubleshooting. Unlike traditional kits that involve sewn conductive threads, which can be tedious to adjust, this kit enables quick and simple error correction, enhancing both engagement and learning efficiency.**

Keywords— E-textile outreach, screen printed textiles, filament electronics, STEM learning.

I. INTRODUCTION

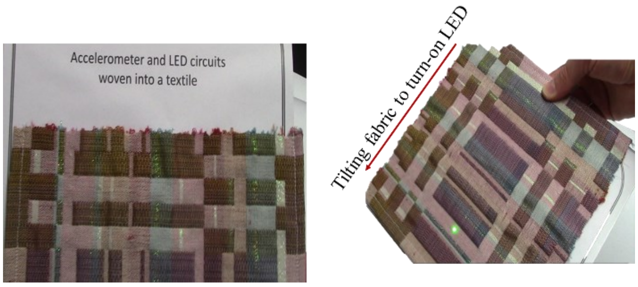
Increasing diversity in STEM (Science, Technology, Engineering, and Mathematics) subjects is a critical global concern. Despite numerous efforts and initiatives, significant disparities persist in these fields [1, 2]. Encouraging greater diversity is essential not only for achieving equity and inclusion but also for fostering innovation and driving economic growth. Women and other underrepresented groups bring unique perspectives and skills, creating diverse teams that produce better operational and organisational performance [3].

E-textiles integrate electronics into textiles, enabling a range of STEM-driven applications across fields such as sports and healthcare, with potential to advance biomedical solutions by leveraging the widespread use of textiles and their close contact with the human body. Although challenges remain regarding the durability, washability, and sustainability of emerging e-textiles [4], their effectiveness for teaching electronics in STEM classrooms to children and other non-specialist audiences has attracted considerable research interest over the past decade [5].

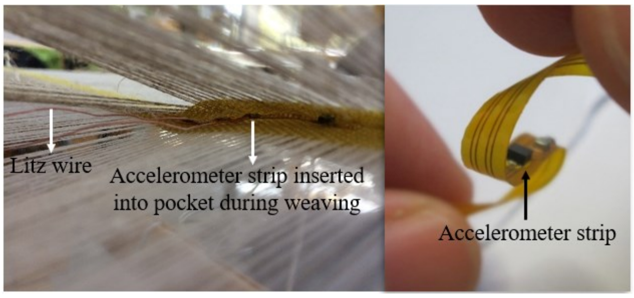
Learning activities in STEM classrooms and workshops involving e-textiles are gaining popularity because they promote student engagement by utilizing everyday materials like textiles and off-the-shelf electronic components or modules [6-9]. However, most of these activities rely on sewable e-textile construction and learning kits, which require students to have some proficiency in stitching or sewing. This can present an initial challenge, especially for inexperienced students. These hands-on activities teach students basic electronic circuit assembly and computer programming by applying craft techniques. Using conductive threads, needles, scissors, and craft knives, students integrate custom components such as sewable LEDs, rigid LilyPad PCBs, and iron-on parts into a single, functional textile circuit [8, 9].

Teachers report increased student interest and engagement in electronics across all genders when using sewable e-textile kits [8], yet certain challenges persist. A teacher survey from the STEAM project raised concerns about the safety of craft tools, such as needles and cutting knives, which carry risks of accidents and injuries [10]. Another issue observed during a short e-textile workshop session conducted by Ioannou et al. was that some children handled conductive threads just as they would standard sewing threads, inadvertently creating short circuits by allowing the conductive threads to overlap or cross inappropriately [11]. Although the durability of sewn components has been demonstrated [12], the tedious process of fixing incorrectly sewn conductive threads presents another challenge to both learning and engagement. Moreover, making mistakes, such as creating short circuits, is a natural part of learning electronics, and students should be able to easily correct these errors. To address this, some construction kits use electronic modules that snap onto metallic snap buttons attached to conductive threads on textiles [13]. However, these kits typically treat the textile as a base for rigid PCBs, which alters the fabric's texture.

The screen-printed learning kit presented here improves on these existing kits by addressing the safety concerns and allowing easy correction of connection errors. Targeting children aged 6 to 11 in Key Stage 2, the learning activity begins with interactive e-textile demonstrations. These demonstrations are intended to motivate interest and engagement in primary school students having proved

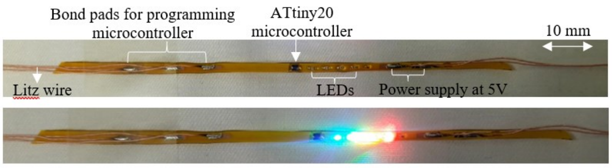


(a) Motion detection fabric with LED indicator

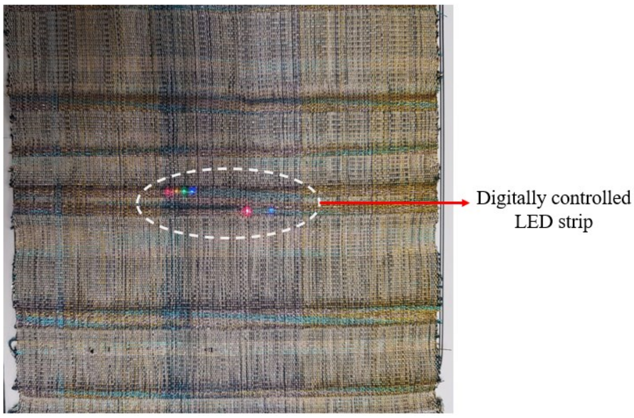


(b) Weaving process of accelerometer strip circuit into a fabric

Fig. 1: E-textile demonstrator fabric for motion detection



(a) Digitally controlled LED strip



(b) Embedded LED strips on textiles

Fig. 2: E-textile demonstrator fabric for digitally controlled LED swatch (adapted image from [14])

successful at the University of Southampton's annual science and engineering events, which typically attract around 2,000 visitors.

As shown in Fig. 1 and 2, the demonstrators include fabrics embedded with motion-detecting sensors and digitally controlled lights, created using traditional weaving process. These demonstrators showcase practical, textile-based applications using sensors such as accelerometers, LEDs, and microcontrollers. For example, the motion-detecting fabric mimics applications in fitness by detecting body movement, while light-up textiles illustrate visual feedback systems on wearable fabrics.

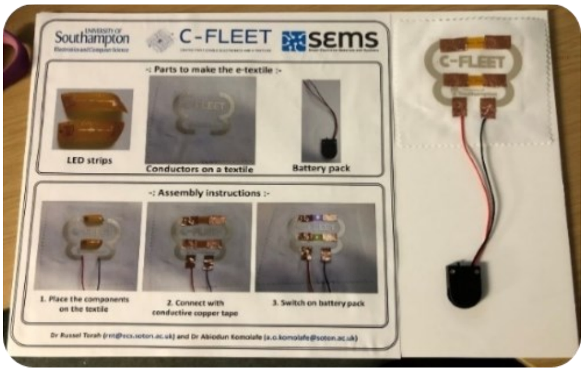


Fig. 3: E-textile learning kit.

The learning kit, shown in Fig. 3, includes a textile swatch containing a screen printed circuit. Screen printing is a simple, high-throughput manufacturing process widely used in the textile industry to produce both simple and intricate patterns on fabric. This method makes it possible to mass-produce e-textile swatches, making them highly suitable for educational activities on a large scale. In addition to the e-textile swatch, the kit contains flexible electronic modules that enable complex circuits to be presented in a format that maintains the fabric's natural feel, unlike traditional rigid PCBs, which can disrupt the textile’s texture and flexibility. The kit also includes a battery pack and conductive copper tape, which students use to complete the e-textile circuit.

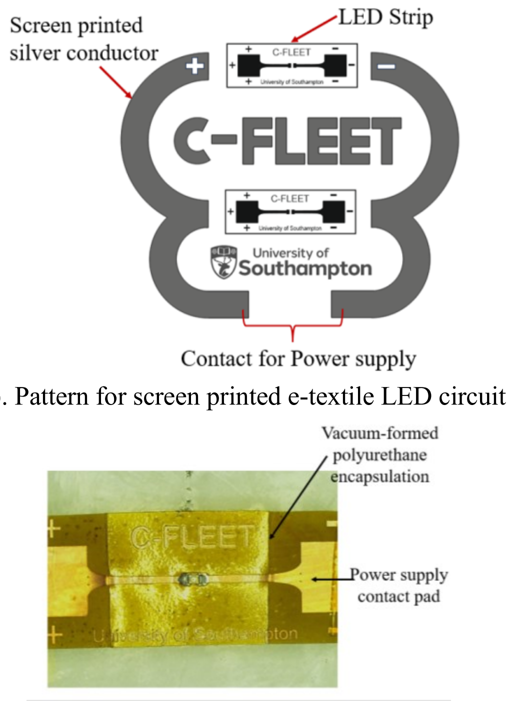
This approach, like traditional sewing kits, offers hands-on experience with basic electronics but also introduces improvements in ease of use. The conductive tape, for example, can be removed and replaced as needed, making troubleshooting simpler. This allows students to easily fix any short circuits or misconnections, promoting iterative learning and engagement. The elimination of sharp tools like needles and craft knives also enhances student safety, creating a safer learning environment.

II. MATERIALS AND FABRICATION PROCESS

A. *Fabrication of e-textile demonstrators*

The e-textile demonstrators consist of two woven textile swatches that discreetly incorporate narrow strip circuits (between 2 – 5mm wide) for motion detection and light indicators. These strip circuits are fabricated on a flexible, single-sided copper-coated polyimide film, manufactured through standard photolithography and etching processes [14].

To enhance durability, the circuits are encapsulated with a layer of heated polyurethane (PU) film under vacuum, which provides a conformal protective layer against abrasion, moisture and strain [15]. The PU film is Platilon U073, supplied by Covestro Ltd. The encapsulated circuits are then woven directly into the fabric using a Toika weaving loom. A double-weave setup is used to create bespoke pockets within the textile, allowing the strip circuits to be embedded securely without affecting the textile's overall flexibility. This setup, shown in Fig. 1, conceals and protects the circuits within the fabric, further enhancing their durability and handling.



(a). Pattern for screen printed e-textile LED circuit

(b) Encapsulated flexible LED strip

Fig. 4: Fabrication of e-textile learning kit

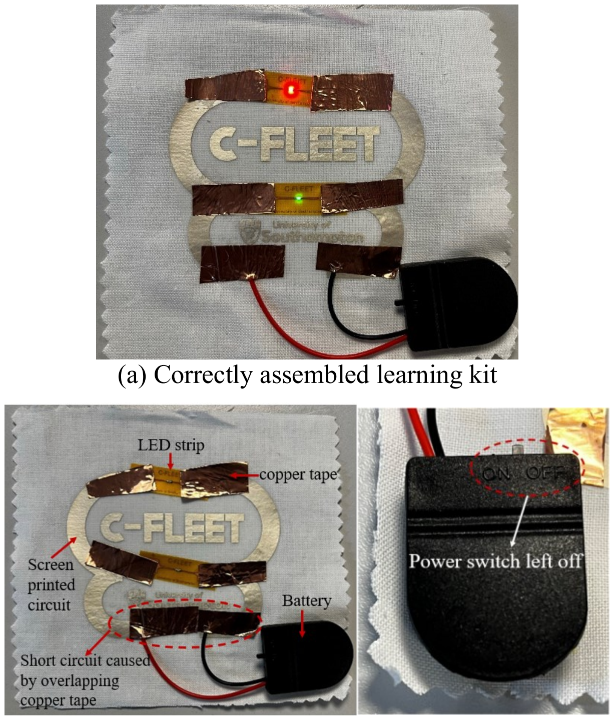
For power, the circuits connect to an external battery pack via flexible Litz wires, soldered to the strip circuits, as shown in Fig. 2, ensuring a stable electrical connection while allowing the textile to remain flexible.

B. Fabrication of e-textile swatch and LED strips

Standard polyester-cotton fabric (optic white A1656), supplied by Klopmann Ltd, was cut into textile swatches. A 100-µm thick polyethylene terephthalate (PET) film, Elecrom Flex, sourced from Policrom Screens Ltd, was used as the substrate for screen printing the LED circuit shown in Figure 5. The 5-µm thick circuit was screen printed using a DEK 248 semi-automatic printer and silver paste (TC-C4001) provided by Smart Fabric Inks. The printed silver paste was oven-dried for 10 minutes at 60°C. Following the printing process, the PET films were laminated onto the pre-cut textile swatches using a commercial heat press (Geo Knight DK20) at 190°C for 1 minute. The LED strip in figure 5 containing soldered surface-mount LED, was fabricated with the process described in Section II.A.

III. LEARNING ACTIVITY AND ASSEMBLY ERRORS

The learning kit was used to engage two Year 6 classrooms, comprising 60 students aged 10 to 11, with approximately 55% girls and 45% boys. Each student received an e-textile swatch, two LED strips, six pieces of conductive copper tape, and a battery pack containing a 3V coin cell battery, as shown in Fig. 3. The task was for students to assemble these components into a functioning LED circuit (fig. 5a), in accordance with the Key Stage 2 activity on science circuits. To support learning, the students were provided with visual instructions (shown in fig. 3), offering a step-by-step guide to complete the assembly. The screen-printed conductors on the textile swatches as well as the LED strips had positive (+) and negative (-) signs imprinted on them to indicate the parts that connect to the positive and negative terminals of the battery.



(a) Correctly assembled learning kit

(b) Common errors during kit assembly

Fig. 5: Assembly and common errors of e-textile learning kit

Fig. 6: Assembly of learning kit by Year 6 students, with and without instructor support.

Interest in the activity was strong among both genders, which aligns with research showing that girls also have positive attitudes toward science [16]. Despite the high overall engagement, a few students required supervision to successfully complete the activity as shown in fig. 6. While most students were able to work independently, some still needed additional guidance or support to fully understand and complete the assembly process. This pattern was also observed during the University of Southampton's (UoS) science and engineering public event, where children aged between 6-11 years assembled over 100 learning kits, though the assembly process was highly supervised and instructed. On average, the assembly time typically lasted about 5 minutes.

When students encountered difficulties during assembly, several common errors typically arose. One frequent mistake was overlapping the copper tape during assembly, as shown in Figure 7, which caused a short circuit, similar to the conventional e-textile sewing kits. This normally occurred when students attempted to assemble the components independently without following the provided instructions. Another common issue was the incorrect placement of the LED strips. Due to their transparency, some students struggled to identify the correct orientation, causing them to flip the strip during assembly. As a result, the copper tape failed to make proper contact with the LED strip. A third issue was students forgetting to turn on the battery switch, which prevented power from reaching the circuit. With guidance from an instructor, students were able to correct these mistakes easily, often reusing the same copper tape. This makes this screen-printed learning kit well-suited for iterative learning, although students may require some supervision to successfully complete the assembly.

The learning activity also highlighted areas for improvement with our alternative learning kit. In some cases, the copper tape did not make proper contact with the printed circuit and strips, even when the students assembled the kit correctly. This points to the need for more reliable interconnections. While the kit can be reused for the same activity, its repetitive nature may lead to monotony. Therefore, it should be redesigned to include a wider variety of electronic activities, offering students more flexibility to creatively explore their understanding of electronics.

Overall, the activity completion rate is 100%, with all students successfully ensuring their circuits worked and demonstrating curiosity when issues arose. To maintain this enthusiasm and encourage greater diversity in STEM, more activities like this are essential. E-textiles, with their real-world applications in fields such as healthcare and fitness, have broad appeal and highlight tangible impacts, particularly resonating with female students [2].

IV. CONCLUSIONS

Screen-printed e-textile learning kit and outreach demonstrators can aid teaching and delivery of electronics within the Key Stage 2 curriculum. Generally, e-textiles offer a unique opportunity to promote diversity in STEM fields by leveraging the familiarity and ubiquity of textiles, as everyone interacts with fabric in their daily lives. By combining STEM with the Arts—fields that often have a reversed gender balance—e-textiles bring together these two communities, fostering greater equity. Based on activities reported in this work, student engagement and interaction with e-textile learning have been enthusiastic both inside and outside the classroom, irrespective of gender or cultural background. This approach provides a valuable platform for parents and teachers to cultivate student interest in a wide range of STEM topics.

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