Move With Me: Co-designing a Tangible User Interface To Promote Physical Activity Among Rural South African Children

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Abstract

Childhood physical inactivity and obesity are growing concerns globally, including in rural South Africa, where children often lack access to safe play spaces and well-resourced Early Childhood Development (ECD) centers and face increasing screen time. These challenges limit opportunities for physical development in early childhood. To address this, we developed Move With Me, a wearable tangible user interface (TUI) in the form of a superhero cape that encourages physical activity as a probe for further investigation. While many commercial technologies that encourage movement exist, they are unsuitable to rural communities due to their high cost and reliance on stable internet and electricity infrastructure. In response to these challenges, we co-designed a more contextually relevant solution with rural South African mothers using the technology probe to support the ideation and co-design process. The final cape design integrates motion sensors, LED lights, Bluetooth Low Energy (BLE), and a solar rechargeable battery pack, delivering real-time feedback without internet connectivity or stable electricity. A companion mobile app gamifies movement with culturally relevant animations to engage children. We found that co-design empowered mothers to tailor the technology to their context, suggesting affordable components and re-purposing existing smartphone features such as sound and animations instead of using costly electronics incorporated into the cape. Their contributions led to a low-cost, offline-capable, and personalized TUI. Our work demonstrates how wearable TUIs, developed through inclusive design, can support physical activity in resource-limited settings. We contribute practical insights for designing sustainable technologies for rural contexts, emphasizing affordability, low power consumption, offline functionality, and the value of embedding co-creation throughout the design process.

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CCS Concepts

• **Human-centered computing → Interactive systems and tools**; **Human computer interaction (HCI)**;

Keywords

co-design, cape, rural, tangible user interface, hci4d,community-based

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1 Introduction

South Africa is currently experiencing challenges with childhood inactivity, which are exacerbated by the rapid increase in the use of technology among children [49]. It is well known that early childhood is a critical growth stage that is crucial for cognitive, social, emotional, and physical development, as children's brains are highly adaptable and responsive during their first seven years [30]. Optimal ECD, thus, heavily relies on a stimulating environment, healthy exercise, and positive social interactions with caregivers who provide attention and support in children's everyday lives [67].

In the last decade, digital devices have increasingly dominated children's free time, where traditional physical activity (PA) has been replaced by sedentary activities, often known as the "PA transition", contributing to significant public health concerns. [49]. This unhealthy lifestyle change is largely a consequence of poor nutrition, limited access to recreational facilities, and the increasing use of digital devices [44].

The scarcity of parks and recreational facilities especially in rural South African communities further poses significant challenges to young children's physical and emotional well-being and early development. This lack of free open spaces hinders the development and promotion of healthy lifestyles, particularly at a young age, as it limits opportunities for physical activity, social interaction, and community participation, which are vital for a child's overall development [13]. To address the challenges around increased sedentary lifestyles in children and lack of access to open spaces, previous research has started to explore how technology can be helpful rather than only treating it as a limiting culprit.

Developing technology to support physical development is not a new concept. Gaming consoles such as the Wii [1] developed by Nintendo already offer a combination of screens, technology, and physical movement. However, rural communities face infrastructural challenges such as unstable electricity and poor internet connectivity. The cost of technology further hinders the acceptance of traditional gaming consoles [2]. Thus, using conventional approaches to encourage physical activity with advanced technology solutions, such as gaming consoles, similar to the Nintendo Wii and Xbox, is not feasible or practical in low-resource community settings.

Given the concerning trends in childhood inactivity in South Africa, especially in rural areas, it is clear that innovative solutions are needed to address existing challenges. However, it is crucially important to ensure that the technology designed is culturally and contextually relevant [26, 52]. In this paper, we discuss the co-creation and co-design of wearable technology, specifically a superhero cape aimed at encouraging physical activity among children. We approach the co-design through the use of a technology probe to assist in the ideation phases of the co-design workshop and report on the findings of both the technological artifact and the co-design process.

We next discuss the background and related literature, followed by the methodology, which outlines our co-design approach as well as the use of technology probes. This is followed by our findings, where we first discuss the implications for the design of TUIs aimed at rural South Africa, followed by the mother's experience of the co-design process. We conclude this paper with a discussion that highlights the importance of designing for rural contexts and working with rural communities to design more sustainable technologies.

2 Background and Related Literature

2.1 Sedentary Behavior and the Importance of Movement

Childhood obesity has grown into a critical global health concern, with 1 in 5 children currently displaying signs of unhealthy weight or obesity [75]. In Africa, this problem is becoming increasingly visible and is aggravated by a lack of physical activity at home, raising concerns across Africa as [53] it was estimated that by 2020, nearly 1 in 8 African children would be overweight. [46].

In South Africa, increasing sedentary behavior is contributing significantly to childhood obesity and general unhealthy behavior. [22]. In addition, urbanization and the widespread use of digital devices have also led children to engage more in sedentary activities, such as watching television and gaming, contributing to the increasing prevalence of obesity [11]. This is unfortunate as physical activity is crucial for the health and well-being of young children.

According to the South African Government, Early Childhood Development (ECD) is an inclusive approach that includes programs and policies that foster the development of children from birth to the age of nine. The country has a formalized ECD curriculum that promotes holistic child development, which includes cognitive, social, emotional, and physical development [60].

ECD is acknowledged as a crucial factor in reducing the rate of socioeconomic gaps. Regardless of this recognition, many children are born into environments where their circumstances limit their developmental activities and chances for growth. This is most commonly due to the limited access to essential resources and healthcare services [24]. Another crucial challenge in South Africa, primarily in the ECD sector, is the shortage of suitably resourced and registered ECD centers. Sello et al. [59] explains that 43 percent of South African childcare centers open and operate without official registration, which does not make them eligible for government funding. The shortage of registered ECD centers is evident in poorly resourced areas such as those zoned as rural in South Africa. Due to the lack of proper funding and resources available in these areas, parents are forced to turn to unregistered ECD establishments which do not have access to government funding to erect playgrounds and other safe spaces to encourage movement in young children [18].

While there is a dire need to incorporate movement into early education to foster physical growth, social skills, and emotional resilience, combating the impact of technology use has also proven to be a complex issue, with many mothers utilizing social media platforms such as YouTube and Instagram to provide educational content to their children. Tangible User Interfaces (TUIs) can serve as an innovative, low-cost solution to encourage movement in young children at home without removing the edutainment factor of technology. The use of TUIs in ECD is not a new concept; many authors have explored the use of this technology to encourage learning in young children [5, 9, 19, 41, 54]. This is because TUIs are particularly suited to holistic development due to their tangible nature as well as the fact that they involve using physical objects to interact with digital technology, bridging the gap between the physical and digital worlds. Studies have shown that TUIs can enhance children's engagement, creativity, and understanding of abstract concepts by providing hands-on, tangible experiences [34], offering opportunities to support children's development and nutrition [45].

2.2 Tangible User Interfaces (TUIs) and Wearable TUIs as a Suitable Technology to Encourage Movement in Young Children

TUIs thus offer a promising avenue for enhancing learning and development in children by integrating and encouraging physical activity through digital interaction. Mostly wearable TUIs have gained attention for their potential to promote physical engagement and creativity. For instance, the MakerWear project introduced a wearable construction kit that allows children to create interactive clothing, combining tangible 'plug-and-play' electronic modules on a textile-integrated socket mesh. This approach encourages creativity and physical interaction, seamlessly integrating technology into children's play [32]. Another study developed TangToys, smart toys designed to communicate and improve children's well-being. These

[1] https://www.nintendo.com/en-za/Wii/Wii-94559.html

toys utilize Bluetooth technology to enable peer-to-peer support, allowing children to communicate their emotions through play. Such innovations demonstrate the potential of wearable TUIs in supporting children's emotional and social development [73].

Integrating TUIs into childhood educational environments such as schools and ECD centers has shown promise in encouraging children to participate in physical activities during learning hours and can, therefore, potentially help to reduce the rising onset of sedentary behavior and lack of movement currently observed in South African children. Vickery et al. [70] explains that children who perform full-body interactions during learning increase their physical activity levels and improve their cognitive functions and social skills. TUIs are also naturally interactive, making learning experiences more enjoyable and interactive for kids [9]. This is because they can fully immerse themselves in their activity and have fun simultaneously. Physical movement and manipulation of the TUI further provide immediate feedback, resulting in encouraging children's interest and motivation. In addition, research by Dijk et al. [15] discusses various successes through the engagement of children with TUIs by stating that they are more likely to remain active and engaged in their physical activity tasks, and express positive moods and attitudes towards learning when they are actively interacting with their TUIs. During the early stages of a child's development, independent exploration and play are crucial for building foundational skills[68]. In addition, a recent review on the use of TUIs in early childhood education highlights their effectiveness in fostering problem-solving abilities and promoting collaborative learning among children [55].

Although previous research has explored using TUIs to encourage physical movement in young children, a major question still remains: Why build something when so many consoles already come with games and add-ons designed specifically to encourage physical movement? The answer is that these solutions are neither feasible nor contextually relevant for rural South Africa and many other areas of the Global South. Furthermore, the design of the TUI needs to be contextually relevant and consider the sociocultural and technical realities of rural South Africa, which we will discuss next.

2.3 Understanding the South African context and limitations with regards to technology that encourages movement in young children

Many commercial devices promoting physical activity, such as gaming consoles and fitness trackers, often come with high costs, making them inaccessible to many families, especially in under-resourced areas such as those in rural South Africa. Especially if one considers that rural South African households have an average household income that is significantly lower than the national average, with data from 2023 indicating an average household income of up to 204,359 rand (10 757,71 USD) per year, but with a median of R95,770 (5 041,46 USD) [61]

Therefore, the high cost associated with these devices limits the benefits of digital devices, as these devices are most likely out of reach for rural South Africans [47]. Additionally, these devices require a stable internet connection and reliable electricity, which are not always available in rural South African areas. The country faces significant challenges regarding internet connectivity and data accessibility, particularly in rural areas. While approximately 92% of the population owns smartphones, the high cost of mobile data and unstable internet connections hinder the utilization of internet-dependent technologies [1]. Furthermore, work done by [23] showed that South Africa has some of the highest data costs in Africa, which introduces another barrier to implementing off-the-shelf digital interventions aimed at promoting physical activity among children, particularly those living in the rural areas of South Africa [62].

Thus, the lack of affordability combined with a lack of infrastructural support limits the effectiveness of commercial, off-the-shelf devices in addressing childhood inactivity in many rural communities facing challenges in digital accessibility and connectivity [38]. Moreover, commercially available devices may not be contextually or culturally relevant to diverse settings [66]. The design, content, and user experience of these devices often cater to a global market, overlooking children's specific needs and preferences in different sociocultural contexts. Therefore, the design and content of these devices that are commercially available in South Africa are not only unaffordable to rural families but also do not align with the cultural contexts of the South African rural communities [8, 25] This lack of cultural diversity in commercial devices further proves the need for efforts to be made that are tailored to the sociocultural realities of its target users in the context of rural South Africa [33, 48].

In this paper, we present and discuss the co-creation of a wearable superhero cape and accompanying mobile application developed with rural South Africans' particular constraints in mind, hoping to ensure that children in rural areas can also benefit from interactive physical activity interventions without requiring constant internet access, stable internet connectivity, or high costs. We next present our methodology, which includes working with rural South African mothers to develop a more contextually situated TUI to encourage physical movement in young children.

3 Methods

3.1 Research site and population

This study occurred in Sweet Waters KZN (KwaZulu-Natal), a rural area 97km from Durban (the biggest city in KZN) in South Africa. The population of Sweet Waters is majority Zulu speaking with a monthly income of around 2400 Rand (128,66 USD). The community has a long-standing, fruitful relationship with a governmental research institution. The institution employs long-standing community liaisons who know the community well. We partnered with this institution to ensure that the researchers and participants in this study are safeguarded by well-defined policies and practices to ensure fruitful research engagement that results in data for researchers and benefits for the community. Finally, the institution also houses a community of skilled seamstresses who use a spare room to create quilts. The quilters served as skilled artisans tasked with not only assisting with the creation of the capes but also teaching mothers how to sew to ensure that mothers benefited by participating in this study. We invited two quilters and eight mothers to participate in this study (see table 1).

Workshop date	Workshop purpose	Total number of attendees
31-Oct-24	Took the technology probe to the mothers to experience and play with.	8: M=5, Q=2, R=1
14-Nov-24	First co-creation session with the mothers, cutting out capes and sewing in first set of LEDs	10: M=6, Q=2, R=2
28-Nov-24	Started working with electronics in capes - creating battery pack	9: M=6, Q=1, R=2
03-Dec-24	Continued work on battery pack , adjusted voltages	12: M=8, Q=2, R=2
12-Dec-24	Programmed micro controllers, discussed code base and added accelerometer	11: M=8, Q=1, R=2
19-Dec-24	Added Neopixel LEDs and connected all the electronics	12: M=8, Q=2, R=2
16-Jan-25	Refining capes	9: M=6, Q=2, R=1
KEY: Mothers (M), Quilters (Q), Researchers (R)		

Table 1: Workshop dates, rationale, and participants

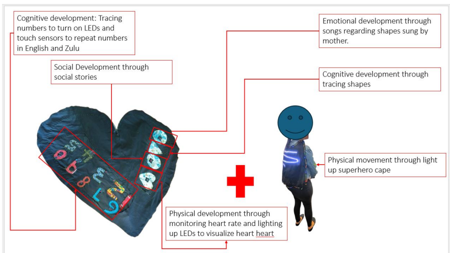

Figure 1: Original cape concept developed during preceding TUI study

3.2 Origins of the cape

The original cape design was conceptualized during a co-design workshop in a study that preceded this one [64] The original cape was proposed as an add-on to an IoT-enabled TUI in the form of a Smart Quilt. The quilt contained ECD activities that focused on the broad areas of ECD in the South African curriculum such as cognitive development, social development, and emotional development[2]. The cape was included to account for physical development as this would be hard to achieve using only the quilt (see figure 1). The mothers described the cape by draping fabric over their shoulders while jumping up and down, explaining that they would like to see lights to turn on and off to encourage physical movement (see figure 1).

This paper reports on the original cape's expansion, pairing it with an accompanying mobile app as a wearable TUI in its own right. The idea for expanding the capes included adding a custom-developed mobile application containing an animated character that would demonstrate movements that young children should follow while wearing the superhero cape. The superhero cape would then use sensors to detect if the children followed the correct movement and send feedback to the mobile app. The character on the phone would then interact with the children and positively reinforce the behavior. The superhero cape should also respond to the movement with sound and flashing LED lights, creating haptic real-time feedback. Next, we discuss the research approach that was followed for this study.

3.3 Technology Probes

Probes are asynchronous tools and methods designed to evoke user insights, emotions, and stories in unconventional and creative ways. The concept of probes has become a key strategy in Human-Computer Interaction (HCI) and Information and Communication Technologies for Development (ICTD) due to their potential to draw out subjective human experiences, values, and views that could inspire design. Therefore, many different types of probes have been developed over the years. Cultural probes, which were introduced by [21], were developed as a way to gather inspirational data following strategies where users were engaged through open-ended, creative tasks. The probe methodology has since evolved with adaptations in the context of technology probes [27] to community-based research in low-resource communities [74]. Thus, probes have been used and adapted in many ways. Hutchinson et al. [27] explains that while in design, technology probes may be similar to cultural probes as they also seek to gain insights into the subjective lives and experiences of participants, cultural probes are not a technology themselves and often only explore a single activity. Technology probes involve installing a working technology into a real-world context to reflect on its use to inspire the design of new technologies [27]. Technology probes, therefore, combine the social science goal of collecting information about technology users in the real world with the engineering desire to explore new ways that technology can be used in real-world settings. Technology probes reject the idea of unbiased data gathering and expect that introducing the probe will change participant's behavior. Technology probes are, therefore, a fully working technological artifact for which the technological problem must be solved. These artifacts are deployed for extended periods during which users are expected to adapt the technology to their needs. Technology probes thus need to be open-ended and explicitly co-adaptable. Finally, the probe must be deployed as early in the design phase as possible. When compared to prototypes, probes differ in the sense that they need to be fully working technology deployments, which are deployed very early in the design process; probes then remain open-ended and encourage experimentation, whereas a prototype is typically deployed later in the design or creation process to test and refine ideas, rather than inspire users to think about technology. Next, we discuss how we incorporate the probe into our design processes.

3.4 Research approach: Co-Design and Co-Design Readiness

The mothers were purposefully selected as they participated in previous studies [64], including the study mentioned above, which used sensors, electronics, and minor electrical circuits. The preceding study had a dedicated co-design readiness phase during which mothers were trained on the use of various sensors, microcontrollers, and electronic components to design the capes. This co-design readiness phase took place over six months, during which mothers received a sensor kit containing 45 sensors [3], a microcontroller, and a laptop configured with the Arduino IDE. The mothers were then trained to connect and configure these sensors to better understand how sensors and microcontrollers are combined to build technology. The final stages of this study included a co-creation phase during which mothers took part in building and co-creating the ECD TUI as part of the study. The mothers developed the concept of the cape during this initial study. The work described below serves as a continuation of the cape, independent of the initial study.

[2]https://www.education.gov.za/Curriculum/NationalCurriculumFrameworkforChildrenfromBirthtoFour.aspx

[3]https://www.diyelectronics.co.za/store/kits/1305-45-in-1-sensor-kit-for-arduino.html

Finally, the fieldwork for the preceding study was completed in December 2023, resulting in a year gap between the two studies.

This work thus uses a co-design readiness, co-design, and co-creation approach as our key considerations informing our methods. These terms often overlap in the literature; therefore, we must state how we understand and apply each term. We rely on the work Akama and Light [4] and [64], who explain that readiness practices are tightly bound to the researchers' and participants' personal histories, experiences, philosophies, and cultures. The work of [40] explains that participants need time to engage fully, Molapo et al. [39] states that co-design skills will grow gradually over time, Densmore et al. [14] highlights the fact that it takes time to build the necessary trust between researchers and community participants. Finally, Miller et al. [37] stress that co-design readiness is highly context-specific and depends on attributes, attitudes, skills, and relationships between the researcher and participants. We see co-design readiness as crucial for preparing participants before the co-design process, especially when using new technologies. This process allows participants the time to build trust with researchers, gain the skills they need to contribute equally, and has the potential to address power relationships. In the case of this study, the participants participated in numerous co-design readiness activities in the previous study.

Co-design is the process of including participants as equal partners in the design of technological or other artifacts [56]. This is a complex process that often includes cultural nuances [65], which can result in the need to pivot and continually evolve the methods used for a single study across different socio-cultural settings. This process requires flexible research methods where researchers act ethically in a changing and unpredictable environment, which often requires researchers to build flexibility into participation [40], plan for alternate events, and, as far as possible, should not include any rigid steps in their planning. Finally, co-creation is primarily described as part of the co-design process, with Strappers and Sanders [56] stating that co-creation involves the creation of value through collaboration and feedback, which could involve communities in the original design of technology or go as far as working with the community to build the technology when appropriate. Wiberg [71] explains that community-driven co-design can and should include communities in the co-creation of digital artifacts. Jackson and Kang [29] supports this by stating that co-creation extends the initial phases of co-design and includes the community, not only in idea generation but also extends to the co-construction of technological artifacts. Akama [3] explains that direct community engagement in the building of artifacts is essential for creating designs that truly meet the needs of the community. Finally, De Vries [12] adds that the co-creation of artifacts is crucial for sustainable design. Based on the above, we define co-creation as an extension of the co-design process, which intentionally includes participants beyond the ideation, prototyping, and design phase by including them in the actual construction of the technological artifact. Following the above, authors Mburu et al. [35] argue that methodological choices can be crucial to empower participants and build their confidence to be ready to participate in co-design.

3.5 Using Technology Probes to Complement Co-Design

Given the complex nature of co-design, and the fact that technology developed in industrialized nations often overlooks sociocultural contexts and regional differences, this can significantly impact the adoption of these technologies [8]. Also the work of Brewer et al. [8] and Ramachandran et al. [51], who therefore advocate for co-design approaches to address challenges such as social network structures and cultural information, which are often present, not only between industrial and developing nations but also between different cultural and geographical areas of a single country [65]. It is important to include communities in research processes as early as possible to better understand and account for these sociocultural contexts [66]. However, co-design is not a silver bullet; Holeman et al. [25] echos that co-design is not a simple process and highlights some of the difficulties of co-design in ICTD settings, such as the alienness of the materials typically used and increased power differentials between the researchers and the community. Being cognizant of these challenges, particularly the alienness of new materials, and because we asked participants to co-design and co-create alongside us, using technologies they have been exposed to but now used in a different setting, we also considered the blank page problem [31], which occurs when no limitations or expectations are placed on creativity often referred to as the paradox of choice, where too much freedom in creative choice can be overwhelming [31]. In line with Garfield [20], we have found that a lack of boundaries does not necessarily liberate creative processes but enslaves them. We have experienced instances where participants in our previous studies suffered ideation fatigue resulting from a "blank page" approach. Schonberger et al. [58] further explain that participants taking part in the co-design process need to believe that they can perform and, therefore, need to be reassured often. Finally, Densmore et al. [14] recommends that researchers use materials that enable participants to express themselves freely and easily.

So, after careful consideration, and in an attempt to alleviate the unintended pressure that ideation places on participants, we decided to use technology probes as simple, flexible, adaptable technologies that can 1) help researchers understand the needs and desires of their participants, 2) allow researchers to field test technologies in a real-world setting, and 3) enable users to think about new technologies [27]. We thus built a fully functional prototype cape, which we provided to mothers to elicit easier and more meaningful conversations about their design requirements. We were fully aware that the cape, in its initial form, did not consider all the design requirements and needs of the mothers but would instead serve as a probe to start conversations and hopefully enable participants and researchers to think about and articulate the cape's design requirements, and share their experiences and ultimately for the mothers to design and create their own capes.

3.6 Building the MoveWithMe Probe as a Concept Cape

3.6.1 Detecting movement. To detect movement, the prototype incorporated motion-tracking through an Arduino ADXL345 accelerometer.[4]. The accelerometer measures acceleration forces along three axes (X, Y, and Z), which enable the sensor to detect changes in speed and direction as when a child jumps up, left, right, or up and down. The sensor further measures whether the cape is upright or tilted, which helps to identify the orientation of the wearable. The following thresholds were implemented to distinguish between active movement and false jumps (e.g., slight bumps) and to provide motion-generated feedback:

- *Baseline Movement Thresholds*: Movement data from the accelerometer was collected during everyday activities, such as walking, jumping, and running. These were used to determine minimum activity levels that qualify as physical motion.
- *Customizable Sensitivity Levels*: The system was calibrated to adapt to individual users, taking into account differences in movement patterns between younger and older children or varying energy levels. A range of motion sensitivity was selected and tested, increasing or decreasing on the basis of average movement triggers.
- *Motion Algorithms*: Motion algorithms were implemented to process the raw data collected from the accelerometer. These algorithms analyzed multi-axis acceleration to detect and classify specific movements. For example, a jump could be identified by a sudden spike in Z-axis acceleration surpassing a predefined threshold, to confirm vertical motion. The algorithms also accounted for natural variations in movement, ensuring accurate classification. This precise processing enabled the cape to differentiate between various activities like the different jumps, allowing tailored feedback to encourage movement.

3.6.2 Controller. An Espressif ESP32 micro controller[5] was configured as the cape's processing unit by managing data collection from sensors, turning on LED's and MP3 players when movement was detected, and communicating with the accompanying mobile application via Bluetooth Low Energy (BLE) technology. For example, once the movement exceeded the predefined thresholds, data transmission occurred to the microcontroller by: 1) Retrieving the sensor data from the accelerometer; 2)Employing signal processing techniques to filter out irrelevant motion and validate the detected motion against the established thresholds; and 3) The filtered data points are classified into specific movement types using the specified algorithms.

3.6.3 Encouraging Movement. Next, the detected movements trigger a feedback loop designed to motivate the child to keep moving through the following:

Audio Feedback: A small stereo enclosed speaker [6] and DF Robot mini MP3 player [7] was used to play the audio cues and provide motivational feedback when a jump was detected. To achieve this, pre-loaded audio files, such as cheers or playful prompts, were stored on a microSD card and then selected and played based on movement type and intensity.

Ultra bright colourful light: The cape further incorporates a 5v Neopixel LED strip [8]which lights up in different ultra-bright patterns to create a sense of excitement and interaction when movement is detected. The lights dynamically change color, providing vibrant and instant feedback.

3.6.4 Materiality. The cape was designed using durable, comfortable, lightweight fabric, in our case containing Bat symbols representing the superhero Batman. This child-friendly fabric was chosen to encourage and excite children to wear the cape. Finally, the cape contains a separate pocket, which is breathable and detachable, which holds all the electronic components. These electronics were also designed to be detachable to make the cape hand-washable.

Figure 2: The MoveWithMe cape created as a probe

3.6.5 PlayWithMe: Gamification via the Mobile Application. The Android Open Source Project (AOSP) platform was chosen to develop the PlayWithMe application in Kotlin. This choice was informed by recent South African mobile statistics which indicate that Android and Android based mobile operating systems dominate the market in South Africa with an 84% market share in the country[9]. Using a RESTful API (REST API), the cape communicates with the accompanying Android mobile application via the Bluetooth Low Energy protocol. The application allows children to participate in a gamified experience that includes visual elements in the form of cartoon characters that instruct them to perform specific movements and react when the cartoon character detects the correct movements. The motion sensors capture the movements, which are then transmitted to the mobile app. Depending on the type

[4]https://dc3dprinters.co.za/product/adxl345-3-axis-tilt-digital-gravity-acceleration-sensor/
[5]https://www.digikey.co.za/en/products/detail/espressif-systems/ESP32-DEVKITC-VIE/12091811

[6]https://www.robotics.org.za/FIT0502
[7]https://www.dfrobot.com/product-1121.html
[8]https://www.diyelectronics.co.za/store/led-strips/1846-addressable-rgb-led-strip-30m-ws2812b-5v-dc-ip65-casing.html/
[9]https://mybroadband.co.za/news/software/574660-most-popular-mobile-operating-systems-in-south-africa-2.html

of trigger received, the mobile app displays a visual cartoon of a movement on the screen (see figure 3).

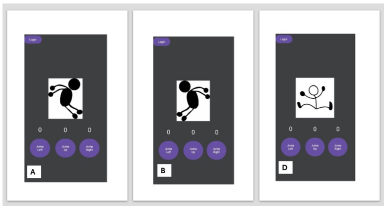

Figure 3: Mobile app display when a jump up is detected

3.7 Cape design and co-creation workshops

The completed probe was taken to the mothers to experience and explore, after which we asked them what they thought about the initial design and functionality. We next had open conversations regarding what they would want from such a cape. Following this discussion, we scheduled seven co-creation workshops where the mothers built their capes alongside the researchers. We provided all the necessary fabrics, hardware, and tools to co-create the capes, asking the mothers to build a cape they would like their children to use. Each session took 6 hours and included an hour-long lunch break. In line with the research facility's policies, each participant received an honorarium for travel, time spent, and inconveniences incurred of two hundred Rand (10,75 USD) per session. We must stress that an honorarium is essential; these mothers are informally employed and could use the time spent on this study to generate income. This does not mean that the mothers did not wish to participate in the study without an honorarium. Still, it shows that their time is valuable and that we, as the research team, understood that their time is valuable and could be used to generate an income instead. The workshops were recorded, transcribed, and anonymized. The recordings, transcripts, and any other research data, such as photos, were stored on the institution's data cloud, accessible only by the researchers via 2-factor authentication (2FA).

3.8 Mobile app workshop: Rethinking the PlayWithMe app

An hour-long co-design workshop was conducted to ensure that the mobile application effectively meets the needs of its intended users'. The workshop aimed to identify improvement points, gather feature requests, and refine the app's design based on the mother's preferences and contextual knowledge. We showed the mothers a high-fidelity prototype of the existing mobile application. We asked mothers if the current mobile application was suitable in terms of 1) the character used to display the different movements on the screen, 2) the movements the character currently encourages, 3) the color palette used for the app, and any other feedback or guidance that the mothers wanted us to implement. This interactive approach to conceptualize, develop, and refine the mobile app design was followed to ensure that the mobile application is designed according to the mother's specifications and desires for an application that encourages children's to move. We provided mothers with a worksheet that illustrated what each screen of the mobile app looked like with a blank mobile screen alongside and asked them to draw how they would like the screens to look and act. This session was also recorded with the permission of the mothers. The recording was transcribed and anonymized and then stored on the institution's secure data cloud, which is only accessible by the researchers via a user and password as well as two-factor authentication.

3.9 Data Analysis

Data collected from the co-design and co-creation workshops were analyzed using a reflexive thematic approach as described by Braun et al. [7]. Our primary goal for this analysis was to identify the recurring themes regarding improvements and changes we could make to the features in consultation with the mothers regarding their children. This included themes such as the cape's features and interaction with the mobile app, and the effectiveness of all the components working together in real-time movement detection. Our data sources included drawings, direct feedback gathered from the workshops and sessions when interacting with them, interactions with the prototype, and further open discussions about suggested features and functionalities. Each of the participants' contributions was taken into consideration and carefully studied to reveal common patterns and requirements in the way they envisioned the smart cape to look and how they expected the cape to respond to movement through the digital mechanisms.

3.10 Ethical Considerations

Ethical clearance for this study was obtained with reference number HREC 378/2021. We started the study by first gathering informed consent and ensuring that the participants were aware that participating in the study was voluntary and that they could elect to withdraw at any time. Each participant received a participant information sheet included in the informed consent form explaining the nature of the study as well as what would be expected of them. We reaffirmed consent often and had open conversations with the participants regarding what data we were gathering and how it would be used. It is from these discussions that our participants explicitly asked that their images not be blurred as they are proud of their work. We further ensured that the participants knew that they could ask for their data not to be included in the study should they wish to no longer participate. While our informed consent forms explicitly addressed the taking of photographs and the recording of conversations, we always reaffirmed and asked the participant's permission before any photos were taken or any recordings took place. The initial capes designed in this study were donated to each mother to give to her children.

3.11 Limitations

This study took place in South Africa and only considered the contexts of rural South Africa. While we believe that our findings are generalizable, they will contain information specific to South Africa. In addition, the capes were developed considering ECD. However, the capes are not suitable for children under the age of twelve months.

4 Findings

4.1 Independent Innovation: Mothers Taking Ownership of the Cape Design

Through working with the mothers and experiencing the probe, we learned the following about designing wearable TUIs aimed at encouraging movements in this community:

4.1.1 No Dependence on Internet Connectivity and low power requirements. The mothers appreciated that the cape could operate entirely offline, using the embedded sensors to detect movement and the microcontroller to process and store data locally without an internet connection. Thus, unlike many commercially available devices that require a stable internet connection and a cloud-based infrastructure and services for real-time tracking, the cape ensures that children in areas with limited or no internet access can still use it effectively. This is achieved through the Bluetooth Low Energy (BLE) protocol, which allows the cape to communicate with the companion mobile app on a parent's smartphone without needing the internet. BLE is also a power-efficient technology that enables short-range data transfer, making it ideal for environments where internet access is unreliable or costly. This is important for the mothers in Sweet Waters, as mobile data is not always an option. One mother specifically mentioned that she does not always have access to mobile data to connect to the internet:

> "It is rare to have data because it is expensive, I only have it for 2-5 days a week."

While access to mobile data is sporadic, the mothers report spending on average between fifty and three-hundred-and-fifty rand (2.75 - 19.17 USD) per month. The mothers often use this data for entertainment, but mainly to provide their children with educational content and entertainment. Regardless, the mothers prefer cost-efficient solutions.

4.1.2 Cost Efficiency. The components used in this study were carefully selected to minimize costs while maintaining functionality and durability. Unlike many fitness devices or mobile apps requiring recurring subscriptions for premium features, the mobile app has no associated costs or data usage. By leveraging the widespread availability of smartphones and the fact that mothers already use their phones to educate their children, the app is designed to work with devices that the mothers already own, eliminating the need for expensive devices. One mother mentioned the following:

> "Our children already use phones; they are so clever with phones, and I often give my phone to my child to watch YouTube. He knows how to find apps and use them, so using my phone for him to play with the cape is useful"

Furthermore, the sensors selected are compact, inexpensive, and provide precise motion detection, allowing the cape to track physical activity accurately. Combining movement detection with cost-effective audio modules provides engaging auditory feedback to encourage movement without relying on external devices. In addition, the cape uses a lightweight, rechargeable lithium-ion battery, which is both cost-efficient and environmentally friendly over time. Initial cost estimates suggest that the MoveWithMe Cape can be produced with a target price range of ZAR300 - ZAR600 (15-30 USD) per unit, depending on the production scale and the features the mothers select. However, the mothers looked at ways to further reduce the cape's cost. One of the mothers stated that one option could be to drop the Neopixel LED strip and use the much cheaper commercial LED lights, readily available at low-cost retailers in South Africa (see figure 4). She explained:

Figure 4: A: Example of how the mothers used low-cost LEDs. B: Example of low cost commercially available LED lights

> "What if we take out the expensive lights, they are very nice, but we can maybe make the cheap lights just turn on and off in different ways. Then we can say, do you have little money right now, let's build with the cheap lights, do you have more money, let's build with the fancy lights, then we can choose."

The mothers explained that they would prefer the flexibility to choose which lights to use for the cape depending on what they could afford at the time. They also suggested that if this ever became a business for sustainability, they would make both options of the capes to enable buyers to select a cape that suited their budget. Using only the low-cost LED lights instead of the Neo-Pixel LED strip would reduce the cost of the capes by one hundred and fifty rand. The mothers further mentioned that the Neopixel LED strips' stiff nature limits their design options, whereas the soft wiring used for the low-cost LED strips enables much more creativity. One mother mentioned:

> "You know what, the expensive light does not bend nicely; I can not make a flower, or a heart, or any other shape. The cheaper lights bend easily so we can make much prettier capes"

Another mother suggested dropping the speaker in the cape and moving the sound to the app, enabling the sound to play off their phones and eliminating the need for the MP3 player module and speaker. These recommendations result in a cape with the same functionality and features at a drastically reduced cost since the only components needed are the battery pack, low-cost LED light strip, and the ESP32 microcontroller.

4.1.3 Familiarity: Bluetooth Low Energy Integration with Existing Phones. Since most smartphones already support BLE, no additional hardware is required for setup or operation, making the system accessible to low-income households. Most importantly, the BLE connection is simple and well-known to most mobile phone users, ensuring that even those with limited technological experience can operate the system effortlessly. One of the mothers mentioned the following:

Figure 5: Example of various capes and cape designs created by the mothers

> "I connect my headphones with Bluetooth. I think it will be easy cause I'm used to my phone I don't think I can have a problem connecting the cape"

Finally, it is important to note that the sensors, micro-controllers, LED lights, and batteries used for this study can be locally sourced to ensure that mothers do not have to incur the cost of traveling should the capes need repairs. Furthermore, a test delivery from an online electronic retailer showed that the cost-effective electronics can be delivered to a local informal shop that offers online delivery cubicles as a service, which is within walking distance from the mother's homes. The mothers also personalized the capes, which resulted in many cape variations.

4.1.4 Personalization. All mothers applied their personal touches to their capes, creating a unique cape to their child (see figure 5). This included different prints on the fabrics, designs, shapes, and sizes. For example, one mother mentioned the following:

> "My baby, shes a girl but she adores superman and batman, so by playing with the cape she will be enjoying being a superhero and learn at the same time, cause it must be educational as well"

This mom used Batman fabric and plain yellow lights to create the cape that suited her daughter's liking. The quilters elected to make capes for their grandchildren and preferred more cultural fabrics, which they carefully and neatly sewed in various superhero capes. Another mother of a very young child made a small quilt that would fit a child of about two years old, also preferring more traditional fabrics. This desire for personalization did not end with the capes; the mothers provided rich and very useful feedback regarding the mobile application as well.

4.2 From User Insights to Application Design: Crafting Contextual Mobile Experiences

Showing the mothers the pre-developed application as a probe resulted in meaningful feedback, with many of the mothers mentioning that the gamification and design of the mobile application need to be redesigned to be more creative and visually appealing for their children. They thus suggested that the animations need to be clearer, more colorful, and depict the movement detected in much more detail and with better animations. One participant pointed out:

> "I think the pictures need to be clearer because I don't know if the kid will understand the movement."

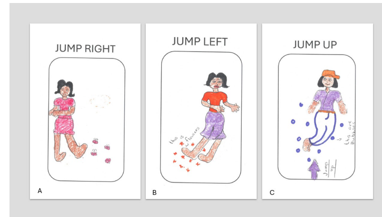

Figure 6: Example of the additional animations and detail mothers recommended for the mobile application

Another mother added to the conversation by stating that the animations need to be much more enticing and exciting to attract and hold the attention of their children:

> "It should be more colorful, so it looks fun and exciting!"

Here again, the mothers asked for personalization, with some participants mentioning that they think a further animation, in addition to the animation that shows movement , should be added (see figure 6): One mother mentioned the following:

> "When he or she [sic] jump up , show bubbles at the time they jump up and sing a song'

The mothers further gave detailed feedback regarding how the character on screen and its animations need to be improved. In addition, the mothers had strong opinions regarding how the limbs of the animated character should be positioned and depicted during different types of jumps and movements. One participant noted the following:

> "Maybe the legs should not be so open wide when jumping. Kids don't jump like that."

Another mother joined the conversation and added:

> "The arms need to move up and down like a real jump, not just stay stiff."

Furthermore, an open discussion was held regarding whether the participants would prefer the character animations to be in the form of an animal or human; here, the mothers indicated a strong need for personalization, with one mother mentioning.

> "I want to choose what my character looks like. Maybe I want an animal or a robot instead of a person."

While another mother suggested including corresponding animation sounds like those from the chosen animal animation.

> "I want it to make a sound, maybe like an animal sound when I touch it."

Another suggestion was to have many options regarding the character's sounds, songs, and animations, allowing the mother or child to choose what their personalized experience should be. This would include being able to choose from a range of visually animated features, sounds, songs, colors, and characters in order to build your own personal experience while using the application.

The mothers also suggested adding playful elements like a musical tone, songs, or encouraging phrases. Some of the mothers also proposed including educational content, such as the cape reciting letters or numbers when performing certain gestures. They believe this can effectively combine movement and learning.

> "What if it can teach ABCs or counting when the child jumps?"

Finally, a few mothers requested the addition of temperature sensors, while others focused on extra movement-based triggers that could respond to specific physical actions. They also expressed interest and desire for the cape to include special features like sound effects. This would be in the form of a sound response, like a song, when the specific movement was detected.

> "I want to make a song for it, like an educational song!"

The mobile app must then display corresponding animations to their liking. The participants also suggested that the cape should have extra visual indications through the LED lights, paired with vibrations to use multi-sensory feedback.

4.3 Overcoming initial barriers

As we started the co-creation phase of the study, some of the mothers were initially unsure about configuring the electronics required for the functionality of the cape. However, they felt at ease enough to begin sewing and building their capes after a member of the research team gave them a detailed presentation explaining the electronics required and their functions related to the work done in the previous TUI and IoT studies, which the participants formed part of. Over time, the mothers became more and more comfortable with the electronics and made steady progress while creating their own unique, personalized versions of the capes. One of the mothers later offered the following:

> "In the beginning I was scared of connecting the wires to the battery and to the charging port. But now I am not scared, it was really not hard"

However, some of the mothers found the electronics daunting and preferred other aspects of creating the capes such as designing the capes and sewing in the electronics. One mother clearly stated :

> " I don't like the batteries, I am scared of them"

Even feeling uncertain, the mothers immediately provided feedback on how the cape could be improved. A mother recommended the following recommendation immediately after experiencing the probe:

> "I like the light but I think we need to put more light and make it colourful. I didn't like the black [sic] in cape quilt [sic]. We can make more interesting like put picture of fruit or emoji on the cape and colour."

Regardless of their initial hesitation around the batteries and electronics, the mothers worked ahead, independently of the researchers, and at each subsequent meeting, progress was always made on the capes. Mothers did not wait for the researchers' help and felt capable of continuing without them. They further made design changes to their capes and gave input on the functionality of what they preferred and felt would better suit their needs to make the capes their own (see figure 7).

Ultimately, the probe made the mothers feel empowered and able to build their capes, often using the probe to guide them as they configured their electronics and sewed their capes. This empowerment translated into the mothers considering how they could work together to utilize their newly learned skills.

Figure 7: Examples of mothers co-creating. A: A mother assembling the electrical components of her super hero cape. B: A mother working on the design of her super hero cape

4.4 Cooperation as future work

During the last workshop, the mothers expressed their desire to work together and construct the capes as a cooperative group independent of the researchers. This group would comprise three teams: One team would be in charge of sewing, another would build the electronics, and a third team indicated that they would like to learn the necessary C++ programming. The mothers also wanted this cooperative to be a place to teach other mothers in the community how to build the capes.

> " I feel confident in making the quilts, and now the capes. I would like to maybe teach other mothers to make capes for their own children"

Evaluating the progress of the capes that the mothers have been able to produce so far is impressive. They have been able to improve their confidence in their sewing skills, as well as working with electronics by being able to sew in LED's to their capes. This shows their growing knowledge and confidence in being able to work independently considering they had little to no experience before.

5 Discussion

5.1 Implications for design

From our findings, it is clear that mothers from Sweet Waters were instrumental in guiding the co-creation of the superhero capes and the design of the mobile application. Working closely with the mothers during a co-creation process, we highlight the following implications for design:

5.1.1 Design for low to no internet connectivity. Mindu et al. [38] highlights childhood inactivity in many rural communities facing many challenges with digital accessibility and connectivity. Here, TUIs designed for this context need to use technology that does not rely on a stable internet connection. Hence, the cape was designed to include the Bluetooth Low Energy (BLE) protocol, which enables the cape to function at its full capability whilst not connected to the internet. This aligns with the findings of [16] who argue that rural regions facing infrastructural issues should explore alternate solutions, allowing user interaction whilst minimizing the reliance on mobile data connectivity. Although the mothers were comfortable spending data on educational content, as noted in the findings, they appreciated that they could not depend on it. Our findings further indicate that our mothers saw this as a significant positive aspect since their children could still benefit from using the cape without being connected to the internet, allowing them to still be active without being dependent on expensive data [1] and unreliable internet connections [23].

5.1.2 *Design for low power consumption and solar rechargeable options.*

South Africa is listed as a fully electrified country [63]. However, the electricity grid remains under pressure, resulting in scheduled rolling blackouts. Unfortunately, the outdated electrical infrastructure in rural areas often results in electricity failures when the power is restored, which can last for weeks [63]. In line with previous findings Mekki et al. [36], Njuguna et al. [42], Okafor et al. [43] and Chepken et al. [10], who discuss the fact that considering power consumption in your design aimed at rural areas is crucial. We found that any TUI developed with this community would need to use rechargeable batteries and solar as a charging option [43]. Furthermore, the design of the TUI needs to be geared for low energy consumption Ditto.com [16]. In addition, the mothers in this study opted to remove many components that drew electricity from the cape and incorporated them into their smartphones. While it was not their intention to reduce the power consumption of the capes, it did result in a significant reduction in power consumption, allowing the capes to function much longer between charge cycles.

5.1.3 *Design for practicality: low-cost options and using technology that is already adopted and understood by the community.*

Our findings show that a carefully considered technology probe [27] combined with the co-design readiness training and exposure to sensors in the previous study reduced the *alienness* of the technologies used in this study, resulting in the mothers making contextually informed decisions regarding the design of the capes. This finding is in line with the work of Holeman et al. [25], who emphasizes the importance of avoiding the alienness of new materials. This was particularly evident when the mothers indicated that they appreciated using the BLE protocol since they are used to interfacing with the protocol when connecting to headphones, friend's phones, and sharing files. Using technologies already adopted by the community, therefore, greatly eases the adoption of new technologies. Furthermore, having learned about the capabilities of the electronics used in this study, the mothers at the workshops were able to discuss the possibility and option of incorporating a speaker and MP3 module into the cape, deferring features such as sound to the mobile application on their phones which they are already comfortable with using. Secondly, the mothers advocated for the agency to build the cape with either the low-cost LED strip lights and the more costly Neo-pixel LED strip or the cape with only the low-cost LED strip, depending on their needs at the time. Based on their reasoning, they were able to build what suited their budget and needs. This aligns with the research by [66] who emphasizes that the device must be relevant to diverse settings and tailored to the needs of its users [33, 48]. The materials used should also enable the participants to present themselves freely [14]. These suggested changes not only significantly reduced the cost of the cape but also made the cape much easier to use and adopt. This finding is important considering the work of Owens [47] who highlights that the high costs of digital devices are out of reach for rural South Africans. To address these needs, the design needs to prioritize what is most suitable for the community and what is already there.

5.1.4 *Design to enable personalization.*

To ensure that designs match the needs of the community, Akama [3], de Vries [12], Jackson [28] and Wiberg [71] suggest engaging the community directly when building artifacts; this was evident in our findings as the mothers personalized the cape to what best suited their children's needs. To Design for personalization, mothers started by: 1) Choosing the material for their children, 2) deciding on the shape and design of the LED lights sewn onto the cape, 3) making suggestions of characters on the accompanying mobile application that their children can choose from, 4) making suggestions about adding a song to create a fun and engaging element, and lastly, 5) making suggestions to include further animations to the user interface on the app to show the direction of the jumps as well as detailed feedback on how the general animations in the app should look and act. As noted by [35], methodological choices are crucial in empowering participants and fostering confidence when participating in co-creation projects. Furthermore, Sanders and Stappers [56] emphasizes that the value of co-creation is achieved through collaboration and feedback, a dynamic that we observed in our study, allowing mothers the confidence to personalize their capes. Thus, TUIs aimed at this community should enable personalization so that each mother and child can create their own unique experience with the capes.

5.2 Reflecting on the role of technology probes and technology exposure in Co-design, and the importance of co-creation processes

Our findings echo the findings of Akama and Light [4], Molapo et al. [39], Miller et al. [37], and [left out for anonymity] who state that co-design readiness is crucial to the success of the co-design process. The co-design readiness work done in the previous study enabled the participants and researchers to know each other, build the necessary trust relationships, and break down some power differentials. The previous technology exposure further enabled co-design readiness steps such as building familiarity with the technology, which resulted in more confidence in the mother's design decisions [omitted for anonymity].

Our findings further highlight that introducing a technology probe facilitated easier ideation, reduced the time it usually takes to orient participants regarding the technology used in a study, and assisted with the co-design process. Many researchers have reported about the difficulty of ideation [20], and the complexity of co-design processes [4, 14, 25, 35, 39, 51], challenges which we also experienced during our previous work. However, providing the participants with a technology probe allowed them to consider what is possible, think about, and brainstorm around possibilities rather than understanding the problem alone. Our technology probe provided a tangible artifact that inspired their imaginations or that was adapted as participants saw fit. Experiencing the probe further reduced the anxiety introduced when we asked participants to ideate from a blank slate [31].

Furthermore, few studies have taken the extended step and co-created the technology with the participants during the co-design process. There are many reasons for this; as co-creation also takes time, can tax participants, and relies on the correct context [3, 57], the skills of the participants [71], and whether the community has access to the proper resources and tools [12]. However, co-creation, especially in combination with a technology probe, provides unique opportunities for insightful and rich feedback but, more importantly, the chance for a more contextually relevant and situated technology that has the potential to serve the communities in which it is deployed. In our case, the co-creation phase and technology probe exposed the mothers to many options regarding what could be possible, which led to the mothers making informed design decisions such as removing the expensive Neopixel LED strip and using the more flexible, cheaper lighting to create more intricate designs which would have a very similar effect for a significantly reduced cost factor. The mothers were able to do this only because they were instrumental in building the artifact and, therefore, better understood the capabilities of the microcontroller combined with the LED lights. Likewise, the mothers focused on what they already had and could use to further reduce cost and increase the ease of use of the capes. This finding closely relates to the conclusions from de Vries [12], who explains that involving the communities in the creation of the technological artifact has the potential to create a sustainable technology. The mothers in this study did this because they decided to use what they already had and focus on creating feasible capes in their community without compromising any of the features. In our case, the technology probe delivered on its original intended promise, as documented by Hutchinson et al. [27], allowing our participants to think about what the technology could be. It is through this rich interaction that we can provide the implications for design, which we discuss next.

5.3 Working With The Community for Scalability, Adaptability, and Sustainability

From learnings in our prior work, we know that the MoveWithMe probe needed to be created with taking into account the unique challenges of rural communities in mind by ensuring that: 1) The cape is lightweight, comfortable, and designed to withstand wear and tear, making it ideal for active children in various environments. 2) It is powered by a rechargeable battery that can be charged via solar, which eliminates the need for continuous access to electricity. However, working with the mothers resulted in further contextualized changes that resulted in a technological artifact much more suited to this community and, in turn, more sustainable. While we initially understood the need to gamify movement and provide positive feedback through audio cues, the changes made by the mother ensured that the cape appeals to children in culturally diverse settings, making physical activity engaging and enjoyable. This finding echoes the work of Verdezoto et al. [69], who explains that involving communities in the design process produces more culturally sustainable technologies.The app is compatible with most smartphones, leveraging South Africa's high smartphone penetration rate. Yet, the recommendations of moving features that did not have to be on the cape, such as sound to the mobile application, made the system more sustainable and affordable in the long run. In addition, electronic elements such as the accelerometer and ESP32 microcontroller were selected not only for their reliability and resistance to wear but also because they are easily accessible, even in rural South Africa but without the mother's insights, these electronics used for the initial cape would have been incorporated in a more costly manner. We designed the probe to minimize power consumption by using energy-efficient components, such as the BLE-enabled and an ESP32 microcontroller. However, the mother's design decisions removed various components, such as an MP3 player and a speaker, which consumed electricity. In doing so, they ensured that the cape operated effectively on a small rechargeable battery, significantly reducing the charging frequency. In doing so , the mothers reaffirmed the findings of Akama [3], Densmore et al. [14], Jackson [28], Sanders and Stappers [56] and Verdezoto et al. [69] who all agree and explain that involving participants in co-design and co-creation processes result in more sustainable technology, that is locally maintainable over the long run and repairable when necessary. In addition, the lithium-ion batteries used are designed to be reusable and long-lasting, considerably reducing the need for disposable batteries, which contribute to electronic waste. Finally, the design incorporates modularity, allowing damaged components to be easily replaced or repaired without discarding the entire unit. Using widely available and standardized electronic components provides maintenance and repairs locally, reducing costs and encouraging reuse. The electronic components and fabric materials have been chosen with recyclability in mind, ensuring that parts can be responsibly disposed of or repurposed at the end of the cape's life cycle. Finally, by empowering the mothers through co-design and co-creation and making the cape and mobile application's design open-source, communities can re-purpose old capes for new users or adapt the design for other sustainability-focused projects by adjusting the system as needed. This open-source nature of the capes resulted in the mothers deciding to start a cooperative to produce and possibly sell capes as a potential business venture, which ties in closely with the findings of de Vries [12] who explains that co-creation is directly linked to the sustainability of technology, arguing that involving communities in the entire life-cycle of a technology (from ideation to maintenance) ensures longevity.

6 Future Work

The workshops and findings in this paper form part of an ongoing study. Our next round of fieldwork will focus on the development of a community of practice where the mothers and we will explore the feasibility of the mothers teaching other mothers in the community to build similar capes. Furthermore, we are in the process of exploring avenues for the mothers to market their capes at a local fair. Finally, we are in the process of applying for ethical clearance to test the capes with children.

7 Conclusion

Given the fact that one in eight children in South Africa is already showing unhealthy levels of weight gain, the need to encourage physical movement is now more critical than ever [46, 50, 53]. However, this is a complex issue. There is a lack of safe playgrounds where children can be active in a secure environment [6, 18]. There is also a lack of ECD centers in South Africa [17], and those that do exist in rural areas are often under-resourced and lack the necessary equipment to embed good physical movement practices [6]. Finally, the impact of technology's uptake on young children's movement cannot be denied [72]. While technology's role in sedentary behavior cannot be underestimated, we opted to lean into technology instead of advocating against it, painting technology as the sole culprit for a much larger issue. The existence of innovative technologies such as TUIs and IoT provides unique opportunities to address this challenge; furthermore, they are not new in the ECD space [9] and have shown promise in many applications. However, these artifacts need to be developed in such a way that they are valuable for rural families, contextually relevant, and take the unique characteristics of the environment in which they will be deployed into account. This is only possible through co-design and co-creation processes, which put the community's voice, in our case, mothers, at the center of the development process [3, 12, 14, 25, 28]. In our case, the use of technology probes greatly assisted in helping the mothers ideate and think about the possibilities of the capes. Thus through combining technology probes with sound co-design readiness and co-design methods, we can state that TUIs aimed at encouraging movement in young children in rural areas need to make use of low-power technologies such as BLE that is also not dependent on a stable internet connection, should incorporate technologies that are already known and adopted by the community as far as possible. Furthermore, our findings clearly indicate that working with the community to create technological artifacts by including them in the entire creation process creates more sustainable, contextually relevant technologies with the potential for long-term sustainability and adoption.

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