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Article

Fostering co-design readiness in South Africa

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Technological artifacts designed by individuals from developing nations often do not flourish in developing regions. Many authors conducting work in these regions have therefore called on researchers to make use of co-design in order to mitigate power imbalances, include the voices of communities in the design of technology intended for them, and design and build more contextually situated technology. Many of these authors also refer to the need for co-design readiness in their work. However, little is known about how co-design readiness can be articulated and achieved, especially when working with rural communities. In this paper, we make use of qualitative meta-analysis to interrogate the data from three distinct case studies in order to investigate co-design readiness. We found that co-design readiness comprises three forms, namely: (1) emotional readiness built through trust, relationship building, and empathy; (2) cultural readiness, which requires that researchers and participants have an awareness and respect for each other's cultural values and beliefs; and, finally, (3) readiness in terms of confidence and familiarity with the technologies used which can be achieved through careful and strategic methodological decisions. We found that researchers should explicitly plan for readiness and should not assume that readiness will grow organically and that co-design, if planned well is a lengthy process. Finally, we provide learnings from our work to how co-design readiness can be achieved through planning and methodological decisions.

RESEARCH HIGHLIGHTS:

- This study investigates how co-design readiness can be articulated and achieved, particularly in rural communities.
- The research identifies three key components of co-design readiness such as 1) emotional readiness, built through trust, relationship-building, and empathy. 2)Cultural readiness which requires mutual awareness and respect for cultural values and beliefs. 3) Technological readiness which involves confidence and familiarity with technology, supported by strategic methodological planning.
- Using a qualitative meta-analysis of three distinct case studies, the study highlights best practices for fostering co-design readiness.
- The study emphasizes that readiness should be explicitly planned rather than assumed to develop organically.
- The findings suggest that well-planned co-design processes take time and require researchers to cultivate readiness for strategic collaboration.

Keywords: *co-design; co-design readiness; South Africa*

1 Introduction and Background

Co-design is a research approach that aims to be more democratic and inclusive by including research participants as equal design partners who have the deep contextual knowledge needed in order to solve the problems communities may be facing. In line with the above, Brewer *et al.* (2005b) found that software artifacts developed by and for industrialized nations were ill-suited to developing nations due to the socio-cultural and regional differences where norms and assumptions become embedded within technologies. To avoid overlooking the sociocultural context in design, Brewer *et al.* (2005b) suggested "Co-design and co-deploy" as an alternative approach when working in developing regions. In addition, Ramachandran *et al.* (2007) also discussed the potential use of early-stage co-design approaches to address similar developing region challenges, such as the impact of social network structures and cultural practices. Sanders & Stappers (2008) define co-design as "The creativity of designers and people not trained in design, working together in the design process." There is thus an overarching call in the Information,

Communications Technology and Development (ICTD) and Human-Computer Interaction for Development (HCI4D) communities for researchers to engage in co-design to ensure that researchers mitigate the potential ethical and design challenges around working in our diverse settings (Anokwa *et al.*, 2009, Brewer *et al.*, 2005b, Dearden & Kleine, 2018, Densmore, 2012a, b, 2010, Holeman *et al.*, 2017, Ramachandran *et al.*, 2007, Sanders & Stappers, 2008, Till, 2023).

Holeman *et al.* (2017) brought together some of the literature on co-design from the HCI4D perspective by highlighting some of the difficulties of co-design in low-resource settings, including the alienness of the materials used and increases in power

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differentials between the researcher-designers and the participant-designers. In HCI4D contexts, previous research also highlights the importance of ensuring that participant-designers are "co-design-ready" before being called upon to co-design effectively (Molapo *et al.*, 2016, Rogers & Marsden, 2013, Ssozi-Mugarura *et al.*, 2016). However, there is limited research understanding and articulating co-design readiness and how it is achieved in low-resource settings.

Akama & Light (2020) explain that readiness practices are tightly bound to the researchers' and participants' personal histories, experiences, philosophies, and cultures. In agreement with (Akama & Light, 2020, Till, 2023) reports on the impact of cultural nuances, which led to a pivot and continuous evolution of the methods used for a single study across different socio-cultural settings. Akama & Light (2020) also touches on the need to be flexible in research methods by explaining that co-design is a messy process that requires researchers to act ethically in a changing and unpredictable environment. Dimopoulos-Bick (2019) and Moll *et al.* (2020) further explain that researchers need to build flexibility into participation, plan for alternate events, and, as far as possible, should not include any rigid steps in their planning. Following the above, Mburu *et al.* (2018) argue that methodological choices can be crucial to empower participants and build their confidence to be ready to participate in co-design. This methodological choice is important as Schönberger *et al.* (2023) highlights that participants of co-design processes need to believe that they can perform well and may need to be reassured often. Densmore *et al.* (2022) recommends that researchers use materials that allow participants to express themselves easily and freely.

The impact of co-design on research methods often results in a more time-consuming process as participants need time to engage fully (Moll *et al.*, 2020), and their co-design skills will grow gradually over time (Molapo *et al.*, 2016); it also takes time to build the necessary trust (Densmore *et al.*, 2022). Miller *et al.* (2017) further stress that co-design readiness is highly context-specific and depends on attributes, attitudes, skills, and relationships between researcher and participants. The highly contextual nature of co-design results in the need for researchers to carefully consider the group dynamics (Mburu *et al.*, 2018) and consider social practices (Densmore *et al.*, 2022, Till, 2022b

2023) which adds to the duration and time needed for successful co-design sessions as well as adding complexity. Mburu *et al.* (2018) et al. explain that co-design can be complex when working with vulnerable groups with Coupe & Cruickshank (2017) adding that co-design is also complex in multi-stakeholder environments and are most likely to be successful in smaller intimate settings. In line with the complexities of co design, Donetto *et al.* (2015) highlight the fact that co-design is rarely equal. All of the above indicates that researchers should create a space where participants believe they can perform well (Schönberger *et al.*, 2023) by investing the necessary time to build relations (Molapo & Densmore, 2015) and empathy (Till *et al.*, 2021). In this paper, we explore co-design readiness by reflecting on three co-design case studies with low-resource communities in South Africa to highlight the different types of preparedness, such as emotional readiness, cultural readiness, and confidence with design elements and technology, which in combination constitutes co-design readiness. Based on these cases, we provide a list of recommendations that includes different ways of addressing and achieving emotional and cultural readiness, as well as potential methods and practices that can assist in fostering co-design readiness and lower the barriers to co-deisgn in low-resource communities.

2 Methods and Research Settings

This paper uses a qualitative meta-analysis (Hansen *et al.*, 2022, Hoon, 2013) to synthesize the findings of three distinct case studies of co-design research with communities in low-resource settings in South Africa, a diverse and multicultural country with a population comprising of approximately 58.8 million people[1] . The country has 11 official languages because the country houses a wide variety of cultures. The country is also classified as an LMIC country with a GNI per capita (the dollar value of a country's final income in a year, divided by its population) of between 1,136 USD and 4,465. USD.[2] [3] For each case we reflect on our learnings regarding the co-design readiness of our participants.

2.1 Case studies

Here we give an overview of the case studies analyzed in this paper. Since some locations are shared between different case studies, we go into deeper detail about each geographic location in the next sub-section, and provide additional detail about each case study in section 3.

- **Case Study 1: Co-Designing Digital Maternal and Child Health (MCH) Technologies in South Africa**: took place from 2020 to 2023, conducting workshops in Ga-Dikgale, Limpopo; Sweetwaters, KZN; Cape Town, Western Province; and Soweto, Gauteng with 36 parents and 8 community health workers (CHWs) to develop community-centered priorities and prototypes for digital MCH technologies.
- **Case Study 2: Co-Designing Tangible User Interfaces (TUIs) and The Internet of Things (IoT) to Support Rural Parents in South Africa** looks at a study in which the researchers work with mothers to incorporate sensors into blankets to support early childhood education. This study takes place in Sweetwaters, KZN with a group of seven mothers and two quilters and one Early Childhood Development (ECD) practitioner from 2022 to 2024.
- **Case Study 3: Co-Designing IoT with Artificial Intelligence (AI) capabilities to Support Hydroponic Farming in Rural South Africa** explores the co-design of AI and IoT-enabled hydroponic farming with seven rural subsistence farmers in Sweetwaters, KZN and Gqeberha, Eastern Cape.

These case studies were purposefully selected (Hoon, 2013) as they all employed co-design as a research method, and the data gathered during these studies provided rich insights into co-design readiness.

2.2 Research settings

This research took place across different geographical locations in South Africa:

- **Sweetwaters - KwaZulu-Natal Province**: The rural area of Sweetwaters is 97Km outside Durban in the uMgungundlovu district. Communities from this area have access to a household income of R2,400 per month [4] ($1 = R14.68). The community comprises of around six hundred thousand people and is representative of the Zulu population in KZN with 100% of the population listed as Zulu speakers.[5]

1 http://www.statssa.gov.za/?p=12362
2 https://www.brandsouthafrica.com/south-africa-fast-facts/geography-facts/language
3 https://www.worldbank.org/en/country/mic/overview
4 http://www.statssa.gov.za/publications/P0318/P03182019.pdf
5 https://wazimap.co.za/profiles/municipality-KZN225-the-msunduzi/

- **Soweto - Gauteng Province**: Soweto is a peri-urban, low to middle-income area in Gauteng, South Africa. Soweto is also South Africa's largest township, located on the outskirts of Johannesburg. This township comprises of around 1,3 million people of which the majority speaks isiZulu.[6] The average monthly income for this region is R2,500.[7]
- **Dikgale - Limpopo Province**: Ga-Digkale is zoned as a rural, low-income area with a monthly income of R1,250[8] and is located 90km east of Polokwane. This community is representative of the Sepedi people with 95% of the 9 353 people in this population listed as speaking Sepedi.[9]
- **Cape Town - Western Cape Province**: Athlone has a population of roughly 38,288 people. The area is zoned as urban with a monthly income of around 4,791 ZAR per month. This population is predominantly English speaking with approximately 44% of the population listed as English speaking followed by 36% Afrikaans and 15% isiXhosa.[10]
- **Green Bushes (Gqeberha) - Eastern Cape Province:** Greenbushes is a rural area located 21.7 km outside Gqeberha, South Africa, located in Nelson Mandela Bay Ward 41. This area has an average household income of R2,450 per month 4 (USD1 = R14.68) and[11] comprises around twenty-six thousand people. The district is representative of the isiXhosa and Afrikaans populations in the Eastern Cape with 44% of the population listed as isiXhosa speakers and 36% listed as Afrikaans speaking.[12]

2.3 Analysis

For the qualitative meta-analysis, we revisited the data from each study with respect to known concepts around co-design, looking specifically for concepts such as emotional connections and readiness, cultural nuances, and readiness, as well as methods that could reduce barriers to co-design, while also allowing related themes to emerge from the data. This was achieved by rereading the transcriptions, research notes, and WhatsApp chats, looking for the overarching themes mentioned above. A coding sheet for each case study was then drawn up and completed to highlight where the concepts were found in the data across the different case studies. This allowed for the synthesis of themes through a cross-case analysis.

This method is useful when extracting in-depth information about specific contextualized factors and to shed light on certain phenomena (Rauch *et al.*, 2014). We thus used this method to identify patterns and insights from highly contextualized data. We then used the qualitative meta-analysis to aggregate not generalizable data into a new generalizable picture Hansen *et al.* (2022)

The research team analyzed data from the following three cases concerning the co-design workshops and deployments to reflect on our learnings regarding the co-design readiness of our participants from low-resource communities in South Africa,

[6] http://www.statssa.gov.za/publications/P0318/P03182019.pdf
[7] https://wazimap.co.za/profiles/ward-79800042-city-of-johannesburg-ward-42-79800042/
[8] http://www.statssa.gov.za/publications/P0318/P03182019.pdf
[9] https://wazimap.co.za/profiles/ward-94703017-makhuduthamaga-ward-17-94703017/
[10] https://wazimap.co.za/profiles/ward-19100044-city-of-cape-town-ward-44-19100044/
[11] https://www.statssa.gov.za/publications/P0318/P03182019.pdf
[12] https://wazimap.co.za/profiles/ward-29300040-nelson-mandela-bay-ward-40-29300040/#demographics/

3 Research tools and co-design workshops

3.1 Case Study 1: Co-designing digital MCH technologies in South Africa

This study occurred from May 2020 to May 2023 in rural areas of Limpopo and KwaZulu-Natal and urban areas of Gauteng and Western Cape in South Africa. The study investigated the role of communities and co-design approaches in creating digital MCH initiatives. The project team comprises a cross-cultural and interdisciplinary group of researchers (seven from South Africa and 13 from abroad) with public health, nutrition, social sciences, medical sciences, psychology, and human-computer interaction backgrounds. The project consisted of three phases: (1) A scoping review on community-based co-design of ICTs health innovations for MCH in South Africa (Till, 2023). (2) Qualitative interviews with key community stakeholders such as mothers, fathers, other caregivers, and Community Health Workers (CHWs) to identify and understand the existing MCH Challenges (see Table 1) (Klingberg *et al.*, 2022, Muthelo *et al.*, 2023, Till *et al.*, 2021). Finally, (3) community-based co-design workshops (Till, 2022b), informed by the findings of the first two phases, in which community participants prioritized the challenges identified in Phase 2 (Coleman, 2023), brainstormed possible solutions and co-created prototypes such as mobile applications and community radio stations to address them.

3.1.1 *Research tools used during workshops: challenge and design cards*

The tools used during the community-based-co-design workshops were created based on the data gathered from the qualitative interviews during which the research team enquired about the challenges mothers and fathers faced while they were accessing health care services for their children. Based on this data, the research team designed a collection of challenge and design cards (see Figure 1) to visualize the identified challenges and aid the discussion and brainstorming of potential solutions. Visual methods have shown great potential to actively engage with the community while capturing maternal health lived experiences (Bagalkot *et al.*, 2020). Further to this, design cards have been successfully used to graphically depict complex concepts, facilitate brainstorming, share understanding (Lucero *et al.*, 2016, Robles *et al.*, 2019), and facilitate co-design while developing sensitivity and empathy (Ayobi *et al.*, 2021, Mannay *et al.*, 2018, Talhouk *et al.*, 2016, Wölfel & Merritt, 2013). These cards were designed to consider the literacy levels of the communities. Thus, the cards were designed with minimal writing using pictorials as a more realistic visual style (Aarts *et al.*, 2020) to support the understanding and sharing of the lived experiences of our communities. These black and white images further depict men and women representing the communities used in this study (Schumacher, 2009, Heerden & De Lange, 1998). The buildings and surrounds depicted in the images represent rural and urban settings typically found in the regions where this study was conducted. Any text on the cards was translated into the languages of each community.

3.1.2 *Workshop processes and procedures*

The multi-cultural nature of this study required careful planning as the researchers only sometimes spoke the local language or needed more insights into the cultural nuances the different regions may present. The research team thus decided to work with our research partners in each region to recruit intermediaries who spoke the local language and either belonged to the local

Table 1. Table: Participant Demographic Information

Case Study 1: Digital MCH Study			
Site	Mothers	Fathers	Community Health Workers (CHWs)
Sweetwaters	7	1	2
Soweto	9	1	2
Ga-Dikgale	5	5	2
Cape Town	8	0	2
Case Study 2: TUI Study			
Site	Mothers	Quilters	Early Childhood Development (ECD) practitioners
Sweetwaters	7	2	1
Case Study 3: AI/IoT Study			
Site	Female Farmers	Male Farmers	
Sweetwaters	4	1	
Gqeberha	2	0	

culture or had in-depth knowledge regarding the nuances of the culture. The team met with the intermediaries, provided co-design training, and reviewed the research plan before each workshop. The intermediaries then took the lead during the workshops, all initiated by discussing and obtaining written or verbal (verbal consent in the case of Kwa Zulu Natal) consent. The intermediaries and participants next discussed the ten existing MCH challenges derived from the data gathered during the qualitative interviews. The participants were asked if they had experienced these challenges and to elaborate on their experiences if they had. The discussions served as both an icebreaker and a means to ensure that the participants and intermediaries had a shared understanding regarding the challenges depicted in the diagrams. The participants were then asked to rate the challenges individually according to their importance to each to see if they were addressed. Each participant was given ten stickers representing varying levels of importance and was asked to place the stickers on each challenge card individually. The stickers were then tallied, and the challenge cards were ranked in order of importance. The intermediaries next went through each design card, explaining the technology with examples to the participants; they also asked the participants to provide examples of where they have used similar technologies. The participants were finally asked to make use of the design cards which included cards for people (such as community leaders, health professionals, etc.), places (such as community centers, clinics, and ECD centers), and technologies (such as mobile phones, wireless networks, internet in a box etc.) to ideate possible solutions to the challenges which were voted and ranked as the top three challenges the community faced.

3.2 Case Study 2: Co-designing tangible user interfaces (TUIs) and The Internet-of-Things (IoT) to Support Rural Parents in South Africa

The second study kicked off in January 2022 in Kwazulu-Natal, South Africa, and is still ongoing. This study investigates the design requirements, materiality, and implications for the design of IoT and TUIs in rural South Africa. The study comprises the following phases: (1) an ice-breaker primer that introduced the participants to the electronics used throughout the study; (2) Co-design workshops to facilitate the co-creation of an IoT prototype that leverages TUIs to assist rural parents in delivering Early Childhood Development to their children; and, finally, (3) the IoT/-TUI prototype deployment. This study included seven mothers, one Early Childhood Development (ECD) practitioner, two quilters, and mothers from rural KwaZulu Natal, South Africa (see Table 1).

3.2.1 *Research tools used during workshops: electronics, fabrics and wireframe software*

A variety of fabrics were used during this study to explore the effects of culturally situated fabrics versus non-culturally situated fabrics. The first two co-design workshops included a selection of ShweShwe - A fabric considered to be a traditional fabric used by many African cultures (Snowball & Mapuma, 2021), African Wax prints known as Ankara[13] and some "non-traditional fabrics" which as no connection to African cultures. We then took the participants to a local fabric store to purchase the fabrics they would like to use for their respective sections on each quilt. Each participant was given a budget of three hundred Rand (12.65 GBP) to select fabric. Traditional and non-traditional fabrics were used for the remainder of the workshops.

The first workshop further included a sensor pack that contained 45 different sensors[14] ranging from touch sensors to tilt sensors. The research team selected this kit as it included a sufficient range of sensors to give the participants a thorough introduction to the types of sensors available that can be used to trigger the necessary actions for the different ECD activities on the quilt. The researchers supplemented the kit with a heart-rate sensor. The participants were also issued with an Arduino ATMega 2560 microcontroller[15] which would control the sensors and the overall functioning of the quilts. The controller and sensors are powered using two 18650 rechargeable Lithium Ion batteries[16], connected to a TP4056 USB C lithium charging unit[17]

[13] https://ashantiempress.com/blogs/news/history-of-african-wax-print-cloth

[14] https://www.diyelectronics.co.za/store/kits/1305-45-in-1-sensor-kit-for-arduino.html?search_query=sensor&results=627

[15] https://www.diyelectronics.co.za/store/boards/9-mega-2560.html?search_query=arduino+mega&results=83

[16] https://www.diyelectronics.co.za/store/li-ion-li-po/3743-molicel-18650-36v-2600mah-li-ion-rechargeable-battery-cell.html?search_query=18650&results=73

[17] https://www.diyelectronics.co.za/store/battery-charger/126-1a-li-battery-tp4056-charging-module-type-c.html?search_query=TP4056&results=2

which connects to a small solar panel[18] . Finally, the mobile application interfaces and features were co-designed using the Figma wireframing tool.[19]

3.2.2 *Workshop processes and procedures*

South Africa is currently experiencing the worst rolling blackouts in the country's history. These blackouts, known as load-shedding, are categorized by different levels, with the lowest level (level 1) resulting in no electricity for a minimum of two hours during a scheduled time slot. Many of these slots occur at night, leading to the decision to introduce the participants to work with electronics by building a small battery-powered load-shedding LED light. As an icebreaker activity, each participant received a 9v LED acid battery kit, a battery holder with an on-and-off switch, wiring, a 20-ohm resistor, and an ultra-bright LED. The participants were then given step-by-step instructions on how to power up the LED light with the battery.

The first co-design readiness workshop employed the 45-sensor sensor kit. The researcher and participants reviewed each sensor, how it functions, and what activities and events it could trigger. The research team then gave each participant a sheet containing a picture and each sensor's name as they started to ideate possible ECD activities. The ECD practitioner discussed ECD with the participants and gave examples of how she would teach shapes, numbers, and letters in her ECD center. The participants then used the fabric to create shapes, letters, or numbers and pinned the sensor they believed would trigger an action to help children learn the chosen concept. At this point, the team realized they needed to stop the co-design sessions and provide co-design readiness training to enable the participants to better understand sensors to co-design the quilts. The research team initially issued each participant a microcontroller, a touch sensor, an LED, and a laptop installed with the Arduino IDE. The team then trained each participant to use the touch sensor to trigger the light to turn on when the participants touched the shape, number, or letter they created in the previous workshop. The participants were asked to work in groups as the older participants were nervous about the laptop and felt much more comfortable working in a group setting with the younger ladies. The team followed the same process for five co-design readiness training workshops, where the team allowed the participants to configure and experience the different sensors during each workshop. The research team resumed the co-design workshops once the participants indicated that they felt comfortable pairing the sensors with their activities. From there, the team conducted five more co-design workshops to create the TUIs for the study. Each co-design workshop took about 4 hours, starting at 10 am in the morning, breaking for lunch at 12 for one hour, and concluding the workshop by 3 pm each afternoon. The final co-design workshop focussed on the interfaces and features of a mobile application that would provide the parents with feedback regarding how their child is progressing through the activities on the quilt. From our previous learning, the team first showed the participants a variety of applications that employed a tracking feature. The research team then only asked them to create a paper prototype of how they would like to see the tracking information for their children. From here, one of the researchers projected her laptop screen and worked with the participants to create a figma prototype that included the flows and features of the application.

[18] https://www.diyelectronics.co.za/store/solar-panels/3717-18v-570ma-solar-panel-275x170mm-polysilicon.html?search_query=solar+panel&results=42

[19] https://www.figma.com/

3.3 Case Study 3: Co-designing IoT with AI capabilities to support hydroponic farming in rural South Africa

The final study started in March 2022; this study explores the co-design of AI and IoT aimed at rural subsistence farmers in South Africa and seeks insights into how rural farmers co-grow crops alongside AI. The study included a simulation to verify the correct functioning of an IoT-based AI-enabled hydroponic grow tent aimed at rural subsistence farmers in KwaZulu-Natal and the Eastern Cape. This study included: (1) initial training on hydroponic farming, AI, and IoT technologies; (2) focus groups to understand farmers' challenges; and (3) deploy two technology probes: (1.1) A fully AI-automated hydroponic grow tent and (1.2) a mobile application that allows farmers to connect to a local WiFi network to control the tent. The deployment included weekly workshops where researchers and participants discussed the farmer's lived experiences while farming alongside the AI-enabled IoT tent, any challenges the farmers faced, and any changes they would like to see made to the system. The demographics of the participants for this study appear in Table 1

3.3.1 *Research tools used during workshops: AI, IoT, and grow tents*

Climate change in South Africa and the resulting weather patterns necessitated a fully enclosed hydroponic system, which included temperature, light, and humidity control. The research team, therefore, used a dark box hydroponic grow tent[20] with 80cm x 80cm x 160cm dimensions. The grow tent contains a 72-hole step-down tiered hydroponic food grade PVC grow stand.[21] An oscillating multi fan[22] and a mixed-flow inline extractor fan[23] controls the humidity and temperature in the tent. Finally, a full spectrum LED grow light[24] provides the necessary heat and lighting. Nutrients are supplied via an eight-liter water reservoir fitted with a submersible water pump[25] capable of pumping water 1.2 meters. The system is gravity-fed from here, with an outlet pipe draining into the water reservoir to complete the circuit. To enable the farmers to visualize and help monitor and maintain the controlled environment, the team installed a DHT22 temperature and humidity sensor[26] , an ambient light sensor[27] as well as PH[28] and Electrical Conductivity (EC) sensors[29] These sensors transmit real-time data to an Arduino Mega 2650 RV3 AT microcontroller.[30] The researhc team next created a REST Application Programming Interface (REST API), which served JSON data over a local WiFi network using an ESP82066-01 WiFi module.[31] This WiFi network, paired with an Android-based mobile application, enabled the farmers to visualize the sensor data in real time. The application

[20] https://www.takealot.com/dark-box-hydroponic-grow-tent-80cm-x-80cm-x-160cm/PLID69343156

[21] https://www.bellandpaton.co.za/products/hydroponic-step-down-tiered-growing-system-72-holes

[22] https://gthydro.co.za/products/1339-ram-180mm-7-oscillating-multi-fan-eu-plug.html

[23] https://gthydro.co.za/products/1465-ram-mixed-flow-inline-fan-100mm-4.html

[24] https://plantliving.co.za/products/samsung-lm301b-full-spectrum-led-grow-light-110w

[25] https://www.takealot.com/sobo-submersible-water-pump-15w-880-l-h-max-height-1-2m/PLID90152378

[26] https://www.dfrobot.com/product-1102.html

[27] https://www.dfrobot.com/product-1004.html

[28] https://www.dfrobot.com/product-1025.html

[29] https://www.dfrobot.com/product-1123.html

[30] https://store.arduino.cc/products/arduino-mega-2560-rev3

[31] https://www.sparkfun.com/products/17146

further allowed farmers to adjust settings through API requests, should the Machine Learning (ML) model make any mistakes. The team used the Random Forest Classifier (RFC) to train models to automate the system by classifying whether the parameters in the grow tent were in an optimal or sub-optimal state. The RFC can predict one parameter; therefore, four models were built for each of the temperature, humidity, EC, and pH parameters. Real-time sensor data was fed into the models at 5-minute intervals for temperature and humidity and every 16 hours for PH and nutrient (EC) levels. The AI would next classify the state of the tent and adjust any element (temperature, humidity, nutrient level, PH level, or light readings) of the tent by turning on or off the necessary element or by using small (100 mils per minute) peristaltic pumps to either pump nutrients.

3.3.2 *Workshop processes and procedures*

Power relationships (Farr, 2018), trust (Goodyear-Smith *et al.*, 2015), a lack of agency (Lee, 2008), and a sense of being overwhelmed often make it challenging to conduct co-design research where the researchers and community work as equal partners. Another problem that should be discussed more is the blank page problem (Joyce, 2009), which occurs when no limitations or expectations are placed on creativity. This is often called the paradox of choice, where too much freedom in creative choice can be paralyzing and overwhelming (Joyce, 2009). Bob Garfield (2024) states that a lack of boundaries does not necessarily liberate creative processes but enslaves them (Garfield, 2003). Many researchers and participants have experienced this problem working with new technologies or ideas in a co-design setting. From previous studies, the research team knew that introducing a new technology to rural subsistence farmers and asking them to co-design the system could be overwhelming. So, after careful consideration, the team decided to use technology probes. Technology probes are simple, flexible, adaptable technologies that (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 (Hutchinson, 2003). So, the team built and deployed four fully functional IoT and AI-enabled hydroponics tents and an accompanying mobile application to allow our participants time to experience the technologies and elicit easier and more meaningful conversations about the community's design requirements. The team was thus fully aware that the system, in its initial form, did not consider the design requirements and needs of the community but would instead serve as a probe to start conversations and hopefully enable the participants and researchers to think about and better articulate the system's design requirements.

The research team created six grow tents, four of which were deployed with rural subsistence farmers. Two tents were deployed on the farms of two farmers in Gqeberha. However, a total of five farmers from KwaZulu-Natal joined the study.The team therefore installed two tents at the HSRC offices in the Sweet Waters, within walking distance of four of the five farmers. Two of the KwaZulu-Natal-based farmers further belong to a quilting workshop which met once a week at the HSRC offices. The Kwazul-Natal-based farmers formed a group and monitored and maintained the tents. The remaining two grow tents served as control tents located at the researchers' institutions. All four tents were deployed in September 2023. The farmers were invited to take part in the deployment after which asked the farmers to install the mobile application on their phones. The researchers finally provided an hour-long training session that focused on the functions of the tent, the role of the AI, and the features available in the mobile application. This information was reiterated with every visit to the farmers. The distance between the two farms, as well as the time constraints of the farmers from Gqeberha, necessitated one-on-one semi-structured interviews. The research team used a loosely prepared open-ended interview script that allowed further probing based on the farmers answers answers (Taherdoost, 2022). Semi-structured interviews can gather in-depth data, making this the most suitable method without focus groups. The open-ended questions allowed the farmers to respond as they saw fit and allowed follow-up questions for clarity. Finding a suitable time to schedule interviews with busy farmers was challenging. Ultimately, they were conducted differently for each farmer through an onsite visit, and WhatsApp chat, followed by a telephone call. The researchers discussed the informed consent form with the farmers to ensure the farmers were comfortable with the contents. The team explained that participation in the study was voluntary and that the farmers could withdraw at any time. The team offered an opportunity for clarification and questions and finally signed the written consent form before proceeding with the interviews and focus groups.

The group formed in KwaZulu-Natal took part in a total of 12 focus groups.The research team invited the farmers to join us on the installation day, and from there on, they met with the farmers once a week. The focus groups were informal, and discussions were often held while the farmers and researchers repaired and maintained the tents. The researchers elected not to record the focus groups but used detailed research notes to report our findings. The research notes are kept under lock and key in the office of one of the researchers.

3.4 Positionality statement

The authors of this paper have extensive experience with the co-design of digital resources with marginalized communities in Africa, India, and Latin America. The first author is a native South African based in South Africa and was raised in a low-income rural area. The first author is also a white Afrikaner who had to be careful of South Africa's difficult history. However, she connected with the community as a mother and as a person who has also farmed land and was able to develop trusting relationships with the communities she worked with. The various differences in the researchers' and communities' cultures were handled with great care and respect by realizing that we remain mothers, farmers, sisters, and friends far beyond the differences in our cultures and that each person has the right to live out their lives according to their culture without judgment. Finally we should note that trust is a complex concept, thus the intersectionality of researchers and participants may have played a role in how trust was built.

3.5 Data availability statement

The interview data set from the stakeholder consultation generated and analyzed during this study are not publicly available due to ethical concerns

4 Findings

Our findings section reports on the themes extracted from all three case studies during our qualitative meta-analysis. We will discuss each theme and elaborate on how the theme played out in the different case studies. We also report on the lessons we learned as well as the tensions that emerged as we explored co-design readiness across all three case studies

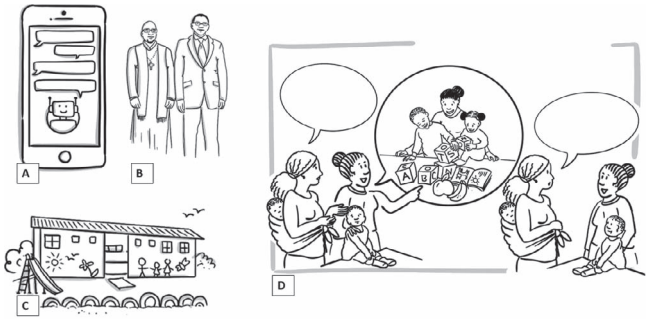

Fig. 1. A -C: Design cards representing technology, places, and people. D: A challenge card illustrating parent's desires to be better parents to their children

Fig. 2. A: Example of pictures of sensors pinned to shapes. B: Example of hand written notes with the desired sensors pinned to quilts

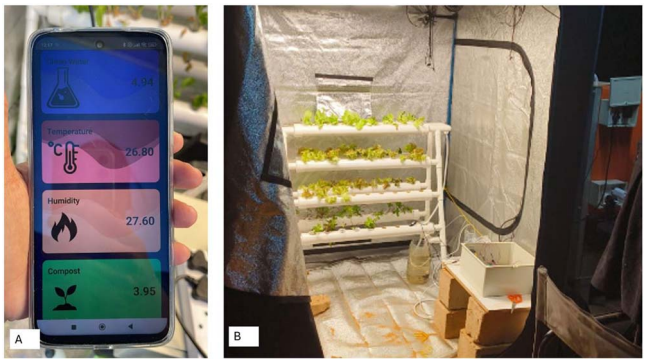

Fig. 3. Deployed technology probes - A: Mobile application that interacts with grow tent via (the Internet of Things) IoT. B: Grow-tent

4.1 Growing confidence in design through iterations

In our work, all the participants found ideation easier when working with tangible examples. We initially intended for the Case Study 1 participants to use the supplied arts and crafts materials to brainstorm multiple solutions to the relevant MCH challenges and then only to prototype one solution which was agreed upon by the community. However, the availability of all the necessary resources in the form of people (e.g., community leaders), and places (e.g., community centers) where the solutions could be rolled out, and technologies (e.g., WiFi, mobile phones, etc.), depicted in the design cards (see Figure 3) resulted in the participants combining the design cards with the art supplies and moved straight into prototyping rather than ideating first. While this was not according to our original intended methods, the actions of the participants highlighted the fact that design cards enabled easy prototyping that allowed the participants to express themselves and build solutions to the challenges.

Similarly, the participants in the TUI study (Case Study 2) elected to cut out the pictures and descriptions of the sensors provided on the information sheet provided to the participants. Participants then pinned the pictures of the sensors they believed would pair well with the ECD activities for the TUI to the section of the quilt they were working on. In later workshops, they also chose to write down the sensor's name as well as how they wanted each sensor to trigger different activities on small pieces of paper. The participants then pinned these pieces of paper onto the activities on their quilts to help them develop the activities they believed would help their children learn basic ECD concepts such as shapes, numbers, and letters (see Figure 2). Further to the aforementioned, the TUI participants also found that experiencing and working with examples of tracking apps, such as health, step, and calorie trackers, assisted in the ideation of the required features and corresponding interfaces used for the mobile application responsible for visualizing how their children were progressing through the activities on the various quilts.

In the third case, the participants in the AI study (Case 3) were able to give much richer feedback after interacting with the deployed technology probes. Experiencing and working with the physical hydroponic grow tent and the mobile app provided many opportunities for the participants to give feedback regarding the placement of the elements in the tent, how the plants were placed in the growing stand, and the features and interfaces of the mobile application. Some examples of the feedback are:

> "We need to change the pictures used in the app; why is there a piece of corn for nutrients? We also don't say nutrients; we say compost. Can you change the picture and make the label say compost?" - Farmer Case Study 3

> "We need to put an empty space between the plants in the stand, bugs like tight, they will get in there and eat our plants, the plants also need space to grow" - Farmer Case Study 3

Furthermore, the fact that the microcontroller housing the AI was present in an electronic box helped the participants see the AI as a tangible object rather than an abstract source code. One participant mentioned the following:

> "That box does its job; it makes the tent do the things we need; the box works for me now."

The participants would often refer to the AI as the box, which was responsible for controlling the tent, and the box as their helper.

4.2 Fostering familiarity with technology

While the participants in the TUI study (Case 2) could pair sensors with ECD activities, they often chose sensors that could not trigger the actions they envisioned for the activity. It became clear that the participants needed help with making choices regarding sensors. We thus elected to stop all "co-design" workshops and instead conducted at five sensor training activities during which the participants were provided with a microcontroller and sensors. From here, one of the researchers trained the participants to use the necessary software to configure sensors to understand exactly how each sensor worked. Taking the time to allow the participants to experience and understand each sensor helped the participants to align sensors with their designed ECD activities

better. In addition, the experience with sensors built their confidence, leading to the participants choosing various sensors for each activity, with some going as far as requesting sensors that we did not have in the sensor kit. The ECD practitioner, in particular, asked the following:

> "You know what I tell the teachers at my creche? I tell them to take the chalk and to draw the shapes; they must tell the children to get in the shape! Walk around the shape so they can learn. I am looking for a sensor they can use to trace the lines of the shape with their fingers; it must turn on the lights as they trace." - ECD Practitioner, Case Study 1

Where previously the link between the sensors and ECD activities was not clear, the time taken for training helped to empower the participants as co-designers.

The farmers in the AI study (Case 3) needed help conceptualizing the working of the AI deployed in the physical grow tent as they initially did not trust the AI. Going through each component in the tent and how it worked along with the AI went a long way to helping the farmers understand, with a good amount of detail, how the AI functions. This was achieved by asking the community to join us when a tent needed the electrical components replaced after they were damaged in a storm. One researcher connected the wiring while the community observed. The researcher explained how each component functioned and how the AI could control each element in the tent using relays. The researcher explained that the AI was installed on the microcontroller connected to each element in the tent through the relays. Drawing the AI as an actor, looking at examples to learn, and making decisions based on the many examples it looked at helped to demystify the AI. Finally, the researcher went through the source code of the AI with the farmers, showing them where the values the AI learned were stored and how the AI instructs the elements in the tent to turn on and off based on the values.

Finally, deploying the mobile app that allows farmers to interject should the AI not act as intended, allowed the farmers to experience the, mobile application while using the grow tents. This experience enabled the farmers to provide detailed feedback as they could better articulate how they needed the application to function. They could further provide feedback regarding the features they liked and disliked and give us concrete information regarding the changes they wanted in the application, why they needed the changes, and how they believed the changes would assist them in their day-to-day monitoring of the tents. Some of the farmers stated the following:

> "I would like to be able to access the tent when I am not on the farm, I am often at the auction in town, it would be good to check in on the tent remotely." - Farmer, Case Study 3

> "Can we not connect to the WiFi from inside the app? I am old, and I sometimes forget where to go. I dont like having to remember how to connect to the network." - Farmer, Case Study 3

4.3 Building trust and considering cultural nuances

The MCH study (Case 1) revealed many cultural nuances regarding gender norms, hierarchical community structures, and how time, power, and space influence how different communities communicate. For example, the participants from KwaZulu-Natal and the Limpopo province displayed more cultural nuances, such as Hlonipha, a cultural politeness phenomenon that dictates the

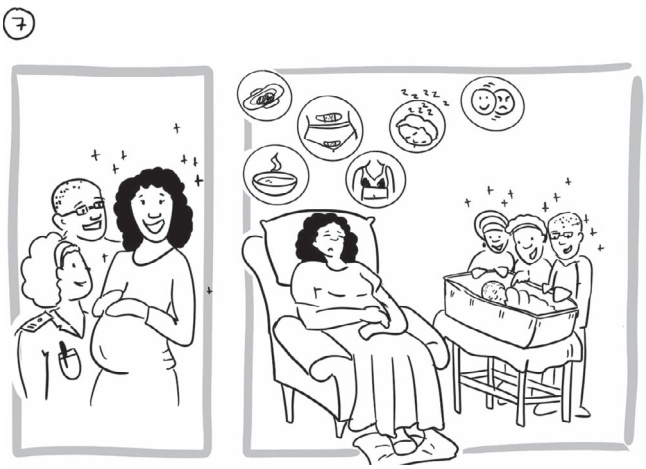

Fig. 4. Post Partum care design card used during Case Study 1.

behavior, language, and gender norms of men and women in many African cultures. In our case, Hlonipha resulted in men often taking the lead during discussions regarding MCH, traditionally seen as a woman's role. Further to this, in Kwazulu-Natal, the women had to first gain explicit consent and approval from the male participant to discuss challenges that refer to the female body, such as those depicted by the **Postpartum Care** challenge card (see Figure 4). These cultural nuances were also present in the TUI study (Case 2) as the researcher provided a wax print that contained patterns and colors associated with traditional healers (Sangoma) in the Zulu culture (a single piece of fabric containing images of snakes and patterns in red and black). The participants were nervous about using the fabric and did not want to cut it up to use it on their quilts. They started nervously laughing, with one participant stating:

> "I am not cutting that one; that is for a Sangoma!" - Mother, Case Study 2

The same rural versus urban differences were also present in Case study 2, as the translator for the study, also a Zulu mother from Durban, the biggest city in Kwazulu-Natal, indicated that she is not scared and willing to cut up the fabric.

Finally, the role of elders and community leaders and the respect they demand in many communities was also present in the TUI, MCH, and AI study, with the participants often ensuring that the older community members are catered for and respected, even when design considerations were discussed. For example, the presence of community leaders and members of the royal family in the Limpopo province greatly altered the group dynamics in the room, with the participants referring all responsibility to the community leader and allowing him to take the lead throughout the workshop by answering any questions first. To follow up on the above, the younger participants in the TUI and MCH study served the older participants their lunch during the lunch break, ensuring the older ladies got food and something to drink first. Last, the younger participants in the AI study deferred the decision-making regarding the UI for the mobile app to the older participants. One participant stated the following.

> "I think we should let the mammas decide how they want the application to look; the rest of us will be fine with using what works for them." - Farmer, Case Study 2

It is well known that trust relationships are important in research settings. However, the time it takes to build enough trust for participants to believe they can co-design alongside researchers is only sometimes discussed in enough detail. In our case, some KwaZulu-Natal-based participants were present in the MCH, TUI, and AI study. At the beginning of the first study (MCH) and well into the TUI study, the participants made many decisions based on achieving what they believed the researchers wanted. However, as time progressed, and the participants understood that the researchers were interested in their needs, not only did the participants and researchers build a better trust relationship that resulted in the participants switching from trying to achieve the researchers' goals to focusing and advocating for their needs, but their confidence grew as well. The aforementioned is also true for the researchers, as the researchers better understood the community, the participants, and the environment and gained more experience and confidence. Still, most importantly, their empathy and understanding of the community also grew.

4.4 Emotional connection and feelings of safety

In addition, we found building relationships during different case studies to be useful. The researchers intentionally decided to have lunch with the participants to learn more about them, often discussing topics they had in common with them, such as their children, hobbies, television shows, shopping, etc. These discussions helped build an emotional bond and readiness through trust, mutual respect, and a mutual understanding of the lived experiences of the researchers and the participants. This emotional connection resulted in participants feeling "safe" in the research space and being more eager to take part in research studies. One participant mentioned:

> "We feel safe with you…and we will be very happy to do more research studies with you." - Mother, Case study 2

Furthermore, forging an emotional bond also assisted in other areas of the study. For example, the participants informing the researchers to rather not purchase lunch and bring it with them, since the participants would appreciate a voucher which allowed them to purchase lunch that they could share with their families. One participant offered the following:

> "Do we have to buy lunch, I am just thinking that I can take that voucher and buy supper for my whole family, then I do not have to cook tonight." - Mother, Case Study 2

Knowing the researchers and feeling safe in the research space enabled the participants to highlight and discuss areas of the co-design work that they were struggling with. One of the older mothers shared the following:

> "I am struggling with the sewing, but I can cut out the shapes, can we rather make teams where two of us work together, one of the youngsters can sew while I cut out the shapes." - Mother, Case Study 2

Finally, It is essential for intermediaries and researchers to respect the cultural nuances that will emerge during co-design sessions, even if these norms are not per their own beliefs. In our case, the intermediaries, who understood the cultural nuances, were able to let these nuances play out in their most natural form, which in turn resulted in the community feeling respected and comfortable during the workshops.

5 Discussion

5.1 Co-design is never truly equal

All three case studies highlight the fact that that co-design is never truly equal (Moll *et al.*, 2020) and requires a attitudinal shift on the part of the researchers and participants to enable participants from potentially different fields and researchers to work collaboratively and to "embody co-design" (Dimopoulos-Bick, 2019) that value equality, respect and reciprocity. This collaborative environment can be achieved by focusing on co-development of knowledge and skills and valuing and accounting for lived experiences (Dimopoulos-Bick, 2019) of both the researchers and the participants.

We, therefore, agree with (Akama & Light, 2020) that readiness is highly personal and can only be achieved when both participants and researchers build enough trust and emotional readiness to bring their full authentic selves and enable empathy to develop to prepare them for co-design sessions.

5.2 Emotional readiness, empathy, and time

Case Studies 2 and 3 highlight the importance and need for researchers to explicitly plan for relationship and trust-building activities before conducting any co-design sessions. The highly collaborative nature of co-design methods combined with the ideal of "equal partnerships" (Sanders & Stappers, 2008) amplifies the need for building trust, balancing power and developing good co-design relationships, and empathy for researchers *and* participants (Ramos-Pedersen, 2020). In both case studies, it took considerable time to establish good trusting relationships and build empathy to work as somewhat equal partners. Many articles speak to the need for empathy on the researchers' part and trust on the part of the participants (Brewer *et al.*, 2005a, Coleman, 2023, Farr, 2018, Goodyear-Smith *et al.*, 2015, Lee, 2008, Till, 2022a b). However, for co-design to occur, with the hopes of an equal partnership, empathy and trust must be reciprocal as shown in Case Studies 2 and 3. In line with Molapo & Densmore (2015) and Mburu *et al.* (2018), all three cases indicate that co-design readiness takes time, and is highly context-specific, and relies on the attributes, attitudes, and skills of the researchers and participants (Miller *et al.*, 2017). The need for skilled researchers who are able to build good relationships is vital for co-design (Dimopoulos-Bick, 2019), especially when working with vulnerable communities, as co-design in these settings can easily become complex (Mburu *et al.*, 2018). It is also important to consider that the iterative approaches used in all three Case Studies and in co-design can also introduce complexity as these methods ask that the participants experience technologies that (1) will change during the different iterations, (2)employ a future focus on what the technology could be as the technologies used are often prototypes or minimum viable products (Dourish *et al.*, 2020), and (3) requires that the participants trust the promises of the researchers.

All of these are evident in Case Study 2, where the participants and researchers have a long working history, which resulted in the researchers' better understanding of the sociocultural context and livelihoods of the participants. Similarly, the participants better understood the contexts and livelihoods of the researchers over time. This, in turn, resulted in reciprocal empathy and trust which led to richer co-design partnerships and sessions. Therefore, researchers must explicitly plan dedicated time and activities to build relationships (Molapo & Densmore, 2015) and grow empathy (Till *et al.*, 2021) for researchers and participants alike (Anokwa *et al.*, 2009). Building trusting relationships and developing empathy takes time, and meaningful co-design where

participants and researchers meet each other to develop solutions to problems cannot occur in a single workshop or within weeks Till (2023). Researchers will likely have less time than they want to invest in relationship-building activities and thus will need to balance different priorities carefully (Akama & Light, 2020) as they will need to consider the time they have available for the work they need to do against the time that is necessary to ensure that the needed trusting relationships are readily in place before they start the co-design activities. From our findings in all three case studies, we can recommend working with community liaisons acting as intermediaries who already know and understand the community needs and values and have some level of trust and empathy that can assist researchers in the relationship-building process (Till, 2022b).

Furthermore, our case studies echo the findings of Schönberger *et al.* (2023), who found that participants will only be ready for co-design if they believe they can perform well. It takes a skilled researcher, who can make good methodological decisions which will assist in building participant confidence. In our case, the participants in all three studies gained confidence as they gained experience that enabled them to express themselves (Densmore *et al.*, 2022) easily. The participants in Case Study 1 greatly benefited from the design cards. In addition, the decision to halt co-design workshops and focus on co-design readiness with sensor training led to participants exploring sensors in a more authentic manner and the decision to enable the participants in Case Study 3 to experience the technology as a technology probe, prior to the co-design sessions, assisted the participants to feel comfortable with the technology beforehand. Aligned with Ortega *et al.* (2024), the increased levels of participant confidence thus assisted in the participant's ability and, therefore, skills to contribute to the co-design process.

5.3 Cultural understanding and readiness for researchers and participants

All three case studies highlighted the importance of researchers planning for cultural readiness. The findings from Case Study 1 clearly indicated how co-design sessions can easily be disrupted if the necessary knowledge regarding the participants cultural nuances (e.g., Hlonipha) is not present. Case Study 2 taught us that participants may not be aware of their own cultural values and nuances and that these values may emerge in unexpected ways with the participants indicating that they do not believe cultural norms affect technology. However the same participants were uncomfortable with cutting up fabric that represents traditional healers (Sangoma). It is also important to note that researchers might bring their own "invisible" cultural norms and beliefs to their work, which can surface unpredictably. Thus, it is advisable always to account and plan for cultural nuances, even those we are not aware of, when planning co-design sessions (Till, 2022b)

Our findings are similar to those of Winschiers-Theophilus *et al.* (2012), who found that research methods that do not consider cultural undertones are likely to alienate participants and might be othering. In Case Study 1, knowledge regarding Hlonipa (Fandrych, 2012), gender norms and community hierarchies would have been beneficial before we commenced the work done in the MCH study. These nuances resulted in a pivot in our research methods to accommodate for and work with these norms instead of working against them by attempting to execute our methods as they were intended Till (2022b). Our findings, therefore, highlight the importance of including researchers who understand the cultural nuances of the communities they co-design with Till (2022b) as readiness practices are often deeply rooted in personal histories and cultures (Akama & Light, 2020). This was evident in Case study 1 in the Limpopo province, where the community delegated leadership to the community leader known as a headsman Till (2022b); prior conversations with this community leader, asking him to use his role to encourage the community to engage directly with the researchers, would have been beneficial. Furthermore, the presence of intermediaries mitigated any cultural missteps that could have taken place both in the Kwazulu-Natal and Limpopo provinces regarding how the cultural nuances should have been handled. It is also important that researchers who conduct co-design sessions are cognisant of the fact that they may have to react ethically in unpredictable environments (Akama & Light, 2020) and pivot or evolve their methods according to the cultural values of the community (Akama & Light, 2020, Till, 2023). Long-term studies often involve constantly evolving research, methods, and participants. While Case study 1 resulted in a direct pivot of our research methods, Case study 2 resulted in the researchers slowly adjusting the research methods as they better understood the cultural nuances. This was achieved by observing and accepting that younger participants shaped their feedback and decisions considering the needs of the older and, therefore, more senior participants before they considered their own.

Considering and responding to the cultural nuances at play closely relates to value-sensitive design as researchers will need to account for human values as a principle (Friedman *et al.*, 2002). Researchers can and thus consider value-sensitive mock-ups and prototypes that will allow researchers to not only understand the cultural nuances and values of their participants but also bring them to the forefront in their work (Till, 2023).

5.4 Fostering familiarity and improving confidence with design elements through research methods

Working with new technologies can be overwhelming for communities and can introduce barriers to co-design that can be difficult to overcome. However, one can make strategic choices to select methods that can mitigate some of the technology barriers present in co-design. Our findings indicate that using materials that allow participants to express themselves easily (Densmore *et al.*, 2022) is important for successful co-design sessions. In our case, the design cards used in Case Study 1, and photos of sensors in Case Study 2 made prototyping easier because it alleviated the pressure on the participants who did not feel confident in drawing. The methods in these case studies allowed participants to use pre-developed images or photos to tell stories with arrows connecting the different pictures provided in the design cards, or the pictures of sensors and their desired actions pinned to pieces of fabric. These methods enabled easier co-design sessions by removing some barriers to the design process as well as reducing possible participant anxiety. The cards and images further served as memory joggers to remind participants of the range of sensors, stakeholders, and technologies available in the design process. These memory joggers helped the participants to ideate solutions or choose sensors. The design cards in Case Study 1 further reduced cognitive load by removing the need to first conceptualize drawings to represent the technology, person, or sensor needed for the activity (Lucero *et al.*, 2016). Case Study 2 highlighted the fact that co-design readiness may require researchers to train participants as well as enable them to experience the technologies envisioned for the study (Molapo *et al.*, 2016).

In case study 2, stopping the co-design sessions and conducting sensor training sessions not assisted in building the participants'

confidence (Mburu et al., 2018) and enabled them to take part in co-design sessions comfortably. The training and subsequent knowledge regarding sensors also resulted in the participants asking for sensors that we did not have in the sensor kit, such as conductive thread used to trace shapes and numbers to turn on LEDs (see Figure 2. This participant was able to build the learning experience she envisioned into the quilts rather than just selecting sensors for the sake of adding them. Furthermore, this same participant could pair her expertise as an ECD practitioner with the new knowledge she gained regarding different sensors' functions to co-design a solution. Using technology probes in Case Study 3 allowed the participants to experience the technology to be comfortable and confident regarding the functionality of the grow tent and mobile application. This experience enabled the farmers to provide rich, contextualized feedback and co-design technologies that would benefit them.

Methodological choices can thus empower participants for co-design (Mburu et al., 2018). We thus argue that methods that include tangible artifacts, such as design cards, images, and technology probes, are useful in supporting co-design as these methods enable the participants to express themselves easily, experience technologies to make informed decisions as well as experience the envisioned technologies in a real-world setting which enabling them to provide feedback and co-design with the researchers comfortably. Therefore, we recommend that researchers carefully consider the methods they chose to plan for the differences in power, knowledge, and skill on both the researcher and the participants to lower barriers to co-design and allow participants and researchers to combine their skills during co-design sessions. We recommend methods that allow participants to experience the technology, as demonstrated in Case Study 3. We further recommend methods that enable the participants to easily express themselves as demonstrated in Case Studies 1 and 2. The findings above are best described by Akama & Light (2020), who explains that researchers should deepen their thinking on how to prepare themselves for encounters and projects, plan for emotional turbulence, and attune to rhythms and rationales that exist in these encounters. This can only be possible we consider methods that allow for flexibility and thus provide more resilience to the needs of co-design (Akama & Light, 2020, Till, 2022b)

While it is true that co-design will never be truly equal (Moll et al., 2020), the learnings provided in this paper echo the recommendations of the *"Minimum Ethical Standards for ICTD/ICT4D"* (Dearden & Kleine, 2018) by choosing approaches that are (1) attentive to changing conditions and circumstances; (2) value critical reflections and reflexivity about the researchers' own plans, decisions, and actions during co-design sessions; and (3) ensure an openness to feedback from participants and fellow researchers paired with the willingness to change one's practices and a realization that we as researchers do not have any automatic right to study other people. At best we can endeavor to work with communities, appreciating their contextual knowledge needed to co-design technology more suited to the communities we work with.

5.5 Limitations

The studies discussed in this paper were conducted in South Africa and contain cultural nuances and references that may not be generalizable to other cultures and nations. The methods are particular to co-design and may not relate to other methods that employ design, such as user-centered design, and are representative of the people of South Africa.

6 Conclusion

This paper employed a qualitative meta-analysis to interrogate the findings of three distinct case studies in order to better articulate co-design readiness as well as provide recommendations on how researchers can make use methods and other strategic research decisions to lower the barriers to co-design. We found that both researches and participants need to be readied for co-design and that co-design readiness in rural area relies on three forms of readying. Firstly, emotional readiness which needs to be present and cultivated for both the researchers and participants. This type of readiness demands time and cannot be achieved in short stints, as it requires that researches and participants build strong relations based on mutual respect and trust. Second, cultural readiness requires that researchers obtain the necessary knowledge regarding cultural nuances that may play out during co-design sessions in rural communities. It is also important for researcher to be cognisant of the fact that participants may not be aware of their own cultural nuances and these may arise in unsuspecting ways during co-design sessions. Finally, researches need to be aware that they bring their own cultural nuances to co-design sessions that requires awareness on the part of the researcher but also consideration from the participants. The third and final type of readiness is confidence and familiarity with design elements. This type of readiness can most easily be achieved by carefully selecting methods that allows participants to easily express themselves, grow confidence in their own skill and believe that they can perform well. Finally, taking inspiration from Te Morenga (2018) who conducted co-design sessions by honoring the key Tikanga principles of the Maori community, it can be stated that co-design flourishes when:

- Respect for all involved, including the researchers is present.
- Researchers are physically seen, known to the community and willing to spend the time to gather trust.
- Researchers and participants recognize and acknowledge the unique value of each participant and protect each other's cultural and emotional safety
- Researchers and participants work in the spirit of reciprocity with genuine care for the communities whose lives they will touch.

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