IMPROVING SMARTPHONE INTERACTION IN FUNCTIONALLY ILLITERATE NIGERIAN USERS

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Doctor of Philosophy

ASTON UNIVERSITY

October 2024

Aston University
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Doctor of Philosophy, 2024

Abstract

As mobile applications become increasingly essential for financial inclusion and economic participation, ensuring they are accessible and usable for everyone is paramount. However, functionally illiterate (FXI) users, often face significant barriers to engaging with digital interfaces. While Human-Computer Interaction for Development (HCI4D) has proposed inclusive design solutions, research specific to Nigeria remains limited despite only two-thirds of its population being literate.

The objectives of this research were to explore the digital skills and challenges faced by FXI users in Nigeria and identify design techniques that enhance usability and user experience (UX) for FXI users. The research comprised two data collection studies: evaluating existing Nigerian mobile interfaces and testing custom-designed improvements. Data were gathered from a total of 50 participants (40 FXI and 10 literate users) through think-aloud protocols, screen interaction recordings, and surveys to evaluate 17 digital skills. The analysis employed a mixed-methods approach focusing on usability, UX, user interface (UI) design patterns, digital literacy, and mental models. Literate users were included to ensure challenges were not only specific to FXI users.

The findings revealed that FXI users experienced significant challenges across most of the 17 digital skills, particularly in usability metrics (e.g., error rates) and UX factors (e.g., enjoyability). Further analysis of 3 digital skills revealed that challenges stemmed from mismatched mental models based on factors like culture, language and textual literacy, and limited technological familiarity. Custom-designed interfaces developed and tested with FXI users demonstrated significant improvements, leading to design guidelines.

This research demonstrates that a mental model approach to designing UIs for FXI users promotes a shift from conventional design assumptions to human-centric solutions. In designing for FXI users, creating interfaces that align with their capabilities and context is important, recognising that established design principles may not always work in practice. These insights contribute to developing more inclusive interfaces for Nigeria's digital literacy goals and the broader HCI4D efforts to create more inclusive technologies in developing contexts.

Keywords: HCI4D, Functionally Illiterate, Mobile Interface Design, Mental Models, Usability, User Experience, Digital Literacy, Nigerian Mobile Users, Inclusive Design, User Interface Design Patterns.

Acknowledgements

Reflecting on this journey, I am grateful to all who have made this work possible.

I would like to thank my Supervision Team, without whom this work would not have been possible. Dr Victoria Uren went above and beyond before I began and throughout this journey. It was through her support that I was able to begin this PhD at all. Truthfully, this would have been impossible without her. Dr Sian Joel-Edgar always played devil's advocate, highlighting different perspectives on the ideas in this work. I also extend my gratitude to Dr Priscilla Omonedo for her valuable contributions.

I am deeply grateful to the Commonwealth Scholarships Commission (CSC) and Aston University for sponsoring this research. Special thanks go to the members of the literacy centre, who provided access and data to conduct the analysis, making this work possible.

I am especially grateful to Farat Ara, whose advocacy ensured I could begin this PhD when it was almost impossible due to COVID.

I also extend my heartfelt thanks to my family, especially my parents, who were actively involved throughout this journey. My brother, Mohammed Lamis, actively provided academic, mental, and emotional support throughout this PhD in countless ways. This PhD would not have been possible without his sacrifice and dedication to my betterment.

I want to express my sincere appreciation to EU Kvac, one of my biggest supporters, who never lets me forget what I am capable of. Special thanks to IT Mohammed, whose reflections and conversations on literacy contributed to how I approached this topic in my research. To F Oyeleke who supported me immensely while I was trying to nail a proposal and narrow the focus of the research in the beginning. To other friends who have provided support in one way or another at different points of completing this PhD: M Hamid, Z Faruk, N Ibrahim, W Alomisi, A Cho, H Abdul Mumin, and many others - thank you. To Dr A Orji, who provided legal advice on reuse at some point and Dr MS Adamu who advised on HCI4D in the African space, thank you.

I am sincerely grateful to my external examiner, Dr Steven Sam, and internal examiner, Dr Panagiotis Petridis, for their valuable feedback, time, and encouragement throughout the viva and final submission process.

I would also like to acknowledge the SW 11th-floor group who worked alongside me to attain their PhDs, particularly K Amissah, Dr M Alhumayzi, and Dr S Gallego. Our one-on-one discussions helped refine my thoughts and kept me motivated throughout this journey.

Finally, this is for all women, especially Northern Nigerian women, whose dreams are often limited by societal expectations. Be fearless.

Disclaimer

The wireframes of the mobile user interfaces provided here are to offer context to the reader and guide the discussion about user interface design. As the original screenshots may be subject to Nigerian copyright laws and are only covered by academic use, these wireframes only serve as a blueprint and are not the original mobile applications studied.

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1 Introduction

1.1 Background and Context

1.1.1 A Functionally Illiterate Society

Illiteracy remains a global issue despite increased access to literacy training in recent years, with more adults lacking literacy skills today than 50 years ago (UNESCO, 2019). Even though literacy provides the basis for a successful career, adults can become functional illiterates (FXI), a complex and less understood aspect of illiteracy. Literacy research uses various terms and definitions to categorise literacy groups. Regarding terms, low literacy is often used interchangeably with functional illiteracy, although the latter seems more widely adopted by researchers. In this research, functional illiteracy will be adopted because it better captures the specific group of interest of the study. In this research, functional illiteracy (FXI) refers to adults who can read and write to some extent in the study language but experience difficulties comprehending, applying, or acting on written information. The definition excludes individuals whose reading challenges are due solely to second-language acquisition or complete illiteracy, and it includes those with low competence in the study's measured digital skills.

A survey revealed that approximately one-fifth of the adult population aged between 16 and 65 years in 39 countries had reading skills limited to recognising single pieces of information in simple texts (OECD, 2019). An estimated 750 million people worldwide cannot read or write at a basic proficiency level, and this figure would significantly increase if those lacking the literacy skills necessary for effective participation in society are considered (UNESCO, 2019). In Nigeria, literacy rates were estimated at 62% in 2018 (UNESCO Institute for Statistics, 2024), indicating that one-third of the population is illiterate or FXI. The lack of functional literacy skills hinders societal engagement and participation due to fewer opportunities in all aspects of livelihood (Cree et al., 2023), especially in the current technology-driven world.

Regardless of literacy levels, Information Communication Technologies (ICTs) are becoming somewhat mandatory for daily activities such as financial transactions, communication, information access, driving a modern car, et cetera. In most circumstances, the adoption of ICTs is still at the user's discretion. However, a smartphone with internet access can potentially improve quality of life and simplify many things, such as online shopping, navigation, healthcare access, et cetera. Due to their affordability and versatility, these portable devices are fast becoming the most adopted form of ICTs in developing countries.

1.1.2 The Framing Model for Inclusive Design

FXI users often face significant challenges when interacting with technology, potentially exacerbating social and economic inequalities. Addressing the needs of FXI users in technology design is crucial to ensuring that digital interfaces are inclusive and usable for everyone. While categorising people as FXI is controversial and may seem discriminatory, this thesis takes the position, similar to Medhi et al. (2013), that it is essential to confront uncomfortable realities rather than maintain a false perception of equality. As such, this section sets the ethical tone of the thesis and clarifies the positionality of the writer, aiming to avoid misinterpretation. To support this section, it is important to understand why categorising people as FXI might be viewed as discriminatory or controversial. As such, this section begins by considering the different views on what literacy offers us.

Literacy is often seen as a marker of societal progress, with FXI perceived to negatively impact personal, economic, and social development (Vágvölgyi et al., 2016). Learning to read and write offers many benefits; for instance, it preserves spoken words, facilitating critical thinking and reflection (Havelock, 1963; Goody and Watt, 1963; Ong, 2002). Research in cognitive science indicates that literacy affects cognitive development, influencing phonological processing, language processing, memory, visual organisation, mental spatial orientation, and attention (Vágvölgyi et al., 2021). These aspects are discussed further in section 2.1.2 The Cognitive Side of Literacy.

However, many aspects of literacy's effects remain debated. The scientific study of FXI is controversial and rarely studied (Vágvölgyi et al., 2016). Researchers have pointed out several methodological challenges with the current studies available. For instance, most of the work on literacy effects was done in developed regions, hence subject to cultural specificity questions (Huettig and Mishra, 2014). Also, basic control variables, like intelligence, are often missing when assessing the cognitive abilities of FXI people (Vágvölgyi et al., 2016). Additionally, comparing unschooled, illiterate adults with schooled, literate adults mixes the effects of literacy and formal schooling (Dehaene et al., 2015).

Opinions vary on whether literacy's effects are due to formal schooling or literacy. Some argue that literacy's effects cannot be separated from its institutional contexts (Olson, 1994; Goody, 1987), while others suggest that Indigenous scripts taught outside formal schools can disentangle these effects (Scribner and Cole, 1981). Researchers propose distinguishing between 'proximate and distal effects': proximate effects are directly related to learning to read, such as higher phonological awareness, while distal effects, likely a result of formal schooling, include performance in memory tasks and abstract reasoning. These effects suggest that literacy is a proxy for broader experiences despite their interconnected nature (Huettig and Mishra, 2014).

The traditional notion that literacy is a primary indicator of societal progress itself has been scrutinised when considering history. For most of human history, written language did not influence cognitive processing. Not long ago, only anyone who could read and write their names was considered literate (Huettig and Mishra, 2014). Our beliefs about literacy blend fact and supposition, creating a mythology that justifies the advantages of the literate and assigns societal failings to the illiterate (Olson, 1994). The effects of literacy are clearly beneficial rather than detrimental, but simply because we live in literate societies, where literacy confers important advantages (Huettig and Mishra, 2014), such as opening bank accounts, understanding medication and food labels, interacting with technology, et cetera.

Research on the cognitive effects of literacy and technology interaction is still emerging. Current findings suggest that the cognitive skills trained by literacy might be required for effective interaction with technology. For instance, studies show that literacy levels correlate with non-verbal abstract reasoning and proficiency in navigating hierarchical UIs, even without textual elements (Skarlatidou et al., 2020; Medhi, et al., 2013). Other studies show that literate individuals outperform FXI individuals using signs and symbols in technology interactions due to prior exposure rather than the common misconception about less cognitive abilities (Saleh and Sturm, 2018). Similarly, in another study, FXI had different approaches from literates in visual searches, attributed to a different search strategy rather than a general deficit related to lesser cognitive abilities or intelligence (Olivers et al., 2014). Further discussions on technology interaction are highlighted in Chapter 3.

The complexity of understanding literacy's effects is evident. While there is evidence that literacy affects cognition, there is a gap in research linking specific cognitive abilities related to higher literacy skills to digital technology skills. Moreover, the challenges faced by FXI users may be due to experience or familiarity with ideas learned through literacy training or other factors rather than lower cognitive skills. Meanwhile, in technology design, any terms, interface design, or function unclear to its target user violates the principles of cognitive accessibility (Bevan, 1999).

Building on this discourse, the categorisation of people as FXI in this thesis is not meant to be discriminatory. However, it recognises the need to address the skills different individuals bring to the table. Despite considering various mental models to understand and redesign technology to improve FXI user performance (discussed throughout this thesis), the primary mental model throughout was *framing*. Framing presents situations or explanations based on life experiences and current situations (Weinberg and McCann, 2019). The framing of a concept or situation can change the perception of it, causing the receiver to take away different conclusions[1].

Thus, framing FXI users' difficulties in interacting with technology within this thesis considers differences in cognitive styles rather than cognitive abilities. Importantly, despite taking on this position, the writer does not infer that literacy training serves lesser value because the effects of literacy are clearly valuable in improving cognitive skills. Hence, people with varying literacy levels would have varying cognitive skills unless, as Medhi et al. (2013) argue, "the mission of education has failed". Building on this understanding, adopting the framing approach can help us move towards a more inclusive and equitable technological landscape where the abilities of all users are recognised and harnessed. Ultimately, this thesis advocates for a shift in design approach.

1.1.3 Mobile Applications in Nigeria

Mobile technology is a predominant channel for digital access in developing countries (African Union, 2020; Federal Ministry of Communications and Digital Economy, 2019). Nigeria has achieved 61.4% Internet penetration, mainly through mobile devices (Federal Ministry of Communications and Digital Economy, 2019). Africa's e-commerce growth rate is 25.8%, higher than the global rate of 16.8%. In Nigeria, the e-commerce market is growing at a rate of 25% annually, with a market potential exceeding 255 billion Nigerian Naira[2] (Olaleye et al., 2018). This rapid e-commerce growth has fuelled the development and adoption of mobile applications, making them increasingly popular for various services, including banking and shopping, as consumers seek convenient ways to engage in online transactions.

1.1.3.1 Mobile Banking and Microfinance in Nigeria

The rapid growth of mobile devices for person-to-person payments has positioned mobile channels as key to financial inclusion in Nigeria. Mobile payments have significantly expanded commerce among financially included and excluded segments of the Nigerian economy (Central Bank of Nigeria, 2021). Electronic payment transactions surged to N600 trillion in 2023, a 55% increase from N387 trillion in 2022 (NIBBS, 2024). This shift from cash-based to

[1] See the essay ‘Common Sense’ by Thomas Paine as an example from history to illustrate the effectiveness of framing (Weinberg and McCann, 2019).

[2] Approximately 120 million GBP as of October, 2024.

electronic transactions was driven by the increasing adoption of mobile banking applications and USSD[3], as well as cash scarcity (NIBBS, 2023).

All Nigerian banks have adopted mobile banking applications with impressive reception (Siano et al., 2020). Popular mobile banking applications include Diamond Mobile Banking, Stanbic IBTC Mobile Banking and First Bank Mobile Banking (Siano et al., 2020). The Central Bank of Nigeria regulates these services, ensuring technology and user interface standards (Central Bank of Nigeria, 2021).

Despite this growth, the adoption of these technologies remains relatively low, especially due to factors such as inadequate infrastructure, low literacy levels, security concerns, cultural factors, high transaction costs, limited digital literacy, lack of awareness, system design complexity, visibility of benefits, and resistance to change, particularly among older and less-educated individuals (Daniyan-Bagudu et al., 2017; Prince et al., 2019; Omotosho, 2021; Siano et al., 2020; Mukalayi and Inglesi-Lotz, 2023; Osirim et al., 2023).

Interestingly, Nigerian banks often target the market segment that does not present the most challenges, such as younger, more educated customers, such as university students, who are more tech-savvy (Ikpuri, 2018; Adekunle et al., 2023).

Despite system design complexity and literacy levels identified as factors influencing the adoption of mobile banking applications, not many studies have focused on understanding these applications' usability and user experience. Most studies that research mobile banking in Nigeria focus on understanding the factors related to adopting these services and heavily rely on surveys to achieve this aim (Omotosho, 2021).

One of the few studies that have taken a user experience approach analysed 37,460 user reviews on Nigerian mobile banking applications. The findings revealed an average user rating of 3.5 out of 5. Positive sentiment words dominate the corpus, indicating a high level of user satisfaction, with 'trust', 'anticipation', and 'joy' being the most prevalent emotions (Omotosho, 2021).

The only study that took on an experimental approach to compare mobile banking applications with FXI users showed that existing Nigerian mobile banking applications were ineffective for novice and FXI users, revealing a significant gap between research-based design recommendations and current designs. Their study showed significant improvement in FXI user performance with a prototype featuring shorter transaction lengths, consistent input region formatting, and simplified functionality (Adama et al., 2017).

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[3] USSD (Unstructured Supplementary Service Data) is a technology mobile network operators use to provide services such as mobile banking and other financial services without requiring an internet connection. It works by sending text-based commands through a dial-up menu on a mobile device

The current landscape of the Nigerian banking systems indicates a need to focus on improving several aspects, such as design that meets the needs of all users. The approach taken by banking institutions to focus on younger and more tech-savvy audiences may neglect people like FXI users rather than prioritising improvements in design and outreach to accommodate a broader range of users.

1.1.3.2 Mobile Shopping in Nigeria

The growth of mobile applications for activities like shopping in Nigeria positively impacts the economy by providing jobs, building an efficient postal network, and encouraging Pan-African trade (Olagunju et al., 2020). For instance, Jumia, a leading e-commerce platform in Nigeria, employs over 3,000 local workers, and collectively, e-commerce companies have created more than 12,000 jobs since 2012 (Olaleye et al., 2018). Other popular shopping platforms include Konga and Jiji (Igwe et al., 2021).

Despite this growth, the e-commerce sector in Nigeria is still in its infancy, with many platforms only currently evolving (Olagunju et al., 2020; Ibam et al., 2018; Esho and Verhoef, 2021). Research indicates that Nigerians increasingly use online platforms to gather information and compare prices but prefer making purchases in offline stores (Oloveze et al., 2022; Esho and Verhoef, 2021). However, the uptake of e-commerce is expected to continue to evolve due to Nigeria's large and youthful population (Igwe et al., 2021). This is supported by findings that Nigerian youth favoured online shopping due to its convenience and the availability of objective reviews from other buyers compared to offline shopping (Chris-Nnamchi et al., 2021).

However, several technological issues, such as payment platform issues, application crashes, and poor search algorithms, hinder the adoption of mobile shopping applications in Africa (Olagunju et al., 2020). In Nigeria specifically, several challenges hinder the adoption of online shopping, including concerns about product quality, a lack of technical knowledge, delivery times, refund policies, internet connectivity issues, insufficient cyber-crime legislation, and trust and security concerns with online payments (Ezennia and Marimuthu, 2020; Olaleye et al., 2018; Oloveze et al., 2022).

To address the concerns related to online payments, Nigerian shopping platforms often provide cash payments on delivery. This is perceived as a safer option due to trust issues (fear of non-delivery) and security concerns (e.g., fear of card information theft) with online payments (Olaleye et al., 2018; Chris-Nnamchi et al., 2021).

Researchers have also noted issues relating to the design of shopping platforms. A study found that platform quality (usability and UX) and trust in vendors both positively affected Nigerian consumers' online shopping intentions, with platform quality being more crucial (Esho and Verhoef, 2021). Their research suggests that low trust in online vendors contributes to Nigeria's low online retail penetration (Esho and Verhoef, 2021). Consumers often equate high-quality platforms with trustworthy vendors, indicating that merchants should improve platform quality to align with consumers' perceptions of 'high quality.' Additionally, the simplicity and ease of navigating shopping platforms play a crucial role in driving the intention to use online shopping (Oyekunle and Kolo, 2019; Oloveze et al., 2022; Olaleye et al., 2018). Moreover, limitations relating to user freedom, consistency, and error prevention in the designs of mobile applications pose challenges (Oyekunle and Kolo, 2019).

Therefore, the design of mobile shopping applications is crucial. The quality of Nigerian consumers' experiences with an online shopping platform strongly influences their future online purchase intentions (Cosmas et al., 2019; Esho and Verhoef, 2021). Further research is needed to understand the use of mobile shopping applications by FXI users in Nigeria, as previous studies have solely focused on Nigerian users in general rather than FXI.

1.2 Research Problem

1.2.1 The Digital Divide and Digital Literacy

Despite the widespread acceptance of Information and Communication Technologies (ICTs) in our societies and their potential benefits to livelihoods, a significant digital divide persists among FXI regarding ICT usage. The term "digital divide" refers to "the gap between individuals, households, businesses and geographic areas at different socio-economic levels with regard to both their opportunities to access ICTs and to their use of the Internet for a wide variety of activities" (OECD, 2001). A report by The World Bank Group (2021) revealed that while 70% of Africa's population has access to mobile Internet, only about 25% utilise it, signifying a 50% gap in usage despite high access percentages (World Bank Group, 2021). This indicates a significant digital divide persisting in Africa despite available access to mobile Internet.

Bridging the digital divide in Africa necessitates building digital literacy capabilities and formulating policies that enhance digital inclusion. Digital literacy entails "the ability to access, manage, understand, integrate, communicate, evaluate, and create information safely and appropriately through digital technologies for employment, decent jobs, and entrepreneurship" (Law et al., 2018). Addressing digital literacy is key to stimulating the participation of excluded groups in the technological landscape and moving the continent towards a digital economy. As a result, several policies have emerged to move Africa to a digital economy. For instance, the Digital Economy for Africa (DE4A) Initiative, formed by the World Bank to support the African Union's Digital Transformation Initiative for Africa, aims to digitally enable every African person, business, and government by 2030 (The World Bank Group, 2019). This initiative aligns with the United Nations' Sustainable Development Goal (SDG) thematic Indicator 4.4.2, which is to attain at least a minimum level of proficiency in digital literacy skills in youth/adults (African Union, 2020).

Specifically, Nigeria itself has initiated efforts to transition to a digital economy. The National Digital Economy Policy and Strategy (NDEPS) aims to achieve 95% digital literacy in Nigeria by 2030. This plan targets areas such as financial inclusion, eGovernment, people living with disabilities, and other digitally excluded people (Federal Ministry of Communications and Digital Economy, 2019). Similar to the digital economy plan developed for 2020, the focus of the NDEPS 2030 initiative is on improving infrastructure and teaching digital literacies through computers as the main access devices to ICTs. This approach is relevant because it addresses some of the major contributors to the digital divide highlighted by a UNESCO report, including lack of infrastructure, low incomes and affordability, low user skills, and lack of motivation (Vosloo, 2018).

However, despite the outlined policies, Nigeria has not achieved the predetermined digital economy goals. A report by the World Economic Forum in 2018 showed that Nigeria ranks the lowest among its regional peers in digital literacy skills (The World Bank Group, 2019). While there have been infrastructure improvements, such as upgrading coverage areas to 4G networks, other contributors to the digital divide, such as low incomes and affordability, low user skills, and lack of motivation, have not received enough attention or progress. Addressing these factors is crucial as they significantly affect a digital economy. Accessibility and affordable infrastructure are foundational to achieving inclusive digital transformation (African Union, 2020). For instance, low incomes limit access to computers due to affordability issues, particularly for populations residing in remote areas with limited internet coverage. Failing to consider these factors in the 2030 plan mirrors the shortcomings of the 2020 approach.

1.2.2 Access and Usability

Returning to the major contributors to the digital divide highlighted above (lack of infrastructure, low incomes and affordability, low user skills, and lack of motivation), mobile phones present an affordable and accessible solution to a significant portion of the Nigerian population despite existing infrastructure challenges. At least 50% of mobile subscribers own more than one SIM card to navigate issues with the quality of internet service in Nigeria (Gillwald et al., 2018). This underscores how individuals in remote areas adapt to existing infrastructure challenges to access technology. There is a necessity to leverage the available infrastructure, as Nigerians have demonstrated resilience in overcoming current challenges.

Despite the increase in the penetration of mobile phones and the opportunities they offer, a digital divide persists in ICT usage. Across Africa, 70% of people who do not use the Internet cite a lack of understanding of how to use it (Vosloo, 2018). This gap exists because access to ICTs does not automatically translate into possessing digital skills beyond the most basic ones (The World Bank Group, 2019), implying limited digital literacy skills. Moreover, Medhi observed that many FXI users use only a few features, such as making and answering phone calls on mobile phones (Medhi, 2017). This finding is supported by usability studies conducted in developing countries, which suggest that mobile phones are difficult to use for FXI (Bayor et al., 2018; Medhi, 2015). This indicates that usability is a barrier to mobile phone use for FXI, consequently contributing to the digital divide.

Researchers have identified factors contributing to difficulties with usability in ICT usage for FXI. These include cognitive differences compared to literate users (Boltzmann et al., 2017), socio-cultural factors (Eme, 2011; Vágvölgyi et al., 2016), limited education (Medhi, 2015), and competency loss (Thatcher and Ndabeni, 2005). These skills gaps are some of the core skills necessary to interact with ICTs (Van Laar et al., 2017). This implies significant implications for technology design that focuses on the needs of FXI users.

1.2.3 User Interface Design

User interface (UI) design is a critical aspect of technology design, shaping how users interact with their devices and affecting overall usability and user experience. UIs on smartphones consist of visual and interactive elements that facilitate this interaction, including icons, menus, buttons, gestures, and other graphical components (Rogers et al., 2023). These elements, known as UI design patterns, are standardised solutions to common usability problems and play a crucial role in developing smartphone applications (Hoober and Berkman, 2011).

However, many current UI design patterns fail to meet the specific needs of FXI, often neglecting issues such as limited literacy, cultural differences, and technological unfamiliarity. The plug-and-play nature of these patterns means unsuitable designs are frequently reused without considering the diverse needs of users or the application context (Hoober and Berkman, 2011).

Moreover, translating desktop UI principles directly to mobile interfaces exacerbates usability issues for FXI users (Punchoojit and Hongwarittorrn, 2017). Desktop interfaces, designed for larger screens and different interaction mechanisms like a mouse and keyboard, do not translate well to the touch-centric, small-screen environment of smartphones (Hoober and Berkman, 2011). This direct adaptation can result in unintuitive interfaces for mobile users, particularly FXI users who experience difficulties with complex interaction patterns designed for more sophisticated desktop environments.

Accessibility options (such as options for navigation) are not helpful in interacting with interfaces effectively because most barriers are related to the complexity of UIs (e.g., unrecognisable icons, deep navigation hierarchies, and complex task sequences) in addition to challenges that are related to understanding textual information by FXI users (Punchoojit and Hongwarittorrn, 2017; Bayor et al., 2018; Hollinworth and Hwang, 2009).

Additionally, many UIs are designed based on the capabilities and interests of Western cultures, making them challenging for individuals from different cultural backgrounds to comprehend (Smith et al., 2021). As noted by researchers, "paradigms inherent in mainstream information and communication technologies (ICTs) are based on urban, Western values, logics and literacies directly implemented in internal structures such as information architectures, databases, meta-data and knowledge representations" (Winschiers-Theophilus, et al., 2012). It is well understood that the fundamental principles of human-computer interaction (HCI) design originated in the developed world and do not directly translate to the developing world when creating usable and relevant systems (Ghosh, 2016).

This cultural mismatch means that visual cues, such as icons, might be meaningless to FXI users, potentially leading to guesswork, frustration, and anxiety. Notably, this negates the aim of having visual cues on the UI in the first place, especially for FXI, given their difficulties with understanding complex texts.

To address these challenges, UI designs must prioritise understanding the needs of FXI users, ensuring equitable access to smartphone technology for all users. While initiatives like Nigeria's Digital Literacy program focus on improving digital literacy mainly through education, they often neglect the design of digital technologies themselves. Usability is a key factor in digital illiteracy, and functional illiteracy significantly impacts usability. By focusing on the specific needs of FXI users, we can ensure that digital literacy initiatives are more inclusive.

Some might argue that functional illiteracy is not a usability or accessibility problem but a socio-economic issue that should be tackled through education and the efforts of humanitarian bodies such as UNESCO. However, technology development cannot ignore this user group despite the socio-economic nature of the issue. In design principles for inclusiveness, Stephanidis and Savidis (2001) define users as *all* people (Stephanidis and Savidis, 2001). Additionally, based on statistics as introduced at the beginning of this thesis, FXI make up a significant portion of the population in Nigeria (i.e., one-third is considered either illiterate or FXI); it is crucial to develop technology that is accessible and user-friendly for everyone.

Consequently, my research is positioned within the Human-Computer Interaction for Development (HCI4D) field, focusing on addressing the challenges of UI design for FXI users.

1.2.4 Human-Computer Interaction ‘for’ Development (HCI4D)

Human-Computer Interaction for Development (HCI4D) addresses the complex challenges of designing technologies for developing communities (Dell and Kumar, 2016). At the intersection of ICT4D and HCI, this research leverages interdisciplinarity to tackle these challenges. HCI4D learns from the limitations of low-resource contexts, navigating through constraints to develop effective solutions (Dell and Kumar, 2016). Through its connection with HCI, it focuses on human factors, while its ICT4D link ensures a commitment to designing, implementing, and evaluating technologies for development.

Several core themes have emerged in HCI4D studies, with "context," "design," and "development" central to differentiating HCI4D as a research area (Van Biljon and Renaud, 2021). Understanding and designing technologies for underserved, under-resourced, and under-represented populations involves addressing user needs, engaging in cross-cultural design (Ho et al., 2009), acknowledging limited resources and considering feasibility (Toyama, 2010). These issues are interconnected, and most HCI4D research references all three (Van Biljon and Renaud, 2021).

Central themes in HCI4D encompass addressing constraints like limited ICT infrastructure, poor connectivity, and high costs (Nabi, 2013); navigating the practice of sharing ICTs in low resource settings (Rayed et al., 2023); accommodating culture and language differences in technology use (Ghosh and Joshi, 2014); understanding socio-cultural factors influencing technology adoption (Ghosh, 2016); integrating theoretical frameworks for enhanced understanding (Belay et al., 2016); and addressing literacy barriers (Islam et al., 2020). Literacy, particularly illiteracy and functional illiteracy is a recurring theme in HCI4D and considered one of the greatest challenges in the field (Medhi et al., 2010).

My research fits within some of these HCI4D themes by focusing on the intersection of UI design and functional illiteracy among Nigerian users. By exploring FXI users' unique challenges in a developing community, my work aims to contribute to the broader HCI4D discourse on designing technologies for such communities.

Although my research does not directly address cultural, language, and socio-cultural influences at the onset, it finds these aspects later in its results as they are common in HCI4D studies, thereby contributing to understanding the barriers FXI users face.

Moreover, my research aligns with the interdisciplinary nature of HCI4D themes, addressing the lack of theoretical focus in current discussions. This involves adopting a digital literacy perspective while applying frameworks, such as mental models, to critically assess the design and use of technology for FXI users. By aligning with these HCI4D themes, my research seeks to bridge the gap between technology design and the needs of developing communities, ultimately contributing to more inclusive and equitable technological development.

1.3 Research Questions and Objectives

Given the prevalence of FXI in Nigeria and the increasing reliance on smartphones, this research addresses the critical need to understand how FXI user interaction can be improved through thoughtful design. Specifically, the focus is on investigating more inclusive UI design patterns tailored to the unique challenges faced by Nigerians FXI when using mobile banking and shopping applications on smartphones. To guide this exploration, we pose the following research questions:

1. What UI design patterns cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?
2. What design techniques can improve interaction for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

To answer these questions, this research aims to achieve the following objectives.

1. Propose a practicable definition and assessment for functional illiteracy in HCI4D.
2. Explore the experiences and challenges of FXI and assess the effectiveness of the current mobile applications' UI design in meeting the needs of FXI users.
3. Identify the essential digital skills required for completing the essential tasks on mobile shopping and banking applications.
4. Evaluate the UX of mobile banking and shopping applications for FXI users.
5. Investigate design techniques that render mobile applications more usable and provide a better UX for FXI users.

1.4 Contributions to Knowledge

This research **addresses a critical gap in the field of HCI4D, particularly concerning the unique challenges faced by FXI users in Nigeria when interacting with mobile banking and shopping applications**. While previous studies have explored difficulties in UI interaction for FXI users, they often lacked a comprehensive perspective of the underlying reasons for these difficulties and design rationales for solutions, particularly in the Nigerian context. This gap presents a potential missed business opportunity, as effective UI design holds significance not only for usability but also for economic growth.

Research has demonstrated the business value of effective user interface/experience design. Poor UI/UX design directly impacts business revenue: 22% of US online shoppers have abandoned purchases due to 'too long/complicated checkout processes,' with improved checkout design potentially recovering $260 billion in lost orders across US and EU e-commerce, representing a potential 35% increase in conversion rates (Baymard Institute, 2024).

To contribute to bridging this gap, **the originality of this work lies in its approach to understanding and designing for FXI users.** The **core contribution of this thesis, therefore, is the provision of a context-sensitive lens on mobile application design for FXI users in Nigeria.** By adopting a mental model-based approach, this research **shifts the paradigm from designer-centric assumptions to user-centric realities, providing a new framework for framing technology interaction based on users' existing knowledge and experiences**. This approach **challenges traditional assumptions about currently established interface usability, redefining what constitutes a "usable" interface for diverse user groups**.

This research is particularly significant given the rapid growth of mobile technology in developing countries like Nigeria, where FXI rates are high. As mobile applications become increasingly crucial for financial inclusion and economic participation, ensuring these technologies are accessible and usable for FXI users is important. By addressing the specific needs of this marginalised group, this study contributes to bridging the digital divide and promoting more inclusive technological development.

Moreover, this work is significant because it extends beyond identifying challenges to offering practical solutions. By developing and empirically evaluating custom UI prototypes, this research offers tangible examples of how interfaces can be designed to better serve FXI users. This practical approach, grounded in theoretical understanding, provides valuable guidance for designers, developers, and, potentially, policymakers.

The contributions of this study are multifaceted:

- **Theoretically**, this research **extends mental model theories** by revealing **unique characteristics of FXI users' cognitive approaches to mobile interfaces**.
- **Methodologically, it introduces a structured approach for conducting ethical and rigorous HCI4D research with vulnerable user groups**, including new participant recruitment and data collection strategies.
- **Practically**, this research provides **actionable UI design guidelines and evaluated prototypes to create more usable interfaces for FXI users**, **expanding inclusive design principles**.
- **Empirically**, the **assessment of 17 digital skills** provides a **comprehensive understanding of the specific challenges FXI users face** in mobile banking and shopping applications, offering **critical reference points for future research, design, and policy efforts**.

Overall, this study **advances our theoretical understanding of FXI users' interactions with mobile interfaces and provides practical guidelines for creating more inclusive digital experience**s. By bridging the gap between users' mental models and interface design, particularly for marginalised groups like FXI users, this research **paves the way for more inclusive, ethical, and effective digital interfaces in diverse global contexts**.

1.5 Study Scope and Delimitation

This research investigates the usability challenges faced by FXI users in Nigeria when interacting with mobile banking and shopping applications. The study explores usability and user experience issues, digital literacy competencies, and user interface design patterns with the aim of improving usability and user experience for FXI users in mobile applications.

The selection of mobile banking and shopping applications was driven by their critical role in digital inclusion. Financial transactions, particularly digital payments, are fundamental to advancing Nigeria's digital economy (The World Bank Group, 2019; Federal Ministry of Communications and Digital Economy, 2019), making mobile banking a high-impact area for FXI users. Similarly, e-commerce is rapidly expanding, yet research on FXI users' engagement with shopping applications remains limited (Chaudhry et al., 2021). Given the risk of digital exclusion, evaluating FXI users' ability to navigate these platforms is essential.

In this study, FXI refers to adults who can read and write to some extent in the study language but experience difficulties comprehending, applying, or acting on written information. The definition includes those with low competence in the study's measured digital skills. The study excludes individuals who are entirely illiterate (i.e., those with no reading and writing skills at all), those who are digitally illiterate but literate in reading and writing, and those whose literacy challenges stem from language barriers rather than functional illiteracy. This definition is adapted from prior literacy and HCI research but is specifically tailored to the context of mobile technology use.

The literature review encompasses some background on the Nigerian context, FXI users, digital literacy, HCI4D, and usability barriers in mobile interactions. Studies focusing on non-graphical user interfaces (GUIs) (e.g., gesture-based interfaces), desktop computing, accessibility for other marginalised groups (e.g., people with disabilities), children or general literacy interventions were excluded, as they fall outside the specific focus on mobile usability for FXI users.

A key delimitation of this study was the inclusion of only English-speaking participants who were not literate (i.e., in terms of reading and writing skills) in any other language. English was selected because, with over 515 languages spoken across Nigeria, choosing a single study language was necessary. Additionally, as Nigeria's official language, English is widely used in financial, commercial, and digital services, including most mobile applications. Because the chosen applications serve financial and commercial functions (sectors where English predominates), most digital platforms in Nigeria are developed in English.

This decision was not intended to exclude non-English-speaking individuals or reinforce the digital divide. Rather, it aimed to ensure that observed usability challenges were directly related to functional illiteracy, not second-language acquisition difficulties. This distinction prevents the misclassification of language barriers as functional illiteracy, as highlighted in prior research (Vágvölgyi et al., 2021).

Importantly, participants were not excluded based on their spoken English ability but based on low proficiency in processing written text. This allowed the study to maintain its focus on the effects of user interface design and functional illiteracy gaps.

1.6 Thesis Outline

In Chapter 2, I lay the foundation by reviewing the cognitive side of literacy in cognitive research and current practices in defining FXI in HCI/4D. This provides the foundation for proposing a definition and assessment method for functional illiteracy within the context of this research and for HCI4D. Following this, I provide additional context on the Nigerian ICT sector, FXI in Nigeria and the cultural aspects shaping smartphone interaction in Nigerian FXI users.

In Chapter 3, I discuss the theoretical aspects of HCI and HCI4D within the context of designing user interfaces, with a focus on the role of the user in design. I conduct a review of related literature, exploring the challenges faced by FXI and the solutions provided by researchers in the field of HCI4D. This review encompasses aspects influencing their ability to interact with UIs on mobile devices. Additionally, I examine the theoretical underpinnings that guide my research, such as the Digital Literacy Global Framework (DLGF), user interface design patterns, and the relevant HCI design models and theories.

Chapter 4 serves as the methodological design for my research. I explain the research methodologies employed throughout my study, which consisted of three distinct phases: Study 1, Study 2, and Study 3. I clarify that data collection occurred in two phases: Studies 1 and 3. Study 2 primarily focused on the analysis and design stages that paved the way for Study 3. Within this chapter, I provide a rationale for the chosen research methods across all three studies, underscoring a logical progression in the research process. This section ensures that each phase of the study builds upon the insights and developments of the previous phases.

In Chapter 5, I introduce my first study, which involves data collection (Study 1). I evaluate seventeen (17) digital skills among FXI individuals in Nigeria. The chapter outlines the processes I employed to identify the three most challenging digital skills. These identified challenges become the focal point for subsequent chapters.

I dedicate Chapters 6, 7, and 8 to address the top three most challenging digital skills identified in Chapter 5, with one chapter dedicated to one skill. In each chapter, I consistently follow a structure that begins with an in-depth exploration of the identified skill. I integrate Studies 2 and 3 together to focus the readers' attention on the details of only one digital skill at a time. As such, the initial study aims to investigate the underlying reasons for the difficulties associated with this skill, subsequently outlining the development of a conceptual model to improve these challenges (Study 2). This conceptual model transforms into an interactive prototype, which undergoes testing with individuals possessing functional illiteracy to evaluate its effectiveness in mitigating these challenges (Study 3).

In Chapter 9, I synthesise the results from the empirical studies conducted in Chapters 6, 7, and 8. I provide a discussion that addresses the research questions. Additionally, I present a set of tailored design guidelines aimed at catering to the unique needs of users with functional illiteracy, highlighting the practical implications of my research.

Lastly, in Chapter 10, I provide an overview of the contributions made by my thesis. Here, I summarise the research by reflecting on its implications and suggesting potential avenues for future exploration. The thesis concludes with the inclusion of appendices and a list of references.

To provide a clear overview of this thesis's structure and the relationships between its sections, Figure 1 presents a visual thesis flow map. This map illustrates each chapter's role in addressing the research questions, allowing readers to understand how the various studies and analyses contribute to the overall research narrative.

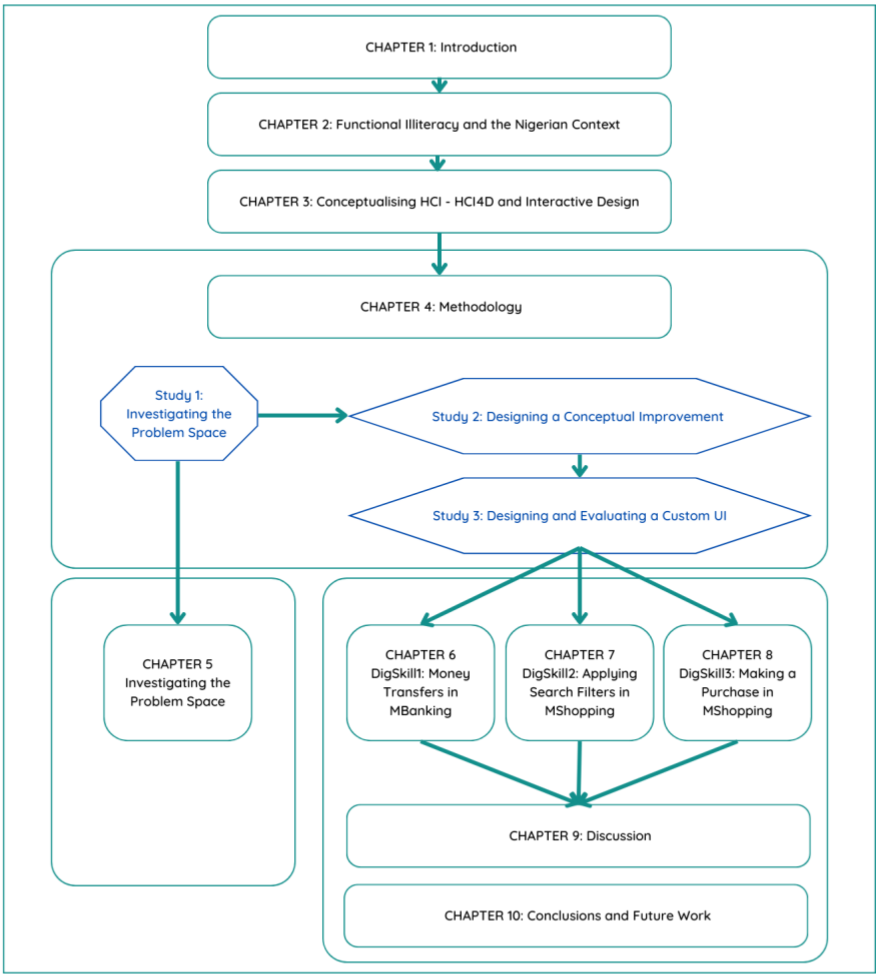

Figure 1: Thesis Structure Overview – Research progression and chapter interconnections.

The thesis flow map will be referenced from Chapter 5 onwards, following the Methodology chapter. The initial four chapters: Introduction, Functional Illiteracy and the Nigerian Context, Conceptualising HCI -HCI4D and Interactive Design and Methodology, follow a straightforward structure typical of academic research. From Chapter 5, where I present specific studies and analyses, the flow map will aid readers in understanding the interconnections between research components.

Building on the context and significance of the study established in this introduction chapter, the next chapter reviews relevant literature to provide the theoretical foundation for this research and identify the gaps in current knowledge that this work aims to address.

2 Functional Illiteracy and the Nigerian Context

This chapter presents the conceptual and contextual foundations for understanding functional illiteracy (FXI) in this research. It begins by defining functional illiteracy through a review of HCI and cognitive and literacy-related literature, leading to a proposed definition of FXI, which is used in this study. Building on this, the chapter then shifts to the Nigerian context, examining the country's digital infrastructure, FXI usage patterns, and socio-cultural conditions. Together, these sections provide the necessary framing to situate FXI within theoretical and practical domains and inform the design considerations explored in later chapters.

2.1 Understanding Functional Illiteracy

Functional illiteracy is a complex and less understood aspect of literacy. Within the HCI/4D community, there is no coherence in the definition and assessment of literacy in published literature despite functional illiteracy being one of the significant challenges in HCI research. Researchers often interchange terms such as 'functional illiterates,' 'low literates,' and 'semi-literates,' further complicating the field (Mohammed et al., 2023; Guimarães et al., 2022; Srivastava et al., 2021). A systematic literature review of 33 HCI studies revealed concerns about the absence of a definition in 41% of the studies and the lack of measurement technique in 74% (Mohammed et al., 2023). Similarly, while industry reports and academic literature provide insights on designing user interfaces for such users, these insights are scattered (Srivastava et al., 2021). This lack of standardised criteria obstructs the clear conceptualisation of user needs and appropriate design solutions (Srivastava et al., 2021).

To address this gap, the following sub sections contribute to understanding FXI user characteristics, leading to an operational definition. As such, this sub section addresses one of the research objectives highlighted in section 1.3, which is to define and measure functional illiteracy in HCI4D studies.

2.1.1 Defining Literacy

Several HCI researchers define literacy in terms of level of education (Medhi, 2015). For example, individuals with low literacy levels have been classified as those who have not attained a formal education above Grade VII, making this a basis for the assumption of whether they can read or write in previous research (Medhi et al., 2011). However, research shows that the ability to read does not always depend on the level of education, meaning that it is more complex than a cause-and-effect relationship (Medhi, 2015; Colter and Summers, 2014). This is because the level of education an individual possesses depends on a variety of factors, which include the institution attended, the quality of teaching delivery, family support and environment, effort dedicated to learning, genetics, and attendance (Medhi, 2015; Vágvölgyi et al., 2016). Moreover, negative experiences relating to childhood school and family environment do not apply to all individuals; hence, they are not enough to define a person as FXI (Eme, 2011). Hence, although there is a higher likelihood for individuals who did not finish high school to be FXI, participants still must be assessed to verify their literacy levels (Colter and Summers, 2014).

Due to these factors' complexities, most HCI researchers use the ability to read and write (textual literacy) as the benchmark for literacy (Medhi, 2015; Ahmed, 2011). However, researchers have argued that defining literacy based on the ability to read and write depends on what is being studied, using an example to explain that in this definition, a literate person might be unable to read a newspaper or operate computers (Thatcher and Ndabeni, 2005). The researchers further argued that this definition is relative to an individual's native language. This implies that for a society like Nigeria, which has multilingual persons, a person could be literate in a language that is not necessarily the lingua franca (English). This also means that operating a basic computer might prove difficult, although a person cannot be classified as an illiterate based on the definition of 'read and write' (Thatcher and Ndabeni, 2005).

Other researchers define literacy in terms of types. For example, researchers introduced an approach based on how literacy will be applied, such as information literacy, media literacy, technology literacy, computer literacy, and even mobile phone literacy (Thatcher and Ndabeni, 2005). This has led to an approach of definitions based on multiple literacies, which refers to the ability of people to possess diverse skills in various media and technology (Thatcher and Ndabeni, 2005) that support diversity in culture and language (Fellowes and Ardoin, 2019). More so, multi-literacies are argued to be best suited for the skills required for the 21st century (Ahmed, 2011). These literacy definitions are classified under the universal definition of 'functional literacy' (Thatcher and Ndabeni, 2005).

According to a UNESCO report, functional literacy is based on the notion that literacy should not be the overall aim by itself but must be targeted towards a specific goal (for instance, social or personal improvement) (Zelezny-Green, 2018). This means that a person requires reading and writing skills to accomplish a particular goal, such as searching for medical information online. The goal varies considerably based on the users and the technology itself (Thatcher and Ndabeni, 2005). In a review on functional illiteracy, most definitions focused on an impaired understanding of texts (Vágvölgyi et al., 2016).

A FXI is defined as a person who cannot "understand complex texts despite adequate schooling, age, language skills, elementary reading skills" (Vágvölgyi et al., 2016). This does not mean they are completely unable to read; a majority can, but they read very poorly and slowly (Eme, 2011; Colter and Summers, 2014). This is more apparent in skills such as word recognition, understanding sentence structure, locating information within written text, forming theories, transferring information learned to personal situations, and using calculations to draw meaning (White, 2003, cited in Colter and Summers, 2014). This leads to incomplete or wrong conclusions from what they have read (Eme, 2011). These incapacities should not result from sensory, cognitive, neurological, or mental disorders (Vágvölgyi et al., 2016).

The underlying causes of functional illiteracy have not been formally established. Research has found that social/financial status, living conditions, and coping mechanisms influence functional illiteracy, especially regarding technology interaction (Medhi, 2015). The lack of motivation and encouragement to acquire new skills in children's development can lead to a lifestyle of unmotivated learning in institutions (Vágvölgyi et al., 2016). Also, a lifestyle of not applying literacy in adulthood could result in the loss of competencies, indicating decreased cognitive demands (Vágvölgyi et al., 2016). This suggests that unless literacy is practised and applied continuously, there is a high probability of perishability (Ardila et al., 2010; Castro-Caldas, 2004; Thatcher and Ndabeni, 2005). Other social factors that influence the understanding of literacy include cultural issues, such as oral traditions or technology acceptance (Medhi, 2015; Thatcher and Ndabeni, 2005). Other researchers have suggested that formal education, which facilitates literacy, influences the development of cognitive skills (Vágvölgyi et al., 2016).

2.1.2 The Cognitive Side of Literacy

Literacy profoundly influences various cognitive processes, shaping how we perceive, remember, and interact with the world around us. Cognition-specific processes include attention, perception, memory, learning, reading, speaking, listening, problem-solving, planning, reasoning, and decision-making (Eysenck and Brysbaert, 2018). It is important to note that many of these cognitive processes are interdependent, often working together for a given activity rather than occurring in isolation. For instance, when reading a book, one must attend to the text, perceive and recognise the letters and words, and make sense of the sentences. Among these processes, attention and memory are particularly relevant for interaction design (Sharp et al., 2019). The study of human cognition can provide insights into various digital behaviours, such as decision-making, searching, multitasking, and designing when using computer technologies, by examining human abilities and limitations.

One study that clearly demonstrates the connection between literacy (specifically reading skills) and cognitive skills involved FXI adults, who were found to have several structural abnormalities in brain areas related to reading due to low literacy skills. After undergoing literacy training, these individuals showed improved cognitive skills on several metrics, and the previously documented structural differences disappeared (Boltzmann et al., 2017). Similar findings were reported in older research (Ardila et al., 2000).

In the following sections, I will provide an overview of the main kinds of cognitive processes related to literacy research. Understanding the differences in cognitive processes among users of digital technologies due to varying literacy levels can significantly impact usability and UX, necessitating a design approach tailored to the abilities of FXI users.

2.1.2.1 Visual Processing and Perception

Previous works have highlighted how literacy influences the ability to discern details in visual stimuli (Huettig and Mishra, 2014; Dehaene et al., 2015). Specifically, literacy fosters "repetition suppression," enhancing the rapid identification of similar items, an advantage seen more prominently in literate individuals (Dehaene et al., 2015). Such findings underscore the profound influence of literacy on not only reading but also on how the brain processes visual information.

Literacy significantly influences one's approach to analysing visual stimuli, often derived from detail-oriented reading experiences (Dehaene et al., 2015). Visual scanning is related to reading and writing habits, as LIT tend to employ a top-bottom, left-right approach when scanning visually. Those with limited reading habits tend to scan differently and use a less structured approach. This finding is dependent on the type of script learned. For instance, the Arabic script might mean individuals scan from the right-left instead (Olivers et al., 2014). Additionally, LIT individuals exhibit a higher proficiency in recognising changes in the order or arrangement of letters or symbols, demonstrating a refined sense of the relative positions of these elements in a sequence (Huettig and Mishra, 2014). This ability proves valuable in tasks requiring problem-solving and attention to detail.

Additionally, the outcomes of grammatical training in language acquisition, which varies across societies, significantly influence how people process visual information. Literacy enhances visual integration capabilities, allowing individuals to adeptly combine segments into meaningful shapes or patterns (Szwed et al., 2012). This capability proves beneficial in tasks requiring pattern recognition and spatial understanding. Dehaene's findings show that individuals with limited reading skills tend to adopt a holistic rather than an analytical approach when looking at visual stimuli (Dehaene et al., 2015).

The dichotomy between analytical and holistic thinking styles plays a pivotal role in guiding individuals' navigation of websites. Research demonstrates that individuals with an analytical thinking style, more prevalent in Western cultures, tend to navigate websites by sequentially traversing different sections. Conversely, individuals with a holistic thinking style, more common in Eastern cultures, tend to adopt a circular scanning approach when exploring websites (Dong and Lee, 2008). Although these findings do not reflect Nigerian or even African cultures, they highlight a complex relationship between literacy, culture, language, and cognitive styles in shaping our approach to information processing.

Furthermore, literacy influences object processing, especially in recognising 2D objects. Research indicates that formal schooling facilitates the rapid identification of black-and-white 2D visual objects (Reis et al., 2006). Low reading skills could result in poor orthographic abilities. Despite this, some researchers have claimed that FXI rely on orthographic knowledge as a compensatory mechanism in reading, making this a relative strength for this group (Eme et al., 2014). In a study by Reis et al., individuals with low literacy had difficulties naming black and white 2D but not 3D representations (Reis et al., 2001). Reis et al. (2006) tested whether colour attributes will facilitate access to stored structural information about objects in different literacy groups to further study this. The result indicated that colour indeed improved the performance of FXI. However, it took longer processing times than in literates, which could be caused by differences in the visual processing system or the interface between the visual and the language systems. This implies that frequent reading and writing habits cause better development in visual skills based on 2D depictions and pattern identification (Castro-Caldas, 2004).

The ability to identify visual patterns progressively develops into symbolic and abstract reasoning skills (Castro-Caldas, 2004). In a study that compares literacy groups, illiterates performed significantly worse than literates in naming pictures and drawings compared to real objects (Castro-Caldas, 2004). The study explains this to be because of poor abstract thinking rather than visual pattern identification.

2.1.2.2 Reasoning and Problem Solving

Most human categorisation and reasoning may be based on implicit and explicit *analogies* (Bechtel and Graham, 1999). Analogies, characterised by partial similarities between different situations, serve as foundations for subsequent inferences. According to Bechtel and Graham, analogies play a crucial role in various cognitive processes, such as relational abstraction, problem-solving, creativity, communication, and persuasion. The core process in *analogy* is mapping, the process by which one case is used to explain and predict another.

Researchers have investigated whether the problem-solving skills linked to analogies are related to literacy. Luria's study on snow syllogisms revealed that East and Central Asian peasants generally found it difficult to provide answers to syllogisms containing unfamiliar information (Huettig and Mishra, 2014). Interestingly, individuals from the same culture who had received just a single year of schooling could respond accurately. Importantly, this difference was not developmental but rather linked to exposure to Western education and styles of reasoning.

Furthermore, researchers have found some answers regarding abstraction skills in relation to literacy skills (Castro-Caldas, 2004; Medhi et al., 2013). Illiterates were found to use visualisation strategies to solve problems as opposed to literates, who used abstraction. For example, one of the respondents visualised a bus's structure (including the number of seats and structure) they used daily to work to answer a question about where 12 people would fit inside (Castro-Caldas, 2004). This means that despite the influence of literacy on abstraction skills, literacy skills do not necessarily influence problem-solving skills as visualisation skills can be used for problem-solving, highlighting a different approach for FXI from LIT (Castro-Caldas, 2004).

In technology use, this could impact users' interaction in many ways. For instance, in one study on mobile technology, FXI users were unable to transfer skills learned from video training to the user interface the training was based on (Medhi et al., 2012). The researchers indicated that in the case of interaction with ICTs, abstraction skills are necessary to understand how instructions can be translated into practice, which might be lower in FXI.

2.1.2.3 Visual Attention

Literacy may have its most specific influences on phonological processing and visual attention (Huettig and Mishra, 2014). Attention involves selecting the most relevant aspects from competing stimuli to focus on, depending on our current actions and goals. An individual's interpretation of visual information substantially shapes their attentional focus.

Learning new words and reading activates the phonological loop, which trains working memory in individuals (Kosmidis et al., 2011), thus recording written material in the brain (Castro-Caldas, 2004). FXI have been recorded to have difficulties both with phonological processing and working memory. Working memory is interrelated with verbal tasks, language acquisitions and processing as well as fluid intelligence (Vágvölgyi et al., 2016). It also plays a role in the cognitive processes required to interact with technology (Kosmidis et al., 2011). Importantly, Kosmidis et al. (2011) attributed these gaps to the absence of literacy and not the absence of formal schooling - more precisely, reading skills.

No difference was identified in visuospatial working memory between LIT and FXI, which is a region of the working memory exercised in everyday tasks such as searching for the keys, navigating our surroundings, and estimating the position of other cars while driving (Kosmidis et al., 2011).

Researchers have shown that literacy significantly influences visual information processing, especially in searching for target objects amidst competing visual data, a phenomenon termed visual attention (Olivers et al., 2014). Their research revealed that FXI tend to perform slower in visual search tasks due to disparities in sensory processing and post-selection processes while navigating through on-screen information. These challenges manifest in the distribution of search performance across the visual field, with higher LIT individuals displaying a distinct attention shift.

FXI often adopt a one-step-at-a-time strategy in visual searches (Olivers et al., 2014). In contrast, LIT employ an integrated approach, managing multiple aspects simultaneously (Olivers et al., 2014). Research has noted a significantly lower performance in sustained or split attention tasks compared to LIT (Van Linden and Cremers, 2008). FXI display a preference for focusing on singular tasks, leading to challenges in multitasking and maintaining sustained attention (vigilance) (Van Linden and Cremers, 2008).

Importantly, Olivers et al. (2014) underscored that individuals with limited literacy did not universally exhibit slower searches; rather, this disparity was observed primarily in motor response. The researchers suggested that this discrepancy might be influenced by factors such as a lack of familiarity with technology, less experience in decision-making, or reduced working memory rather than being linked to general intelligence or motivation. Therefore, the distinction between individuals with limited literacy and those with higher literacy levels lies not in their intelligence or familiarity but in how search performance was distributed across the visual field.

2.1.3 Approaches to Literacy Assessment

Researchers use three main approaches to recruit FXI (Vágvölgyi et al., 2021). In the first approach, FXI are recruited as people with poor reading skills despite years of schooling. The second approach does not consider years of schooling but looks at the level of reading and/or writing. The first and second approaches usually use some sort of reading and writing assessment tasks to assess FXI. In the third approach, participants are recruited as FXI because they attend basic adult literacy programs (Vágvölgyi et al., 2021). However, most HCI4D do not use any form of explicit measurement. In a review of 39 FXI studies in HCI, two studies relied on self-identification based on educational level (Ahire et al., 2014; Cuendet et al., 2013), while four used assessments: two of which specified pre-established tests (Rhodes and Walsh, 2016, Medhi et al., 2013), and two that did not describe the type of assessment used (Tulasker 2020, Adama et al., 2017). This reflects a lack of consistency in how literacy is operationalised and further supports the adoption of a replicable assessment method in this research (see Table 58; Appendix R for review table).

Research has criticised the third approach because it makes it difficult to diagnose the severity of illiteracy and blurs the line of whether participants are illiterates or FXI (Vágvölgyi et al., 2016). Although the first approach is more commonly adopted, most researchers suggest the second approach (Boltzman et al., 2017). This is mainly because, as seen in the literature, the number of years of schooling is not a reliable variable for either defining or assessing FXI. Moreover, the concept of the second approach is definitive, easily understood, and does not need a new assessment because the researchers use general comprehensive tests (Vágvölgyi et al., 2016). However, researchers have stressed the need for cut-off values when using such. As a result of the above arguments, this research will adopt the second approach to recruiting functional illiterates (Boltzman et al., 2017).

Within the second approach, researchers have used different grade equivalent scores and reading-level match designs (Vágvölgyi et al., 2016). Several of these assessment methods exist and have been used to assess literacy groups. For example, UNESCO developed a widely adopted method in collaboration with national teams from developed and developing countries called the 'Literacy Assessment Monitoring Programme' (LAMP) (Ahmed, 2011). Other methods include the International Adult Literacy Survey (IALS), Adult Literacy and Life Skills Survey (ALL) and Programme for the International Assessment of Adult Competencies (PIAAC) (Chaudry et al., 2012; Vágvölgyi et al., 2016). All of these contain prose and document literacy assignments that aim to assess how information is perceived and used in different text formats. However, these methods do not provide any specific assessment advice for functional illiteracy (Vágvölgyi et al., 2016).

Moreover, most literacy assessment methods are very time-consuming (average 30-45 mins) to administer and score (Colter and Summers, 2014). As a result, researchers have used other methods to reduce frustration and time consumption for participants (Ahmed, 2011; Medhi et al., 2013). For example, Medhi (2013) developed a suitable tool in collaboration with an elementary education instructor. Researchers have suggested that better solutions for this user group should involve assessments that take less than five minutes, like the Slossen Oral Reading Test (SORT) or the Rapid Assessment of Adult Literacy in Medicine (REALM) (Colter and Summers, 2014).

Also, when using reading assessments to measure literacy, it is important to note that various tests measure different components of reading comprehension, as this influences the choice of assessment that fits each study's purpose. According to the simple view of reading, reading has two components. The researchers claim that reading comprehension results from good decoding and language comprehension skills (Gough and Tunmer, 1986). This view claims that as reading skill progresses; readers shift from a dependence on the former skills to the latter. As a result, the general view in literacy research is that the level of ease with which word reading is achieved is linked to the cognitive skills that can be allocated to the processes involved in drawing meaning from text (García and Cain, 2014).

Other researchers claim reading is more complex than that and propose that reading comprehension depends on more skills such as background knowledge, inferences, word reading, strategies and vocabulary (Cromley and Roger, 2007). In another research, fluency was claimed to have a significant impact on reading comprehension because besides the ability to decode words and associate them with their meanings, "texts must be dealt with fluently enough so that the meanings are retained throughout before next ones are processed" (Mellard et al., 2010). Another study found vocabulary, working memory, and planning skills to significantly impact reading comprehension (Sesma, 2009).

Due to the above complexities in understanding reading, some researchers have tested specific components of reading with FXI based on the definition of functional illiteracy adopted in each study. In the context of this study, the component of interest is reading comprehension itself because this study identified the 'inability to fully comprehend meanings' from text in its definition for FXI. This is also in line with the suggestion for assessing FXI by Vágvölgyi et al. (2016).

Given these complexities and inconsistencies in literacy assessment approaches, it is necessary to adopt a clear, replicable method tailored to this study's context.

2.1.4 Assessment for Functional Illiteracy

There are several tests for reading comprehension. For this research, the reading comprehension subset 'Maze' of the Dynamics Indicators of Basic Early Literacy Skills 8th edition (DIBELS8) will be used to assess FXI. DIBELS8 was developed based on Curriculum-Based Measurement (CBM) to assess literacy skills, specifically reading skills, to identify people with dyslexia and other reading difficulties (Good III and Kaminski, 1996). Research has shown that Maze measures are valid assessment methods for low-level comprehension (January and Ardoin, 2012). The DIBELS8 Maze measure was standardised in second through eighth grade, and the internal reliability estimates at a median of .072 (University of Oregon, 2018).

In DIBELS8 Maze, a passage is presented to the participants where every seventh word is left blank, and three options are provided to fill in the blank. The results are calculated by multiplying the total number of overt errors within 3 minutes by one-half (University of Oregon., 2023). In scoring, the skipped items are categorised as errors, while the items that have not been reached are not considered errors(University of Oregon, 2018). Although the DIBELS was developed to assess students, researchers have adopted and validated it in studying adults (Binder et al., 2012).

The DIBELS8 Maze comprehension test was chosen for three reasons. The first is although DIBELS8 materials were initially developed to be linked to the local curriculum, current DIBELS measures are generic and do not draw content from any specific curriculum (University of Oregon, 2018). This makes the test items generalisable to various contexts and cultures. Secondly, the DIBELS8 Maze takes only 3 minutes and can be administered in group settings, which means it is quick to administer. Moreover, because DIBELS8 is timed, efficiency and accuracy in reading skills are examined (University of Oregon, 2018). Thirdly, the DIBELS8 provides comprehensive guidelines both on assignments and scoring. There are benchmark values that lead to the classification of readers into groups (Smolkowski and Cummings, 2015). For instance, participants that score below the 20th percentile are characterised as belonging to the lower-level literacy group.

While the DIBELS8 Maze offers a practical tool for assessing comprehension, defining who qualifies as functionally illiterate requires further conceptual clarity, especially in HCI4D contexts.

2.1.5 Definition for Functional Illiteracy in this Research

A synthesis of relevant HCI4D publications (see Table 58 in Appendix R) reveals a widespread inconsistency in defining users with limited literacy skills. Terms like "low literate," "semi-literate," and "illiterate" are often used interchangeably with neither clear distinctions nor definitions (Guimarães et al., 2022; Srivastava et al., 2021). Many studies rely on proxies like education level or use informal labels without directly assessing reading or writing abilities. For example:

- Medhi et al. (2013) categorized users into level 0 (no ability to read) and level 1 (ability to read Grade I content)
- Chandel et al. (2013) distinguished between semi-literate (Class 7–11) and highly literate (undergraduate to PhD)
- Doke and Joshi (2015) used schooling between Standard 4 and 8 as a proxy for low literacy
- De et al. (2015) described semi-literate users as having rudimentary English alphabet knowledge
- Rhodes and Walsh (2016) defined low-literate adults as those reading at or below eighth-grade level

Notably, many other studies provided no clear definition at all, for example Dodson et al. (2013), Gupta et al. (2015), Islam et al. (2020), and Ninsiima (2015). This pattern continues in more recent studies by Melo et al. (2024), Teran and Mota (2024), and Cheema et al. (2022), who use terms like "low-literate" or "emergent users" without specifying an operational definition or measurable criteria. Although this issue has been acknowledged (Guimarães et al., 2022; Srivastava, 2021), it remains unresolved and creates blurred participant categories and a lack of clarity in design implications.

The term functional illiteracy is adopted in this study because it foregrounds the importance of context in how literacy is defined and applied, and it is recognised as such by UNESCO. Rather than treating literacy as a fixed trait, FXI reflects individuals' difficulties performing everyday reading and digital tasks, making it more suitable for HCI4D design and evaluation.

Proposed Definition of Functional Illiteracy (FXI)

Responding to the inconsistencies in current HCI4D literature, this thesis proposes the following working definition:

> "Functional illiteracy (FXI) refers to adults who can read and write to some extent in the study language but experience difficulties comprehending, applying, or acting on written information. The definition excludes individuals whose reading challenges are due solely to second-language acquisition or complete illiteracy, and it includes those with low competence in the study's measured digital skills."

This definition has been developed through a combination of literature review and refinement throughout this doctoral project. It emphasises that FXI individuals are not completely unable to read or write; rather, they have limited comprehension of extended text and face difficulties with tasks requiring interpretation of written content (Vágvölgyi et al., 2016). They may be able to decode or recognise words yet experience difficulties in extracting meaning from unfamiliar content or complete tasks requiring reading comprehension, abstraction, or responsive action (White, 2003, cited in Colter and Summers, 2014). The definition builds on the understanding that reading and writing skills, particularly reading comprehension, are key indicators of functional illiteracy.

It also emphasises the role of contextual assessment of digital skills in shaping how these reading comprehension factors affect users' ability to perform tasks. Individual differences stemming from social roles or other contextual factors make it impractical to apply a universal literacy threshold; for instance, an IT professional requires different reading and digital skills than an automobile mechanic (Thatcher and Ndabeni, 2005). Therefore, reading comprehension and task context are essential in determining functional illiteracy. As noted in UNESCO's definition, FXI should be defined based on everyday interaction demands (Zelezny-Green, 2018), such as interpreting a mobile money transaction or navigating search filters.

Cognitive Foundations of FXI

A key insight from section 2.1.2 on the cognitive aspect of literacy is that reading and writing skills affect various cognitive processes regardless of language, including attention, abstraction, problem-solving, and visual perception. These cognitive patterns fundamentally shape how users interact with digital interfaces and interpret symbolic or textual information. Therefore, FXI is not merely a lack of education or language proficiency but a specific challenge in processing and applying written information in everyday contexts.

Key Distinctions in the FXI Definition

Adult-Specific Focus: FXI, as defined here, applies specifically to adults. Developmental factors affecting children's literacy acquisition differ significantly from the cognitive patterns observed in adult FXI users. As Martin et al. (2022) explain, early brain development is characterised by critical periods where language can reorganise extensively. This plasticity makes it difficult to distinguish between temporary developmental delay and stable functional illiteracy in children. Furthermore, the cognitive patterns linked with FXI closely resemble those observed in children rather than regular adult readers (Vágvölgyi et al., 2016).

Despite this important distinction, many HCI4D studies do not explicitly identify adults as a prerequisite for FXI. In the review of 39 studies, only three explicitly mention adult users (Melo et al., 2024b; Michael et al., 2019; Rhodes and Walsh, 2016), while others only imply adulthood indirectly through terms like "parents" (Madaio et al., 2019) or occupational roles such as "farmer" (Cheema et al., 2022); see review in Table 58, Appendix R.

Distinction from Complete Illiteracy: This definition distinguishes FXI from individuals who cannot read or write at all (i.e., illiterates). While illiterate users lack foundational decoding and reading skills, FXI users possess some reading and writing ability, albeit at a level insufficient for functional engagement with most digital interfaces. Evidence from Boltzmann et al. (2017) supports this distinction: in their study, adults who were completely illiterate underwent nine months of intensive literacy training. Prior to the training, neuroimaging revealed they had significantly less grey matter in brain regions associated with reading and weaker neural connectivity compared to literate individuals. Interestingly, after the training, their reading abilities improved and the previously documented structural brain differences largely disappeared. This highlights that FXI users, by already possessing some literacy skills, likely operate from a different cognitive baseline than completely illiterate individuals.

Distinction from Digital Illiteracy: FXI should be differentiated from digital illiteracy. Digital illiteracy refers broadly to individuals who lack familiarity or competence in interacting with digital devices, which may include illiterate, functionally illiterate, and literate users (Srivastava, 2021). FXI users often exhibit low digital skills not simply due to unfamiliarity with technology, but because of a complex interplay of factors including their reading comprehension difficulties, which may prevent them from learning or transferring digital skills across tasks.

Although FXI individuals may have prior experience with technology, research shows that these skills often remain task-specific and do not transfer easily due to abstraction challenges (Rayed et al., 2023; Medhi et al., 2012). As Van Laar et al. (2017) note, interacting with ICTs effectively is about "mastering ideas, not keystrokes." This reflects the need to assess digital skills directly, rather than assume they are lacking based on FXI status alone.

Excluding Second-Language Acquisition Challenges: In this study, participants were classified as FXI only if they could speak and read to some extent in the study language (i.e., English). Individuals who could read and write only in a different language but not in English were excluded to avoid misclassifying second-language learners as FXI. This prevents conflating FXI with other groups facing reading challenges due to fundamentally different reasons, such as individuals who are in the early stages of learning English as a second language or those already proficient in their native language but lacking sufficient English proficiency for mobile interfaces. This distinction is also emphasised by Vágvölgyi et al. (2016), who stress the importance of separating second-language acquisition challenges from functional illiteracy.

It is important to note that even if languages share the same script (like Hausa[4] and English both using the Latin alphabet), proficiency in one does not guarantee comprehension in the other. A person who reads and writes fluently in Hausa may still experience difficulties with English comprehension due to differences in vocabulary, grammar, and structure, even if they speak English conversationally. According to the Simple View of Reading (Gough and Tunmer, 1986), comprehension and decoding are distinct but necessary components of reading. Reading comprehension relies not only on letter recognition or decoding but also on interrelated skills, for example, vocabulary knowledge, syntactic awareness, and inference-making (Mellard et al., 2010; see section 2.1.3 for more details). Thus, script familiarity alone is not sufficient for reading comprehension across languages.

Importantly, while the study focuses on English interfaces due to contextual relevance in Nigeria, the conceptual and design insights remain applicable to multilingual contexts and could support future inclusive digital systems beyond English.

[4] Hausa is one of Nigeria’s most widely spoken languages, considered amongst the five (5).

Education Level as an Unreliable Proxy: This definition intentionally avoids using formal education as a proxy for reading comprehension. In line with prior findings (Medhi, 2015; Colter and Summers, 2014), education level does not reliably predict functional reading or task performance due to several factors such effort dedicated to learning, quality of teaching delivery, among many others (see section 2.1.1 for more) .

Contextual Factors Affecting FXI in Digital Environments

Building upon our core definition, it is essential to recognise several contextual factors that influence how functional illiteracy manifests in digital interactions. These factors help explain why FXI users may demonstrate varying levels of proficiency across different digital tasks, despite consistent reading comprehension challenges and further justify the need for considering digital skills in the definition.

Routine Use and Rote Memorisation: While not explicitly included in the formal definition, this study also considers contextual factors such as routine use and rote memorisation. In HCI contexts, functional illiteracy cannot be assumed to be the only reason someone has difficulties with a mobile application. As Thatcher and Ndabeni (2005) note, people may interact successfully with certain technologies out of habit or routine use, even if they have difficulties with reading comprehension. For example, a FXI person may use Uber confidently if their livelihood depends on it, while a literate person may find Twitter difficult to navigate. Several studies have shown that users with limited literacy often rely on rote memorisation of steps rather than understanding interface concepts (Melo et al., 2024b). This highlights the influence of routine use and rote memorisation, which can sometimes mask functional illiteracy. This reflects another reason to include digital skills in defining FXI.

Motivation and Perceived Relevance: Motivation and perceived relevance can also influence how functional illiteracy manifests in digital contexts (Thatcher and Ndabeni, 2005). UNESCO's report identifies this as a contributing factor to digital exclusion (Vosloo, 2018), and Hasan et al. (2021) similarly observe that many FXI users often show limited interest in learning complex sequences or engaging with sophisticated tools, even when these tools are designed to enhance their quality of life. These insights also reflect another reason to include digital skills in defining FXI.

In this study, participants were selected based on whether they self-reported needing assistance with the mobile applications tested, helping to the above contextual factors. This makes both willingness to engage (motivation) and a lack of proficiency that makes habitual memorisation less likely. It also differentiates FXI users from those who rely on routine use or memorised steps without transferable understanding.

Summary of Themes Informing the FXI Definition

Drawing on the themes established throughout this section, Table 1 summarises the key themes and insights that inform the definition of functional illiteracy adopted in this study.

Table 1: Summary of Themes and Insights Informing the Definition of Functional Illiteracy (FXI)

Theme	Description	Supporting Literature	How It Informs the FXI Definition
Cognitive Basis of FXI	Reading and writing affect cognitive functions like attention, abstraction, and visual processing.	Vágvölgyi et al. (2021; 2016); Eysenck and Brysbaert (2018); see prior section on 'The Cognitive Side of Literacy'	FXI is more than language or education, it influences cognitive styles used in applying skills beyond reading.
Lack of Standardised Definitions in HCI4D	Studies inconsistently use terms like “low-literate” or “semi-literate,” often without criteria.	Srivastava (2021); Medhi et al. (2013)	Justifies the need for a clear, context-specific FXI definition.
Reading Comprehension	FXI can decode or recognise words but have difficulties with comprehension. The difficulty is not with recognition alone but with understanding extended or unfamiliar text. This is the central distinction of FXI.	Vágvölgyi et al. (2021; 2016); White, 2003, cited in Colter and Summers, 2014)	Justifies partial reading and writing ability in study language
Context-Dependence of Literacy	Literacy should be defined relative to goals and tasks.	Zelezny-Green (2018); Thatcher and Ndabeni (2005)	Justifies inclusion of digital skill as part of FXI in your context; FXI is defined in terms of everyday digital tasks, not abstract literacy levels.
Exclusion of Second-Language Users	Users literate in another language may have difficulties with the study language for different reasons.	Srivastava (2021); Vágvölgyi et al. (2016)	Ensures FXI is not confused with second-language acquisition difficulties.
Adult-Specific Focus	FXI applies to adults; children's literacy challenges have different developmental causes.	Vágvölgyi et al. (2016); Eme (2011)	Justifies limiting the FXI definition to adults.
Education Level as an Unreliable Proxy	Schooling does not predict actual reading comprehension.	Medhi (2015); Colter and Summers (2014)	Supports using reading tasks rather than educational history for FXI classification.
Distinction from Illiteracy	FXI users have basic reading skills but lack full comprehension.	Vágvölgyi et al. (2016)	Differentiates FXI from complete illiteracy.
Distinction from Digital Illiteracy	Digital illiteracy can affect any literacy group; FXI includes reading-based digital difficulties.	Srivastava (2021); Medhi et al. (2012); Van Laar et al. (2017)	Justifies inclusion of digital skill as part of FXI in study context.

Routine Use and Rote Memorisation	FXI users may rely on habit, repetition, or memorised steps.	Rayed et al. (2023); Ahire et al. (2014)	Helps explain why some FXI users might appear digitally competent when they are not, reinforcing the need to include digital skill in the definition.
Script Familiarity ≠ Comprehension	Users literate in a language may still have difficulties with another language with a similar script even if they speak both languages (e.g., Hausa, one of Nigeria's languages and English).	Vágvölgyi et al. (2016); Mellard et al. (2010); Gough and Tunmer (1986)	Ensures script use does not misclassify users as FXI; thus ensuring that FXI is not confused with language acquisition difficulties.
Motivation and Perceived Relevance	Not all FXI users engage unless they see the personal value of technology, which may dilate the results of usability assessment.	Hasan et al. (2021); Forenbacher et al. (2019); Thatcher and Ndabeni (2005)	Recognises that motivation shapes exposure, which may influence digital skills assessment.

Having established a working definition of FXI grounded in cognitive, contextual, and digital factors, it is important to now situate this within the broader ICT landscape of Nigeria.

2.2 The Nigerian ICT and Telecommunications Landscape

The telecommunications sector in Nigeria is primarily driven by mobile services, which account for most user access and industry revenue. In 2023, the mobile ecosystem alone contributed approximately ₦33 trillion to GDP and ₦2.4 trillion in tax revenues (GSMA, 2024). As of early 2024, 80.9% of Nigeria is covered by a 4G/LTE mobile network at least (Ani and Batisai, 2024). Nigeria had 205.4 million active mobile cellular connections (90.7% of the country's total population) as of early 2024 (DataReportal, 2024). In the same period, the Nigerian Communications Commission (NCC) reported over 83.3 million broadband subscribers, indicating a broadband penetration rate of almost 43% (NCC, 2024). As of January 2023, 103 million Nigerians (45.5% of the population) had internet access, with 36.75 million (16.2%) being active social media users. With an annual improvement of 33.5%, the median mobile internet speed was 26.48 Mbps, demonstrating continuous infrastructure improvement (DataReportal, 2024). Notably, these figures may overstate actual user access, as they likely include multiple SIM ownership, which is typically used to overcome issues of network reliability in Nigeria (Gillwald et al., 2018).

Despite these impressive growth metrics, significant disparities in access and service quality persist across the country. Compared to regional peers such as South Africa and Kenya, 4G adoption remains lagging, limiting access to high-bandwidth services. Infrastructure is unevenly distributed, particularly in rural and peri-urban regions. A micro-spatial analysis showed that proximity to 3G/4G towers strongly predicts individual internet use, underscoring the role of infrastructure access in digital inclusion (Odusanya and Adetutu, 2020). However, 42 percent of people in urban areas use the internet, compared to 22 percent in rural areas (Banyan Global, 2023). Affordability, digital literacy, power supply, and trust also continue to affect adoption (Ani and Batisai, 2024). Meanwhile, the dominance of foreign firms, particularly Chinese companies like Huawei and ZTE has driven broadband expansion via state-backed loans and affordable smartphones. Yet, this raises concerns about technological dependency and limited local ownership (Arnold, 2024).

Within this evolving infrastructure landscape, mobile applications have emerged as critical tools for digital service delivery in Nigeria, particularly in sectors like banking and shopping due to their convenience and the expansion of Nigeria's e-commerce and fintech ecosystems. As outlined in Chapter 1.1.3, mobile banking services have surged, contributing to a dramatic rise in electronic payment transactions, which reached ₦600 trillion in 2023 (NIBBS, 2024). However, these platforms are not effectively inclusive. Studies show that FXI and novice users face significant challenges due to complex system design, limited digital literacy, and a lack of accessibility features (Omotosho, 2021).

Beyond banking, the e-commerce sector demonstrates similar patterns of adoption and challenges. Mobile shopping applications are widely used by the Nigerian youth, but their adoption is constrained by poor user experience, distrust in vendors, unreliable internet, and non-transparent refund policies (Olagunju et al., 2020; Esho and Verhoef, 2021). Usability challenges such as unclear navigation, inconsistencies, and limited error prevention, disproportionately affect less experienced users (Oloveze et al., 2022).

Notably, studies have also highlighted a lack of standardised metrics for evaluating digital progress in developing countries. In Nigeria, standardised metrics often fail to reflect digital development due to inconsistent definitions and limited data. As a result, scholars have called for the development of localised toolkits that better capture informal and mobile-driven digital activity (Oloyede et al., 2023). Consequently, caution is needed when interpreting national digital inclusion statistics.

Despite these infrastructural advances, not all Nigerians benefit equally, particularly those who fall within the FXI category.

2.3 FXI in Nigeria

In Nigeria, 40.33% of adults aged 15 years and older are either illiterate or functionally illiterate (Aguboshim et al., 2022). These people have varied levels of exposure to mobile technology and frequently work in informal economies. FXI typically consists of low-income earners, older adults, and rural or semi-urban residents with limited literacy, according to a synthesis of studies on digital exclusion, literacy rates, and mobile access patterns in Nigeria (Aguboshim et al., 2022; Uduji and Okolo-Obasi, 2018; Otonekwu et al., 2019; Iyalla-Amadi, 2024). Banyan Global (2023) confirms this demographic pattern, reporting that digital access and usage "favours men, individuals of higher income and education levels, and residents of major urban areas," which further marginalises rural and less-educated populations in the digital sphere.

Beyond demographic characteristics, access to devices presents another barrier for FXI. Mobile phone ownership is inconsistent among FXI users Uduji and Okolo-Obasi (2018) found that among individuals without a registered SIM, only 11% had their own phone, while 83% relied entirely on using someone else's device, underscoring the prevalence of shared and dependent mobile access. In such settings, phones are often borrowed from family or community members.

When FXI do gain access to mobile technology, their learning patterns differ significantly from digitally literate users. Many users acquire skills by observing others, repeating actions, and gradually forming habits. As Iyalla-Amadi (2024) reports, rural learners employ localised teaching methods and repetition. Some of them pick up knowledge by observing others, imitating their behaviour, and progressively gaining self-confidence (Iyalla-Amadi, 2024). This reliance on observation and memorisation enables them to perform simple, familiar tasks like sharing photos on WhatsApp but leaves them vulnerable when faced with new applications, updates, or other UI patterns (e.g., form-based interfaces).

The most common digital activities among FXI users are basic communication tasks such as phone calls, SMS, and WhatsApp messaging. As Otonekwu et al. (2019) note, the majority of rural mobile phone owners utilise their devices for making calls rather than browsing the internet to find crucial information. Use of complex applications such as mobile banking, e-commerce, or government platforms is often limited among FXI users in Nigeria. This has been attributed to unfamiliar interface structures, fear of making mistakes, or unawareness about these services (Mohammed et al., 2023; Aguboshim et al., 2022).

Although Nigeria shows impressive growth in its digital literacy efforts, the actual engagement with digital services remains highly stratified. As demonstrated, mere access to mobile networks does not translate to meaningful digital inclusion when obstacles such as literacy, device ownership, and interface complexity persist.

Beyond demographic and infrastructural barriers, cultural factors further shape how FXI users engage with smartphones and digital platforms.

2.4 The Influence of Nigerian Culture on Smartphone Interaction among FXI Users

As outlined in the Section 2.1.2, cultural norms play a significant role in shaping how people interact with technology. In Nigeria, these norms manifest through gender roles, access restrictions, and sociocultural expectations, all of which influence the digital engagement of FXI people. Contextual norms in some Northern Nigerian communities may result in lower mobile phone access for women (GSMA, 2022). Based on data from the 2018 Nigeria Demographic and Health Survey (NDHS), which sampled 41,821 women aged 15 - 49 nationwide, Adeleke et al. (2024) report that female internet use is "abysmally low (17.48%)" and that factors like age, marriage, and educational attainment significantly predict non-use. Additionally, in many rural households, women require permission to use mobile phones (Obi-Jeff et al., 2022), illustrating how social control limits women's autonomy in digital spaces. These gendered constraints intersect with literacy and economic exclusion, deepening the digital divide (GSMA, 2022).

Even where access exists, FXI users may not engage meaningfully with digital tools due to low confidence or uncertainty about their usefulness. Many FXI Nigerians do not find current ICT platforms useful or simple to use, reflecting low digital self-efficacy (Aguboshim et al., 2022). According to Obi-Jeff et al. (2022), the primary obstacles include poor mobile phone ownership and the inability to comprehend text messages because of low literacy. For FXI, fear of failure, embarrassment, or financial loss discourages experimentation, especially when support systems are lacking (Aguboshim et al., 2022).

Beyond social barriers, practical challenges further limit digital engagement among FXI users. Basic infrastructure challenges like inconsistent electricity and poor mobile connectivity compound digital exclusion. According to Otonekwu et al. (2019), despite the existence of ICT infrastructure, those on the underprivileged side of the digital divide, particularly in rural areas with low levels of information literacy, continue to be excluded from the digital world. Even when FXI people are motivated to learn, charging phones, buying data, or sustaining signal access are daily challenges that disproportionately affect them (Otonekwu et al., 2019; Iyalla-Amadi, 2024; Uduji and Okolo-Obasi, 2018).

The design of digital interfaces compounds these access issues, creating additional barriers to meaningful participation. Interface design often fails to accommodate users with limited literacy or exposure to technology. Interfaces built in English text, unfamiliar icons, or complex navigation patterns can alienate Nigerian FXI users and make even basic tasks feel intimidating (Forenbacher et al., 2019; Adama et al., 2017) Aguboshim et al. (2022) call for easy-to-use interfaces and stress the need to "include women's voices in design and local content creation.

These cultural constraints, coupled with infrastructure limitations and design oversights, create a complex web of barriers for FXI users in Nigeria. Understanding these intersecting challenges is essential for developing more inclusive digital services that can effectively contribute to digital inclusion.

With the contextual landscape now established, covering the demographic and infrastructural foundations shaping FXI users' digital experiences in Nigeria, the next chapter builds on this foundation by exploring the conceptual frameworks in HCI and HCI4D that underpin interface design and evaluation in this research.

3 Conceptualising HCI - HCI4D and Interactive Design

This section follows a progressive structure, introducing the evolution of the HCI field using the wave-to-turns metaphor, while acknowledging the importance of the discourses in the field (section 3.1.1). This discussion aims to set the stage for subsequent discussions that include the theoretical backgrounds relevant to this thesis, including models for designing usable UIs, usability and UX, and UI design patterns (section 3.1.2 and 3.1.3). It also highlights the historical aspects of designing UIs for users by looking at the traditional view of 'the user' in HCI. Next, I provide a review of research that considers the design and evaluation of UIs specifically for FXI users (section 3.1.4). The two prior subsections provide background and context for the subsequent section that introduces HCI4D, which deconstructs the view of 'the user' in HCI research, aligning with the *fourth wave* of HCI (section 3.1.5). This section acknowledges efforts in considering design alternatives that address the shortcomings of traditional approaches.

It is within this context of alternative approaches that the next section builds upon, where I provide the rationale for selecting a digital literacy framework as the theoretical lens that guides aspects of the investigations in this thesis (section 3.2). Lastly, I provide a summary to guide the next section, which discusses my approach to addressing the research questions (section 3.3).

3.1.1 HCI - From Waves to Turns

Human-Computer Interaction (HCI) is a discipline concerned with "the design, evaluation, and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" (Hewett et al., 1992). Research in HCI is fascinating and complex, driven by many intriguing questions and changes over time due to technological advancements (Lazar et al., 2017). This evolution is often characterised by various "waves" and "turns".

The evolution of HCI can be conceptualised through successive waves and turns (Bødker, 2015; Resende et al., 2017). Initially, it emerged from cognitive science and human factors research, which laid the groundwork for a formal understanding of scientific knowledge. Subsequent waves shifted the focus towards the interaction between human factors and actors, researching issues such as situated action, distributed cognition, and the embodiment of interaction. The third wave expanded the scope of HCI to consider broader contextual factors, including geopolitical differences in design and application areas. In the fourth wave, there has been a heightened emphasis on design's ethical, political, and value-based dimensions, transcending traditional technological considerations to encompass ontological and epistemological aspects, particularly regarding power dynamics and knowledge (Ashby et al., 2019).

This progression has led to notable turns in HCI research methodologies in designing and evaluating digital technologies, marked by interdisciplinary collaborations and methodological innovations. Scholars like Lucy Suchman and Jonathan Grudin have played pivotal roles in exploring diverse approaches to understanding the design and evaluation of digital technologies, moving beyond conventional sociological studies and laboratory-based methods in HCI (Crabtree et al., 2013; Rooksby, 2013). This transition marks a significant methodological change. It involves investigating how people interact with technology in real-world settings rather than solely in controlled lab environments. Analysing human behaviour in social settings differs from studying them in labs, requiring distinct approaches and methodologies (Rooksby, 2013). The "turn to the social" and the "turn to the wild" are two recognised shifts in HCI theory. The "turn to the social" involves understanding the social aspects of human practices within digital technology use, while the "turn to the wild" involves studying these practices in natural, real-world settings rather than controlled laboratory environments. However, this metaphorical "turn" has led to conceptual and methodological challenges within HCI. Some perceive 'the wild' as a natural setting where genuine social interactions occur, while the lab is seen as a controlled environment where behaviours are both artificial and context-dependent (Rooksby, 2013).

Specifically, HCI researchers within the African space express reservations regarding the established theories and methodologies in HCI, particularly concerning the implications of these theories, known as the 'canon of turns/returns of HCI,' on localised design approaches design (Ssozi-Mugarura et al., 2016). This includes the recognised shifts in HCI theory, such as the 'turn to the social' and the 'turn to the wild,' which represent significant changes in how HCI researchers approach their work, aiming to gain deeper insights into users' behaviours and technology use. These shifts have prompted concerns among African HCI researchers about their applicability to localised design contexts. Additionally, adopting social science disciplines into HCI research inevitably involves using the methods and techniques associated with those disciplines to study aspects of social life, further complicating the landscape of HCI research in African contexts.

3.1.2 Mobile HCI

The evolution of HCI research has witnessed a significant transition from fixed technologies to mobile and portable computing, particularly smartphones and tablets, spanning 1994–2003. This shift towards mobile computing gained momentum around 2004–2013, marked by a growing focus on user-generated content, social networking, and user diversity (Liu et al., 2014).

The modern era of mobile HCI dawned with the introduction of the iPhone by Apple in 2007, a milestone that ushered in innovative designs such as multitouch gestures, the removal of physical keyboards, and the advent of context-awareness capabilities (Lazar et al., 2017). While early challenges in mobile interaction and interface design centred on physical aspects like size, screen display, and keyboards, later evolving to incorporate features like cameras and media players, modern challenges have shifted towards software application development and mobile interaction design (Punchoojit and Hongwarittorrn, 2017).

In the next section, I will explore theoretical backgrounds central to HCI and mobile HCI, including usability, user experience (UX), the concept of the 'user' in HCI and UI design patterns. This exploration will be framed within the context of mobile HCI research.

3.1.3 Theoretical Backgrounds

3.1.3.1 Models and Concepts for Designing Usable User Interfaces in HCI

A model serves as a simplified depiction of a system or process, aiding in understanding its functionality (Sharp et al., 2019). This section outlines essential models and concepts specifically relevant to this thesis. Each model offers insights into how users perceive and interact with interfaces and how designers utilise this understanding in their work.

Mental Models

Mental models in Human-Computer Interaction (HCI) are rooted in various disciplines, including cognitive psychology, computer science, information science, engineering, education, and human factors (Staggers and Norcio, 1993; Hu and Twidale, 2023). This interdisciplinary background has contributed to the diverse perspectives and approaches in mental model research.

Many HCI researchers trace the origin of mental models to Craik's (1943) work. Craik proposed that humans translate external events into internal models and use these models to reason, explain phenomena, and anticipate events (Craik, 1943). This foundational idea of internal representations that mirror external reality has been instrumental in shaping subsequent research on mental models.

Building on Craik's work, Johnson-Laird extended the concept, focusing on how mental models are used in language comprehension and reasoning. Johnson-Laird described mental models as mental representations of the physical world used for understanding and inference (Johnson-Laird, 1983). His work drew from integrating the psychology of meaning and the psychology of reasoning, representing mental models in a formal format like logical calculus

(Staggers and Norcio, 1993; Hu and Twidale, 2023). Importantly, Johnson-Laird argued that some authors draw distinctions among various concepts of mental models when they likely represent "the same underlying reality" (Johnson-Laird, 1989).

While Johnson-Laird's work on written text and reasoning is certainly related to FXI users due to its focus on the 'comprehension of discourse', this thesis focuses more on mental representations formed through human-computer interaction and experiences. In this regard, Gentner and Stevens provided a crucial human-computer interaction perspective, focusing on how people form and use mental models in their interactions with physical systems (Gentner and Stevens, 1983).

Building on this HCI perspective, Norman's work (a chapter in Gentner and Stevens, 1983) significantly advanced mental models' application to HCI, providing crucial insights for understanding user behaviour and designing effective interfaces.

Norman's Contributions and Distinctions

Norman's HCI approach to mental models defined them as "what people really have in their heads and guide their use of things" (Norman, 1983). Norman's contribution was particularly significant in highlighting the practical implications of mental models for system design.

Norman emphasised the importance of distinguishing between three related but distinct concepts (Norman, 1983):

- The user's mental model: This is the model constructed by the user through interaction with the system. This is based on the user's interpretation of the system's behaviour and is used to predict and explain the system's operations.
- The designer's conceptual model: This is the model the designer develops and uses as a framework for creating the system. It represents the designer's idea of how the system should work and how users should interact with it.
- The system image: This is what is presented to the user through the system's interface, documentation, and overall behaviour. This is the bridge between the designer's conceptual model and the user's mental model.

These distinctions highlight potential mismatches between how designers envision a system and how users perceive and interact with it. They are crucial for HCI research as they help avoid confusion, even if the models are based on the same underlying reality as theorised by Johnson-Laird (Johnson-Laird, 1989).

As designers have a vast amount of knowledge in UI design, they form deep mental models of their designs, directing them to believe that the UI is easily understandable (Sharp et al., 2019; Nielsen, 2010). However, users' mental models may differ significantly, leading to misinterpretations and usability issues. Both gaps between the designers' model and the users' model can be bridged through developing transparent conceptual models (Sharp et al., 2019).

Norman's work highlighted several crucial characteristics of mental models, which have significant implications for user interface design (Norman, 1983). Mental models are often incomplete and evolving, although even partial models can be useful (Johnson-Laird, 1989). These models are inherently unstable, with users forgetting details over time and lacking firm boundaries, leading to potential confusion between similar operations. People's ability to "run" their mental models is limited, and models can be "unscientific," with users maintaining unnecessary behaviours. Notably, there's a tendency towards users to prefer physical actions over mental complexity.

These characteristics highlight the challenges in designing systems that align with users' mental models.

Construction of Mental Models

Different views exist on how people construct mental models. The traditional view in HCI is that the formation of mental models often involves the use of analogies or metaphors of past represented interactions or objects.

Gentner proposed that people's understanding is structured in the form of analogies imported from a base domain of knowledge. This concept of "structure mapping" suggests that users draw on familiar concepts to understand new systems (Gentner, 1983). However, Carroll and Mack criticised this view, emphasising the role of metaphors in learning to use computers, arguing that the process is structured by metaphoric comparisons. Their view acknowledges both similarities and dissimilarities in metaphoric comparisons and suggests a more dynamic, evolving understanding compared to the former static mapping (Carroll and Mack, 1985).

Whether one calls these entities analogies or metaphors seems less important than the overall notion that these entities serve as model construction devices. As Staggers and Norcio (1993) point out, "instead of being strict entities by themselves, these smaller objects may serve as the genesis for a larger mental model of a new domain of knowledge. Users may transfer knowledge about familiar systems to new systems through visual phenomena known as analogies or metaphors".

More studies have pointed out that mental models are developed based on experience, culture, values, and beliefs (Biggs et al., 2011; Bender, 2020). Additionally, higher levels of education tend to be associated with more complex mental models (Levy et al., 2018). Notably, the latter study was not in HCI or mobile interaction.

These factors highlight that designing interfaces for diverse user groups requires contextual understanding. Researchers have developed various methodological approaches to studying mental models to gain this understanding.

Methodological Approaches

The methods used to study mental models have evolved over time. Early approaches include protocol analysis and observational studies (Staggers and Norcio, 1993), while more recent research indicates diversification of methods in HCI in recent years (Hu and Twidale, 2023). These recent methods include naturalistic methods (e.g., interviews, surveys, think-aloud protocols), usability methods (e.g., card sorting, concept mapping, cognitive walkthroughs), experimental methods (e.g., task performance measures, physiological measures), and emerging computational approaches (e.g., algorithmic modelling, statistical learning) (Hu and Twidale, 2023).

These methodological approaches inform the understanding of how users conceptualise and interact with technologies. They can also provide the empirical means to develop more transparent conceptual models.

Conceptual Models

Building upon the earlier discussion of conceptual models as a means to bridge the gap between designers' and users' mental models, a conceptual model "provides a working strategy and a framework of general concepts and their interrelations" (Sharp et al., 2019). The importance of conceptualising a design at this level is that it enables "designers to straighten out their thinking before they start laying out their widgets" (Johnson and Henderson, 2002, p. 28; cited in Sharp et al., 2019). The core components of a conceptual model include metaphors, concepts (e.g., saving), and their relationships. Organising these components is a major determinant of user experience (Sharp et al., 2019). Some of these core components are discussed in the subsections that follow.

Affordances: One approach to designing interfaces to be more transparent is using 'affordances' (Sharp et al., 2019). Affordances signify an object's feature that lets people understand how to use it (Sharp et al., 2019). In simple terms, to afford means "to give a clue" (Norman, 1988). For example, the handle of a mug affords gripping. In designing UIs, affordances are used to make interacting with an interface for a user more obvious. Interface design patterns and elements are designed based on how to make interacting with them more obvious, e.g. icons should afford clicking.

Wyche et al. (2019) employed an affordance-based approach in rural Kenya to investigate what affordances of phones were used and what affordance types of support/constrain rural women's usage practice. The study found that phone designs afford voice communication but lack affordances that support novice users in using other features, such as messaging and browsing (Wyche et al., 2019). In another study, the signifiers for dragging and double-tapping affordances for objects in an interface were evaluated at different textual literacy levels (Damkjær et al., 2019). Affordances provide opportunities in HCI to design more understandable interfaces.

Metaphors: are the central elements of conceptual models. Metaphors are often used to explain an unfamiliar or misunderstood phenomenon with something that is familiar and easy to understand. This has been adopted in Human-Computer Interaction (HCI) (Norman, 1988). One such is the search engine metaphor, which invites comparisons between a mechanical engine, which has various working parts and requires searching for a thing in different places (Sharp et al., 2019). This concept is now referred to as interface metaphors. Interface metaphors aim to simply user interaction by making the user of an interface link unfamiliar aspects of an interface with their familiar knowledge (Turner, 2008). The closer the bridge between new ideas and pre-existing knowledge is, the easier it is to understand new ideas (Carroll and Thomas, 1982)

Metaphors and analogies are used on an interface as a way of visualising an operation (e.g., an icon of a shopping cart on an eCommerce website), as a conceptual model represented at the interface level (e.g., the desktop metaphor), and as a way of representing user ongoing activities (e.g., saving a file) (Sharp et al., 2019).

Interaction Types: encompass various ways users engage with products or applications, serving as a fundamental aspect of conceptualising design. Interaction types can be grouped into five categories (Sharp et al., 2019): Instructing involves users issuing commands to the system via various methods like typing, selecting from menus, speaking, gesturing, or pressing buttons. Conversing entails users engaging in dialogue with the system and receiving responses in return; examples include chatbots, advisory systems, and help facilities. Manipulating involves users interacting with objects in virtual or physical spaces by performing actions like opening, holding, and closing. Exploring allows users to navigate through virtual environments or physical spaces, e.g., Google Maps. Responding is where the system initiates interaction and prompts users to respond. For example, a mobile shopping application may alert users of current in-store sales when the user is within proximity to the physical store, giving them the option to engage with the information.

While these interaction types are not mutually exclusive, users may engage with a system through various activities. Additionally, the labels used for each type denote the user's action, even though the system may actively initiate the interaction.

Mental Model Research on FXI

While the theoretical foundations and general principles of mental models provide valuable insights, understanding the specific mental models of FXI users is crucial for designing inclusive and effective interfaces. Research into the mental models of FXI users is limited, with even fewer studies focusing on HCI4D contexts. However, the few existing studies provide valuable insights.

For instance, Asipade et al. used community-based participatory design and mixed methods to capture and analyse mental models of FXI users in Nigeria (Asipade et al., 2021). Their study revealed that "FXI and illiterate Nigerian women arranged clustered categories in chronological order, regardless of the physical layout (i.e., top-bottom or left to right)." This finding contrasts with Western users' preference for topically arranged information. The study also found some similarities in mental models across cultures, as the Nigerian women largely understood the underlying meanings of image cards designed by American researchers.

Connelly et al. employed card sorting and content analysis to elicit mental models from women in Mexico for a mobile health application (Connelly et al., 2016). Their findings highlighted differences between users' and researchers' mental models, particularly in terminology. Users preferred context-specific descriptions for behaviours (e.g., 'eat eat' instead of 'binge eating').

Though focused on web interfaces, Kodagoda et al.'s findings are relevant for their insights into FXI users' mental models in digital environments (Kodagoda et al., 2010). Their results indicated that LIT users had more consistent mental models in online searching on web interfaces, while FXI searches were more divergent.

Van den Broek et al. designed M-Tool, a mobile application to elicit participants' mental models, specifically FXI in sustainability research (Van den Broek et al., 2021). While beneficial for its fixed and unified set of concepts, the tool has limitations in allowing participants to add concepts or reveal the 'why' behind concept relationships.

The findings from these studies highlight the importance of understanding the unique mental models of FXI users and the challenges in designing interfaces that suit all users.

Summary

While mental model research in HCI has evolved, much of the theoretical discussion still relies heavily on milestone research from the 1980s (Hu and Twidale, 2023). This reliance shows that these theories have continued to provide valuable insights. Although some issues remain unresolved, mental models are valuable in HCI research and practice. As Hu and Twidale (2023) pointed out, directly taking users' answers to need assessment questions can be risky because of the potential discrepancy between users' actual, perceived, and stated needs. Moreover, the diversification of research methods noted by Hu and Twidale (2023) suggests that researchers are refining their approaches to studying mental models, potentially addressing some of the noted challenges.

Mental models offer advantages in this research with FXI users who, due to their lower literacy levels, may not clearly articulate their challenges with interface elements. In this context, mental models can reveal underlying human thinking and reasoning that may not be accessible through direct questioning. This is especially relevant when examining how FXI users interpret and interact with specific UI design patterns, such as buttons and icons. Although research on the mental models of FXI users is limited, especially in HCI4D contexts, exploring these mental models can uncover patterns of thinking that influence their engagement with design elements. Such insights can inform the development of more effective design techniques, leading to more inclusive solutions for FXI users.

3.1.3.2 Usability and User Experience

Usability and user experience (Ux) concepts are pivotal in guiding the evaluation and design of interactive systems to meet diverse user needs effectively. By clarifying the primary objectives of interactive products, these concepts ensure alignment with user requirements and preferences.

Usability

Usability plays a pivotal role in Human-Computer Interaction (HCI), defined as the measure of how effectively, efficiently, and satisfactorily a product can be used to achieve specific goals in a given context (ISO) (Punchoojit and Hongwarittorrn, 2017). In HCI, usability criteria serve to evaluate a product's potential to enhance user performance, encompassing factors like effectiveness, efficiency, satisfaction, safety, utility, learnability, and memorability (Sharp et al., 2019).

In the case of mobile HCI, guidance for mobile interface usability often takes cues from established principles in software design (Huang and Benyoucef, 2023). In addition, HCI studies often employ varying criteria to describe the usability of mobile interfaces. This variability means that the attributes and factors considered important for evaluating mobile application usability vary widely between studies (Huang and Benyoucef, 2022). For instance, effectiveness, efficiency, satisfaction, safety (error tolerance), utility, learnability, and memorability are fundamental elements (Punchoojit and Hongwarittorrn, 2017). Additionally, constructs like "usable," "usefulness," "desirable," "findability," "accessibility," "credibility," and "valuable" contribute to characterising mobile usability. Others focused on design aesthetics and readability (Guo et al., 2019), while others emphasised system visibility, user control, standards, error prevention, system recognition, efficiency, aesthetic design, error recovery, and help functions (Joyce et al., 2017). Other researchers leveraged Microsoft's mobile usability guidelines encompassing criteria such as aesthetic graphics, colour, control clarity, entry points, fingertip size, font, gestalt, hierarchy, subtle animation, and transition (Lim et al., 2022).

Usability criteria often centre around task-based metrics like time to complete a task (efficiency), time to learn a task (learnability), and number of errors made when doing a task over time (memorability) (Sharp et al., 2019), enabling quantitative assessments of productivity and/or learning in usability testing (Lazar et al., 2017). However, subjective aspects such as satisfaction and engagement underscore human emotion, which poses challenges for quantitative measurement, underscoring the importance of considering user experience alongside usability metrics (Sharp et al., 2019).

User Experience

Historically, HCI primarily focused on usability, but it has since broadened its scope to encompass a broader range of aspects of user experience (UX) (Sharp et al., 2019). While usability goals aim to meet specific criteria like efficiency, UX goals aim to explain the overall nature of the user experience, for example, aesthetic appeal (Sharp et al., 2019).

User experience (UX) refers to how people interact with and perceive a product in the real world. According to Jakob Nielsen and Don Norman (2014), it encompasses "all aspects of the end-user's interaction with the company, its services, and its products" (Sharp et al., 2019). ISO defines user experience as "perceptions and responses resulting from the use or anticipated use of a product, system, or service," which includes emotions, beliefs, and expectations before, during, and after use (Chammas et al., 2015).

Specifically, UX focuses on users' feelings of pleasure and satisfaction when interacting with a product, including how it looks, feels, and operates. The goal of UX design is to evoke positive emotions (e.g., satisfying, engaging, enjoyable, and experiencing 'flow'[5],

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[5] Flow, a concept by Csikszentmihalyi (1997), is pivotal in interaction design, shaping UX in web interfaces and video games. It denotes deep emotional engagement, like losing track of time while immersed in an activity like playing music. Rather than catering solely to goal-oriented goals of users, designs can induce flow, guiding users to unexpected destinations. Csikszentmihalyi (1996) compares this to a gourmet meal, where the experience unfolds gradually, leaving users eagerly anticipating the next course (Sharp et al., 2019).

while reducing negative emotions (e.g., boring, unpleasant, annoying, and patronising) (Sharp et al., 2019).

Unlike usability, which evaluates a system's utility and productivity, UX considers users' holistic experiences from their perspective. However, the distinction between usability and UX is not always clear-cut, as aspects like aesthetics and usability are closely intertwined. Therefore, while distinguishing between usability and UX is helpful for clarification, it is essential to consider them together when designing for the user experience (Sharp et al., 2019).

3.1.3.3 The User in HCI

The user holds a central position in HCI (Satchell and Dourish, 2009), embodying the core principle of universal design. This philosophy advocates for creating products and services accessible to the widest possible user base, aligning with the 'design for all' concept (Petrie and Bevan, 2009). Recognising individual differences is crucial, as solutions effective for one user group may not suit another (Sharp et al., 2019). Understanding users within their contexts- where they live, work, and learn - facilitates the design of interactive products that deliver optimal user experiences or cater to specific needs (Sharp et al., 2019).

To achieve the goals of universal design, it is imperative to understand the diversity among users (Punchoojit and Hongwarittorrn, 2017). Various dimensions of user diversity differentiate user groups, encompassing disabilities, age-related factors, cultural influences, and levels of computer expertise (Stephanidis, 2014). For instance, disabilities may include visual impairments (e.g., understanding), auditory impairments, motor impairments (e.g., (poor muscle control, arthritis, paralysis), and cognitive impairments (e.g., Alzheimer's, dementia, dyslexia, Down's syndrome), all of which impact interaction with technology. Furthermore, age-related differences affect physical qualities, cognitive abilities, and information processing, particularly among older adults and children. Cultural factors introduce variations in interpreting symbols, colours, gestures, communication styles and language. At the same time, differences in computer expertise exist among user groups with varying levels of familiarity with technology, particularly among older adults and those with limited education (Stephandis, 2014).

Two key concepts are pivotal to further advancing universal design: accessibility and inclusiveness. Accessibility ensures that interactive products are usable by as many people as possible, inherently promoting inclusive design. Inclusive design fosters fairness, openness, and equality for all users, striving to accommodate the widest possible audience (Sharp et al., 2019). According to ISO/IEC 25010 (ISO, 2011), accessibility is a sub-characteristic of usability, emphasising the importance of considering the latter in achieving universal design objectives (Zaina et al., 2022).

With these foundational principles in mind, the concept of User Interface Design Patterns emerges as a framework for applying well-defined, well-researched best practices in design.

3.1.3.4 User Interface Design Patterns

User Interface Design Patterns have evolved from the concept of reusing and repurposing best practices in graphic design, coupled with principles from object-oriented development, leading to their natural evolution (Hoober and Berkman, 2011). The notion of patterns originated with architect Christopher Alexander in the late 1970s, who viewed them as components of a language for building and organising spaces, reflecting human existence (Hoober and Berkman, 2011; Sharp et al., 2019). In the late 1980s, object-oriented software development embraced Alexander's concept, applying it as problem/solution statements for selecting the most suitable pattern in technology design (Hoober and Berkman, 2011).

In mobile interactive design, user interface design patterns are simply well-defined, well-researched best practices that offer reusable solutions to common design problems while adhering to fundamental design principles that involve understanding user needs, context and others while keeping the user at the forefront (Sharp et al., 2019; Zaina et al., 2022). Patterns serve as a collection of heuristics condensed into accessible forms for quick reference, embodying best practices in design (Hoober and Berkman, 2011).

A pattern must not only be a best practice but also characterised as 'commonly encountered' to be recognised as such. Numerous design patterns either fail to function effectively or do not perform as efficiently as alternative approaches, often labelled as antipatterns (or "worst practices"). Typically, a pattern must represent a best practice and be prevalent enough to be widely acknowledged or encountered (Hoober and Berkman, 2011).

Importantly, while patterns offer well-defined best practices, adherence to fundamental design principles, user-centricity, and design purpose remain paramount in their application, particularly in mobile interactive design (Hoober and Berkman, 2011). Designers need to understand the context in which a pattern is applicable, the conditions under which it should be used, and the rationale behind its application (Javahery et al., 2011; Zaina et al., 2022).

According to Hoober and Berkman (2011), despite the potential for customising solutions to meet specific system needs, user interface design patterns remain largely plug-and-play in mobile HCI. Surprisingly, many so-called "super-cool" design practices are merely slight modifications or direct replicas of methods used in older devices, such as PDAs from a decade ago or feature phones. Notably, in some instances, the latest technologies have strayed from the established practices of older scroll-and-select devices. This trend highlights the tendency of design practices to draw heavily from past experiences and iterations, often resulting in the recycling of old ideas in new contexts.

Various user interface design patterns are accessible in mobile device libraries (Zaina et al., 2022). In this thesis, I will utilise the detailed categorisation of major UI design patterns outlined by Hoober and Berkman (2011) in "Designing Mobile Interfaces." This foundational work outlines 14 categories of design patterns and their sub-elements, providing a comprehensive guide for mobile interface design (see Table 2). Notably, the authors cover various elements, including antipatterns, variations, and best practices, rendering their textbook an invaluable resource for comprehending and applying UI design principles in mobile interfaces.

Table 2: Categories of major mobile UI design patterns (Hoober and Berkman, 2011)

S/N	**Design Patterns**	**Elements**
Part 1 Composition		
1	Page Composition	Scroll, Annunciator Row, Notifications, Titles, Menu, Screens and Advertising
Part 2 Components		
2	Display of information	Lists, carousels, grids, film strips, slideshows, and infinite areas.
3	Control and confirmation	Confirmation, sign-on, exit guard, cancel protection and time out
4	Revealing more information	Window shade, pop-up, hierarchical lists and returned results
Part 3 Widgets		
5	Lateral access	Tabs, peel away, stimulated 3D effects, pagination, and location within
6	Drilldown	Links, icons, buttons, indicators, stacks of items and annotations
7	Labels and Indicators	Ordered data, tooltip, avatar, wait indicator, reload, synch, and stop.
8	Information Control	Zoom and scale, location jump, search within, and sort and filter
Part 4 Input and Output		
10	Text and Character Input	Keyboards and keypads, pen input, mode switches, input method indicator, and autocomplete and prediction
11	General Interactive Controls	Directional entry, press and hold, focus cursors, hardware keys, access keys, dialler, and gestures.
12	Input and Selection	Input area, form selections, mechanical style controls and clear entry.
13	Audio and Vibration	Tones, voice input, voice readback, voice notifications and haptic output
14	Screens, Lights and Sensors	LED, display brightness controls, orientation and location.

Having explored principles like usability, user experience (UX), universal design, accessibility, and inclusiveness, it is clear that understanding the user is pivotal in HCI research. These principles demonstrate users' diverse needs and experiences, underscoring the importance of designing interactive systems that accommodate various user groups. Building on this foundation and considering the differences in capabilities between FXI and LIT users, particularly in their interaction with mobile UIs, the next section examines UI patterns within the context of FXI users. This examination aligns with the user diversity dimension of expertise, recognising that to achieve UIs suited to a wide range of abilities, FXI are categorised as one of the dimensions to consider, suggesting that they have distinct needs compared to other user groups. This examination considers the interaction of FXI with mobile UIs through the lens of design patterns by Hoober and Berkman (2011).

3.1.4 Prior Research on FXI's interaction with User Interface Design Patterns

Hoober and Berkman (2011) present a comprehensive framework for mobile interface design by categorising UI design patterns into four parts (see Table 2). Part 1 emphasises Page Composition, ensuring cohesive designs aligned with user understanding, while Part 2 explores components essential for user interaction. Part 3 explores Widgets, and Part 4 examines Input and Output dynamics, addressing user preferences and interaction methods. The rest of this section is based on each of these parts.

Importantly, not all UI elements listed in Table 2 are covered in this section due to a lack of information in prior literature. Some uncovered elements are briefly described without prior works cited because they are observed in our investigation and will be discussed in the Results and Discussions sections.

3.1.4.1 Part 1: Page Composition

Page composition involves assembling components, concepts, and content to create a final design (Hoober and Berkman, 2011). Research has suggested specific considerations for page composition design tailored to FXI. Only scroll and menu patterns are discussed in this section because the other elements are out of the scope of this thesis.

Previous studies have noted that FXI users often experience challenges with vertical scrolling due to low discoverability and unfamiliar gestures (Adama et al., 2017; Ahmad et al., 2017). Many expect all content to fit on one screen and feel disoriented when faced with scrollable layouts. Researchers recommend limiting information to a single screen when possible and using cues like arrows or scroll indicators to guide users (Rayed et al., 2023; Shah and Sengupta, 2018). Although some attempts have experimented with animations or pop-up hand gestures to prompt scrolling, these techniques often confused users who are unfamiliar with such interface metaphors (Ahmad et al., 2017).

Menus present similar usability issues, particularly those involving deep hierarchies or nested structures. FXI users frequently lose track of where they are within layered menus and experience challenges in backtracking (Melo et al., 2024b; Anam and Abid, 2020). Simplified menu structures with reduced depth have therefore been recommended. FXI participants in several studies expressed a preference for linear paths and fewer submenus, as longer sequences demanded more cognitive load and patience (Padhi et al., 2018). Some users relied on memorised sequences to navigate, such as counting of button presses to reach a feature (Agrawal et al., 2013; Ahire et al., 2014). This prompted researchers to include visual step-counts or numbered items in redesigns to aid memory and navigation while also maintaining consistent positioning.

3.1.4.2 Part 2: Components

Components play a crucial role, occupying substantial portions of the screen and serving as primary elements for user interaction (Hoober and Berkman, 2011). This section encompasses various components in UI design, broadly categorised into information displays, control and confirmation, and revealing more information.

Display of Information

When presenting information, aligning with the user's mental model is essential, mirroring how they organise and process knowledge (Hoober and Berkman, 2011). Additionally, limited literacy further influences visual processing, causing variations across users, as discussed in section 2.1.2.1. Broadly, the widely adopted methods of organisation for information architecture are hierarchy and faceting (Hoober and Berkman, 2011). In a hierarchical model, information is structured based on divisions and establishes parent-child relationships, offering a structured and ordered view for user navigation. In contrast, faceting, without parent-child relationships, organises information based on attributes (e.g., colours or tags), allowing sorting and filtering to present the most relevant information.

FXI users experience significant challenges when navigating hierarchical structures due to the cognitive demand of nesting and memory recall. Flat, list-based structures using the faceting model have been shown to improve usability by reducing complexity (Melo et al. 2024b; Medhi et al., 2013; Ahmed et al., 2015). List navigation does not demand much from the user's memory, it primarily involves moving back and forth along a single line (Islam et al., 2023). In contrast, hierarchical navigation appears more complex because users must remember their position within a hierarchy and maintain awareness of the hierarchy structure starting from the root level in their thinking (Padhi et al., 2018). Consequently, many researchers recommended designing information architectures in UIs as flat and linear, following the faceting model whenever feasible and reducing hierarchical depth, even if it means sacrificing conciseness (Medhi et al., 2013).

Thumbnail-enhanced vertical lists help FXI users recognise items more easily, especially when paired with culturally relevant or familiar imagery as the recognition of images was found to be a common coping mechanism for such users (Agrawal et al., 2013; Ahire et al., 2014).

While the above view shows a preference for the faceting model, other researchers have suggested the concept of hybrid navigation, combining elements of faceting and hierarchical models to offer navigational flexibility without compromising usability (Chen et al., 2016; Medhi et al., 2013).

However, this recommendation brings into question whether grouping by categories as a concept is easily perceived by FXI. Although we touched on how to structure and organise data on a mobile UI for FXI above, it is important to point out that this is dependent on the data we perceive and the knowledge types we store. Hoober and Berkman (2011) note that although all humans have similar visual processing systems, a standardised method is required to describe and note our perceptions. Otherwise, communicating this information can become arbitrary and unsuccessful when designing information displayed on UIs. Similarly, we also employ a standardised method to classify our perceptions.

Research also suggests that FXI categorise information differently across cultural contexts. Indian users preferred file-folder metaphors for grouping songs (Ahire et al., 2014), whereas African users had difficulties with conventional office metaphors, favouring culturally specific metaphors instead (Heukelman and Obono, 2009). These findings highlight the importance of tailoring categorisation schemes to user context. However, the findings from both studies do not tell us why this categorisation was done that way for FXI. Consequently, we cannot ascertain whether the findings were influenced by literacy or other factors discussed in the subsequent paragraphs.

Beyond structure, information design elements like consistent positioning, colour coding, and visual hierarchy are critical. Some studies have observed FXI behaviour regarding the position of information designed into mobile UIs. FXI benefit from predictable layouts and fixed button positions and often memorise spatial layouts rather than symbolic icons (Guimarães et al., 2022; Ahmed et al., 2015). This resonates with the well-established design principle of consistency in interaction design (Rogers et al., 2023). Interestingly, FXI tend to focus on the middle of the screen for key functions (Islam et al., 2016), which contrasts with established design norms that place priority content in the upper-left (Nielsen, 2010).

Colour is another critical visual attention cue for FXI (Singh et al., 2016). While colour names may be unfamiliar, users can distinguish colours and associate them with functions (Shah and Sengupta, 2018; Agrawal et al., 2013). This makes colour changes useful for highlighting transitions or alerts (Matthews and Microsave, 2017). Additionally, colour-coded icons can support grouping (Doke and Joshi, 2015) and clarify menu hierarchies (Ahire et al., 2014). However, Tandon et al. (2019) found mixed results, where colour coding worked in one task but failed in another, highlighting the limits of visual cues alone and suggesting that audio may offer better support in complex tasks.

Cultural variation in categorisation styles also influences how users interact with UI structures. For instance, African adults often group by colour, unlike Western users who shift from colour to shape and function as they age. These differences are attributed to culture than cognitive development (Bechtel and Graham, 1999). Reinecke and Gajos (2011) argue that societal structures play a role too: people from individualist cultures tend to group objects by categories (e.g., monkey and panda), while those from collectivist cultures prefer relational groupings (e.g., monkey and banana) (Ji et al., 2004). They also suggest that language structure, which emphasises nouns in Western languages versus verbs in East Asian ones, can shape users' focus on individual objects versus relationships. This influences how different cultures process and categorise content. Although these studies focus on non-African contexts, they imply that FXI users' UI categorisation challenges may arise not only from limited literacy, but also from broader sociocultural patterns that shape attention, reasoning, and grouping preferences.

Design-wise, limited screen space makes clarity essential. Studies recommend reducing on-screen content and using white space for cleaner layouts (Srivastava et al., 2021). Presenting information with bullet points and avoiding repetition improves readability (Kodagoda et al., 2010). Additionally, highlighting keywords in brief instructions was recommended to highlight desired actions (Melo et al., 2024b). FXI benefit from contextual headings and standalone pages, as they tend to read word-for-word rather than scan content like more literate users (Anam and Abid 2020; Colter and Summers, 2014).

Control and Confirmation

Control and confirmation patterns serve as proactive safeguards, helping FXI users avoid costly mistakes due to physical or cognitive limitations. Although no specific literature is cited here on control patterns, they are included because they are referenced in the redesign and discussion chapters. A common form of confirmation is the pop-up dialogue, which prompts users to confirm actions or make choices. However, prior research showed that pop-up messages containing written instructions caused confusion and difficulty for FXI users, even among those with relatively better reading skills (Agrawal et al., 2013). Users expressed a strong preference for audio prompts, which enabled them to perform tasks more accurately when paired with recognisable button.

3.1.4.3 Part 3: Widgets

Widgets such as buttons, links, icons, indicators, tabs, and tooltips serve various purposes within the user interface designed to display concise information, offer alternative views of data.

Widgets for Lateral Access

Widgets are visual UI elements that enable interaction, selection, and navigation in mobile interfaces (Hoober and Berkman, 2011). For FXI users, research has identified several usability challenges and adaptations

Lateral Access: Widgets such as tabs and pagination enable users to access related content horizontally without diving deep into hierarchies. These can reduce cognitive load and support clearer navigation, though no FXI-specific studies were identified on these patterns (Hoober and Berkman, 2011).

Drilldown Widgets: ***Buttons*** and ***links*** are widely used to initiate actions. FXI users benefit from symbolic and visually distinct buttons, especially when supported by high contrast or colour differentiation as black and white action elements tend to be misinterpreted as labels (Srivastava et al., 2021; Anam and Abid, 2020). Additionally, poor button placement, such as awkward screen positions, can hinder discoverability (Srivastava et al., 2021). These considerations of colours and button positioning are interconnected with other UI patterns discussed previously. To avoid redundancy, refer to the information design discussion in the previous section on the *Display of Information* above.

Indicators, such as icons with text labels, can aid understanding when they clearly communicate what action, or content will follow (Hoober and Berkman, 2011). These elements support task guidance and reduce ambiguity for users unfamiliar with standard UI conventions.

Icons: Icons play a fundamental role in UI design due to their ease of recognition and recall. For FXI users, icon interpretation depends heavily on memory, visual recognition, and cultural familiarity (refer to section 2.1.2 for a fuller discussion). Studies show that too many or abstract icons increase cognitive load (Islam et al., 2023; Guimarães et al., 2022). Researchers have suggested iterative testing to improve clarity on accurate user interpretation (Mehmood et al., 2019), though findings may not generalise across all FXI groups.

The assumption of icon universality is challenged across cultures (Guimarães et al., 2022; Cheema et al., 2022). Redesigns aligned with specific cultures have shown improved recognition and interpretation. For instance, international icons such as arrows were replaced with socio-cultural objects such as trees, hands and bowls in a study in Ghana (Bayor et al., 2018). Yet, cultural substitutions can still cause misinterpretation or socio-political controversy, as seen with an umbrella icon linked to a political party in Bayor et al. (2018).

Designers have also drawn from user's prior experiences. For example, using local currency photos for mobile money (Mesfin et al., 2015) or gramophones for music apps (Ahire et al., 2014. However, Ahmad et al. (2017) used real hand gestures (3D graphical representations intended as a real-life metaphor) to animate UI interactions that confused all FXI users. Instead, users preferred static black-and-white images or cartoon art to depict selecting an option, indicating a complexity and variability in choosing effective icons for FXI. Some studies recommend pairing icons with audio rather than text to support comprehension (Guimarães et al., 2022; Bailis et al., 2016). Although icons are often relied upon to replace text, supplementing them with brief cues remains important for clarity (Wiedenbeck, 1999)..

Widgets for Labels and Indicators

Labels and indicators enhance UI understanding by conveying device status, presenting data, and guiding user action. While general UI patterns like tooltips and status indicators are widely documented (Hoober and Berkman, 2011), research on their adaptation for FXI is limited.

Avatar: An Avatar is an iconic image representing an individual, often used to identify contacts in address books or user profiles. Although underexplored in FXI research, avatars have shown the potential to build emotional connection and trust. Coetzer (2019) tested different mobile health UIs, finding that an anthropomorphic design, featuring a character and interactive element was more positively received than earlier versions. FXI users responded better to this avatar-based design, which evoked emotions and encouraged engagement, suggesting that well-designed avatars can support trust and usability for this group.

Widgets for Information Control

These widgets help users interact meaningfully with large datasets through drilldown, sort, and filter mechanisms (Hoober and Berkman, 2011).

Search Within: The Search Within UI pattern enables efficient navigation within extensive lists or data arrays by offering a searchable function, which helps users locate specific items quickly and reduces browsing effort (Hoober and Berkman, 2011). Researchers highlight the importance of optimising search elements to handle human error and misspellings for FXI users (Guimarães et al., 2022). Although general research has explored the search behaviour of FXI, Ahire et al. (2014) specifically examined this behaviour within the context of the Search Within UI pattern. FXI users developed memorisation strategies when using search functions, recalling the initial letter and relative list position of items, such as songs, to locate them quickly. This behaviour reinforces the role of familiarity and positional memory in interactions for FXI.

Sort and Filter: While not extensively explored in FXI-specific studies, these UI patterns enable users to narrow information based on attributes and are discussed further in this thesis's redesign chapters due to their relevance to task performanceClick or tap here to enter text..

3.1.4.4 Part 4: Input and Output

This section addresses how FXI users interact with mobile interfaces through input and output patterns, focusing on text, numeric, and audio interactions. Other patterns such as vibration, lights, and sensors are beyond the scope of this thesis.

Text /Character Input and Keyboard/pad: FXI users face challenges with keyboards, mode switches, and inconsistent input types. Agrawal et al. (2013) found users had difficulties in dismissing on-screen keyboards, prompting a redesign with static keyboards to reduce confusion. Adama et al. (2017) highlighted inconsistent keyboard types (e.g., showing alphabetic instead of numeric keyboards for phone numbers), which led to frustration in a mobile banking application. Researchers emphasised the importance of maintaining consistency in automatically displaying the correct keyboard format based on input and careful consideration for case sensitive entry fields to enhance accessibility for FXI (Durrani et al., 2019; Ahmed et al., 2019).

Besides the virtual keyboard, text entry itself is extensively studied in HCI4D, especially concerning FXI users due to their limited textual literacy skills (Ahmed et al., 2019). Researchers have recommended interfaces that consist of graphical icons, voice and limited text as a replacement for traditional text-based for sending/receiving SMS (Gondal et al., 2021). Many FXI users develop coping mechanisms, seeking assistance from others who understand English and the device's functionalities (Ghosh et al., 2016). Others rely on the recognition of images, colours and sounds to navigate interfaces rather than reading (Melo et al., 2024b). Even those with relatively higher textual literacy skills in English may have difficulties with specialised or technical terms in UIs (Adama et al., 2017; Medhi et al., 2009).

Some HCI4D researchers advocate for localised language options rather than English for FXI users to resolve issues independently (Srivastava et al., 2021; Shah and Sengupta, 2018; Matthews et al., 2017). However, some FXI users experience difficulties even with local language terms (Ahire et al., 2014; Medhi et al., 2011). Many researchers emphasise similar recommendations on the importance of using simple, straightforward language that is easily understood by FXI (Chaudhry et al., 2021; Vosloo, 2018).

Considerations extend beyond text to numerical entry, which has shown to play a significant role in interface design (Chaudhry et al., 2021). FXI users are often more confident with numbers than with text. Designers have leveraged this, such as prefixing contacts with digits to improve recognition (Srivastava et al., 2021). Despite this, some users encounter difficulties associating numbers with specific actions, requiring a nuanced consideration in the design process (Parikh et al., 2003).

Further explorations into alternative methods beyond traditional text/numerical input for FXI users have considered QR codes. De et al. (2015) compared text-based and QR code-based mobile payment applications and found a substantial improvement in task completion rates and time with the QR code-based input vs text across IL, FXI and LIT users. Interestingly, most of the participants who preferred text input were FXI users. The authors concluded from the interviews that this preference was influenced by the unfamiliarity of the QR code method, as FXI users were accustomed to text-based inputs for other activities.

Apart from numerical and QR-based alternatives, researchers have explored completely text-free designs to improve interaction for FXI users. Audio-based interfaces, for instance, bypass the need for reading and can enhance usability. In a study by Bayor et al. (2018), spoken user interfaces significantly outperformed text-based ones in task completion among FXI participants. However, other research highlights trade-offs: Padhi et al. (2018) found that audio increased cognitive load and slowed interaction for some users. As a result, multimodal interfaces that combine text, icons, and audio cues are widely recommended as a more flexible and inclusive approach (Melo et al., 2024b; Chaudhry et al., 2021; UNESCO, 2018).

Other Input Methods: Research on alternative input methods for FXI is limited but included here due to their appearance in the results and redesign sections. Autocomplete and prediction features (e.g., for URLs) can reduce text input demands, but care is needed to avoid overwhelming users. Gesture-based controls and mechanical elements (e.g., sliders and spinners) offer alternatives for numeric and functional input, though these were not the main focus of prior FXI studies.

Forms remain a central interaction point, especially for tasks like checkout or registration. Their design must minimise cognitive load and input complexity to support FXI users effectively (Wroblewski, 2010). Researchers have highlighted that for FXI, dividing form-filling steps by screen is important to avoid cognitive overload (Melo et al., 2024b).

3.1.4.5 Prior Design Guidelines for FXI Users

Several studies have proposed design considerations to support FXI users. Early work by Medhi-Thies et al. (2007, 2009) emphasised flat navigation and pictorial UIs. More recent contributions include Islam et al. (2023), who categorised 16 recurring considerations, and Teran et al. (2024), who proposed 29 considerations for real-time payment systems. Melo et al. (2024b) validated 33 accessibility guidelines through inspection of Brazilian banking applications, while Srivastava et al. (2021) outlined design principles based on a synthesis of prior works focused on form clarity, input consistency, and visual cues. These works are referenced where relevant in the above sections.

However, most of these guidelines were developed in specific domains or cultural contexts and do not comprehensively link UI patterns to user difficulties across tasks, as addressed in this thesis. Additionally, the Nigerian context remains underexplored in existing design recommendations for FXI users.

3.1.4.6 Summary of Mobile UI Patterns

In reviewing prior work on UI patterns within the context of FXI users, it becomes evident that certain UI patterns pose significant challenges for this user group. For instance, menu structures featuring deep hierarchies and numerous parent-child relationships can bewilder FXI users. Interestingly, FXI users are inclined to categorise by metaphor, such as utilising file folders to organise media, a practice influenced by cultural and literacy factors. Consequently, designing mobile GUI widgets for FXI users necessitates addressing perception, interaction, cultural relevance, and cognitive load issues. These challenges profoundly impact the usability and UX of mobile interfaces for FXI individuals. Notably, such difficulties may stem from the tendency of the design community to adopt UI patterns as a "plug-and-play" approach in mobile HCI without fully considering their appropriateness or implications.

As highlighted in the literature section introducing UI design patterns, effective application of UI patterns requires designers to be well-informed regarding when, how, and why a particular pattern should be employed (Javahery et al., 2011). Failure to do so can lead to suboptimal outcomes. Context and user considerations are paramount in determining the suitability of UI patterns in design. However, despite technological advancements, many contemporary design practices are merely adaptations or repetitions of methods found in older devices (Hoober and Berkman, 2011), indicating a reliance on past experiences and iterations. This also demonstrates that such patterns are normative for designing and using mobile devices. This reliance underscores the need for a shift towards more user-centric design practices, particularly considering the diverse user demographics often overlooked in earlier waves of HCI.

The literature also prompts a broader discussion on how design patterns can inadvertently marginalise certain user groups, including FXI users, through a "plug-and-play" approach that neglects their unique needs. HCI researchers and designers frequently view users in abstract terms (Cooper and Bowers, 1995), neglecting the nuanced realities of diverse user populations. Recognising the complexities of users in HCI is crucial, whether as relational entities (Bardzell and Bardzell, 2015) or contextual features within design processes (Martin et al., 2007).

The historical framing of users in HCI as generic entities reflects a colonising dimension of modernity, which risks marginalising certain user groups through UI design patterns that fail to accommodate their needs, whether unintentionally or negligently - allowing such arbitrary constructions to persist risks legitimising categorisation that may exclude FXI users. As Adamu and Lazem (2024) argue, the African user continues to be positioned as an “outlier” in HCI design processes, constructed within capitalist or imported paradigms of user-centricity that often fail to reflect local realities. Prioritising the recognition and constitution of users as worthy entities is essential for satisfying their quest for personhood. This requires decentralising universal definitions of the user.

Notably, another implication of the 'universal' frame of the user in HCI is it may contribute to the proliferation of dark patterns in UI design. Dark patterns involve deceptive practices that prioritise persuasion over usability, potentially exacerbating the marginalisation of certain user groups (Sharp et al., 2019). These patterns exploit designers' knowledge of user behaviour, often resulting in interface interference that hinders UX. While some stem from poor design practices (anti-patterns), many result from intentional decisions influencing user behaviour (Gray et al., 2018; Mathur et al., 2021). For instance, aesthetic manipulation (an aspect of a dark pattern), involves using visual elements to distract or persuade users using language, style, colour, or other elements to evoke emotions. False hierarchy, another aspect, visually or interactively emphasises certain options over others, misleading users into believing they have limited choices, such as presenting the "custom" installation option in grey text, suggesting it is disabled while clickable, thus guiding users to select the "recommended" option" (Gray et al., 2018).

These observations underscore the importance of ongoing research to evaluate and adapt UI patterns, particularly within the context of evolving user demographics. This need for adaptation aligns with efforts in HCI4D, focusing on considering users and contexts that are not clearly understood, which prioritise user-centred design perspectives and address issues that include politics, ethics, and values, in line with the fourth wave of HCI (see 3.1.1. HCI - From Waves to Turns). The evolution of HCI4D emphasises the importance of considering design alternatives and addresses the shortcomings of traditional design paradigms. The next section discusses the main themes in HCI4D and its approaches.

3.1.5 HCI4D Concepts, Approaches and Methods

Human-Computer Interaction for Development (HCI4D) started to develop in the early 2000s (Ho et al., 2009). It emerged at the intersection of the Information and Communication Technology for Development (ICT4D) and Human-Computer Interaction (HCI) disciplines (Van Biljon and Renaud, 2021). HCI4D aims to understand, design, and deploy ICTS for users and contexts that are not clearly understood (Dell and Kumar, 2016). To achieve this, HCI4D strives to learn from the limitations associated with low-resource contexts and how to navigate these constraints (Dell and Kumar, 2016). HCI4D incorporates HCI/UCD principles, but the mission is to translate and adjust them to fit the developing contexts adequately.

Several themes have emerged in HCI4D studies. These themes include the recognition of cultural, linguistic, and literacy disparities between HCI professionals from affluent backgrounds and the beneficiaries of global development efforts. Additionally, there is a focus on addressing hardware and infrastructure constraints, often requiring innovative solutions or alternative approaches (Dell and Kumar, 2016). Another prominent theme is the reliance on community sharing of technology and the involvement of intermediaries such as friends and family in technology use (Toyama, 2010). Furthermore, HCI4D research emphasises the complexity of problems, acknowledging that technological solutions alone may not suffice and that social, political, economic, and cultural factors also require attention (Dell and Kumar, 2016). Despite these challenges, there is a noted lack of theoretical focus in HCI4D research (Van Biljon and Renaud, 2021). Further themes include the study of how application design impacts livelihoods, the influence of cost-consciousness on UX, and the design of UIs to accommodate both content consumption and production by FXI users. Finally, there is a growing interest in sustainable development (Van Biljon and Renaud, 2021) and developing natural UIs suitable for LIT and tech-savvy users, with potential applications for UIs designed for FXI users.

In HCI4D, researchers have employed diverse methods and approaches to address the complex challenges of designing technologies for underserved communities. Among these methods are user-centred, community-based, and participatory approaches, each offering unique insights into the needs and contexts of the users involved. Moreover, HCI4D encompasses various theoretical lenses, including postcolonial and decolonial perspectives, critically examining power dynamics and historical legacies in design processes. This section acknowledges these approaches, exploring how they inform the 'user' and the design and implementation of technology solutions.

3.1.5.1 User-Centred Design

The User-Centred Design (UCD) approach, rooted in Ergonomics and Usability, prioritises understanding user needs and involvement throughout the design process (Marti and Bannon, 2009). ISO standards, notably 9241-210, underscore principles crucial for following a UCD approach (Saffer, 2010). This includes starting with a deep understanding of users, their tasks and environments, continual user engagement throughout, and iterative design processes. Additionally, UCD emphasises holistic consideration of UX and the integration of a multidisciplinary project team for diverse perspectives (Chammas et al., 2015).

For example, in addressing digital accessibility in questionnaires for FXI users, Cremers et al. (2017) developed a conceptual framework including key problem areas (cognitive, social/psychological, cultural, technological, and application-related) and mapped these to design solution spaces encompassing human-machine interface, physical appearance, and environmental factors. Through UCD with FXI participants, they demonstrated how interactive digital questionnaires could be made more accessible through features like speech output, simple language, clear visuals, and step-by-step navigation (Cremers et al., 2017). While their focus was on healthcare applications and questionnaire development, their findings stride towards models for designing interactions for FXI through a UCD approach.

In HCI4D contexts, UCD aims to empower users by giving them a voice in the design process, fostering a sense of ownership and agency over the technologies being developed (Chammas et al., 2015). However, its effectiveness relies on genuine user input and avoiding biases from the design team. Moreover, user involvement must consider factors such as age, ability, and environment. For instance, researchers advocate for tailored user participation, especially in fields where users have diverse mental abilities and involve caregivers as stakeholders to address potential misinterpretations of user needs (Marti and Bannon, 2009). Also, while ISO standards provide guidelines for UCD, Norman (2007) questions the political and economic influences shaping these standards and advocates for early user input to mitigate market dynamics' limitations. Newer critiques have emerged questioning whose experiences are genuinely centred. Adamu and Nkwo (2023) highlight how African users are often only considered ‘worthy’ in design when they align with economic goals, while Adamu and Lazem (2024) critique how abstraction in UX and HCI practices erases the situated experiences of African users, arguing for a re-centring of users' worth through contextually grounded and relational approaches.

Despite these challenges, the UCD approach is the most widely embraced in HCI4D. However, Saffer (2010) notes that the most effective designers often employ multiple approaches within a single project. Among these other approaches is a shift towards community-centric approaches (e.g., participatory design) as researchers navigate design challenges in socially interconnected but resource-challenged settings (Marsden et al., 2008). This transition emphasises community engagement, recognising diverse socio-cultural contexts. It is also within this evolving landscape that the concept of de/postcolonial computing emerges, focusing on cultural and power dynamics in design practices (Irani et al., 2010). These approaches are discussed below.

3.1.5.2 Participatory Design

Participatory design, originating in Scandinavia in the 1970s, involves engaging users in the design process, emphasising the concept of "use-before-use" to predict how designs will be used in everyday life before implementation (Redström, 2008). It values democratic principles and exploits the tacit knowledge of users. However, Adamu and Nkwo (2023) argue that participatory design in African HCI contexts often retains a Eurocentric grammar of participation, limiting authentic co-creation. Similarly, Adamu and Lazem (2023) show how even in participatory processes, abstraction and neutrality erase racialised experience, reinforcing structural exclusion. This challenge raises questions about the need to reassess participatory design and the goal of envisioning 'use before use'. Moreover, Nisha criticises participatory design because it mainly focuses on spatial aspects and overlooks power dynamics and control during the design process. She notes that participants often find it difficult to engage with the imagined space created/controlled by researchers, which limits their ability to effectively connect with the design process (Nisha, 2022).

Suggestions for flexible or open systems and ongoing adaptation beyond the initial design phase have been proposed in response to these limitations (Ehn, 2008).

3.1.5.3 Post-Colonial Design

In recent years, Western researchers have increasingly criticised the dominance of Western perspectives in global HCI discourse, advocating for more inclusive approaches to design (Bardzell and Bardzell, 2016). Other researchers offer a postcolonial critique of ubiquitous computing, highlighting how new technology-related knowledge tends to originate and revolve around Western research hubs, aspiring for 'universality' (Dourish and Mainwaring, 2012). The tendency for technological standards to be defined in Western contexts and then globalised exacerbates this trend, potentially neglecting or underrepresenting 'others' (Irani et al., 2010).

Simultaneously, non-Western researchers are directing initiatives to reimagine HCI studies and designs in the Global South. Through the establishment of local HCI frameworks and social intervention efforts, these researchers aim to address local challenges using locally designed solutions (Bidwell, 2016; Winschiers-Theophilus, et al., 2012). Central to these efforts is the inclusion of authentic voices from indigenous communities in technology design, challenging the dominance of Western approaches in non-Western contexts (Ali, 2016).

In HCI4D, researchers are increasingly exploring how foreign forces migrate to other regions, impacting Indigenous peoples' cultures, socio-political structures, and economic systems (Loomba, 2015). Within this discourse, two main perspectives have emerged: postcolonial and decolonial (Bhambra, 2014).

Postcolonialism and decolonialism have distinct origins and motivations. Postcolonial scholars analyse the impacts of colonialism primarily in the cultural sphere, with a focus on the nineteenth and twentieth centuries. In contrast, decolonial perspectives reject the racial supremacy of the West over colonial subjects and explore colonialism from the fifteenth century onward (Bhambra, 2014).

Postcolonial computing, introduced in 2010, highlights how technology originating from the West can inadvertently perpetuate colonial tendencies when introduced to diverse cultures (Irani et al., 2010). It underscores how projects aimed at "others" often mirror our cultural biases and power dynamics. Recognising this cultural specificity is vital in design practice, broadening the discourse on effective design (Irani et al., 2010).

While postcolonial theory addresses some aspects of colonial computing, it has been critiqued for its narrow focus and elite worldview (Ali, 2014). In HCI4D, there is a tendency to view local contexts as underdeveloped or lacking, which perpetuates a narrative of Western superiority. This perspective suggests that knowledge about non-Western contexts is primarily meant for Western consumption (Ali, 2016). To counter this, the decolonial agenda aims to dismantle colonial ideologies by prioritising peripheral perspectives and fostering critical self-reflection and dialogue with marginalised communities (Lazem et al., 2022).

3.1.5.4 Decolonial Design

In 2014, the concept of decolonial computing emerged, focusing on innovation practices in the Global South that resonate with local needs and values. Decolonial design inquires deeply into the actors, locations, and implications of computing. It surpasses postcolonial theory by scrutinising the historical foundations of fields such as ICT4D, HCI, and Interaction Design and urging for reparative actions to address past discriminations (Ali, 2016).

Decolonial computing redirects attention to peripheral regions, addressing geopolitical and bodily political issues while confronting the lasting impacts of colonial structures (Ali, 2016). Projects adopting a decolonial lens aim to empower researchers globally, challenging prevailing power dynamics, rectifying historical biases, and reducing the disproportionate influence of Western perspectives in technology design (Lazem et al., 2022). This approach contributes to shifting perspectives away from universalist knowledge creation rooted in grand narratives by focusing on contextualising diverse experiences, epistemologies, and narratives (Bidwell, 2016).

Decolonising existing practices involves reflecting on design's historical neglect of marginalised communities, particularly in the global South (Bidwell, 2016). It requires dismantling Western-centric foundations by contextualising design within diverse cultural contexts (Smith et al., 2020). Advocates call for "designing otherwise," resisting biases, deconstructing oppressive systems, and embracing diverse human values and perspectives (Leitão et al., 2021; Escobar, 2017; Ansari, 2020).

Importantly, Lazem et al. (2022) emphasise the nuanced understanding that an approach or method is not inherently colonising. They stress the importance of considering the interplay between factors such as who applies certain methods, where they are applied, to whom, and how. This understanding is crucial as it can prevent the unintentional continuation of neo-colonisation through the application of certain approaches or methods.

3.1.5.5 Summary of HCI-HCI4D

This subsection showed the notable shift from traditional UCD approaches and HCI view of 'the user' by researchers in designing for resource-poor yet socially interconnected contexts towards adjustments that reflect the diverse socio-cultural, infrastructural, and economic landscapes encountered in HCI4D. In doing so, researchers have substantially adapted their methods and practices. The discussion on postcolonial and decolonial approaches showcased the political/social science of what needs to be done, but in order to do it well, we need to consider the ways to do it in the context of the objectives of this research.

Within this context of evolving design methodologies in HCI4D, this research adopts a unique approach. Rather than solely relying on usability perspectives, it utilises a digital literacy perspective as a theoretical lens. This lens allows for a deeper understanding of FXI users and the essential skills required to interact with smartphone devices within the specific context of each mobile application. The significance of digital literacy in today's world cannot be overstated, as underscored by various national and regional initiatives aimed at enhancing citizens' digital capabilities (Iordache et al., 2017). The current shift towards digital platforms poses a challenge to those lacking essential skills, intensifying the urgency of fostering digital literacy (Bashir, 2020). Research conducted by experts in digital literacy emphasises that digital skills are increasingly critical for ensuring societal participation (Van Deursen and Van Dijk, 2014; Helsper and Eynon, 2013).

Combining usability and digital skills perspectives provides a structured approach for researching and evaluating specific digital competence areas through usability tasks by providing a backbone for selecting the set of tasks to assess from each mobile application. Mapping usability tasks within digital literacy frameworks in HCI4D will enhance our understanding of user capacities and needs. Digital literacy frameworks will not only provide structured design themes for in-depth research but also offer a more comprehensive perspective for potential collaboration among policymakers, designers, and researchers based on research findings. Therefore, a digital literacy perspective may offer important insights for HCI4D research.

Although this combination of digital perspectives is uncommon in the context of this research objectives, it is aligned with Toyama's insight into HCI4D, emphasising the strength of HCI in addressing issues of interdisciplinarity and respecting the unique strengths of different methodologies (Toyama, 2010). Moreover, as highlighted in the discussion on HCI4D themes, there is a historical lack of explicit theoretical focus in HCI4D research (Van Biljon and Renaud, 2021; Dell and Kumar, 2016) attributed to not necessarily a lack of theorisation but an indication of the use of alternative formulations and formats for contributions (Van Biljon and Renaud, 2018). Therefore, within this broader context, this research aspect also responds to this gap in theoretical application, aligning with the evolving design methodologies that contribute to the interdisciplinarity of HCI4D research.

Building on this view, this research considered digital literacy frameworks as a theoretical approach for HCI4D investigations. Notably, at the start of this study, Nigeria lacked a national digital literacy framework. However, a significant development occurred in July 2023 when the National Information Technology Development Agency (NITDA) unveiled the National Digital Literacy Framework (NDLF). In response to the absence of a national digital literacy framework in Nigeria at the onset of this research, it was crucial to consider alternatives to digital literacy frameworks from prior literature, as discussed below.

3.2 Digital Literacy Frameworks

Digital literacy frameworks have emerged as crucial tools for assessing and improving users' competencies in interacting with Information and Communication Technologies (ICTs). Various digital literacy frameworks have emerged in previous research; see Table 3.

Among them is Eshet-Alkalai's (2004) framework, which emphasises cognitive and socio-emotional skills beyond technological tools. Van Laar et al. (2017) focus on 21st-century digital skills, encompassing technical proficiency and higher-order thinking processes. Van Deursen et al. (2014) propose practice-oriented skills, integrating aspects of communication and content creation. The Digital Competence Framework for Citizens (DigComp), developed by the European Commission, undergoes iterative revisions to address evolving digital competencies. Similarly, the Digital Literacy Global Framework (DLGF) builds on DigComp, adapting competencies to diverse contexts and addressing differences between developed and developing countries. The DLGF aims to offer a globally relevant and adaptable framework for assessing digital literacy (Law et al., 2018).

Table 3: Digital Literacy/Skills Frameworks

Digital Literacy Frameworks	Skills and/or Competences
(Eshet-Alkalai, 2004)	Photo-visual, reproduction, information, branching, and socio-emotional literacies
(Van Laar et al., 2017)	Core skills (technical, information management, communication, collaboration, creativity, critical thinking, and problem-solving) and Contextual skills (ethical awareness, cultural awareness, flexibility, self-direction, and lifelong learning)
(Van Deursen et al., 2014)	Operational, formal, information, strategic, communication and content creation skills
(Ferrari, 2013)	DigComp1.0 skills (creation of content and knowledge, managing information, collaboration, communication sharing, and evaluation and problem-solving) proficiency levels (foundation, intermediate, and advanced)
(Vuorikari et al., 2016)	DigComp2.0: maintains DigComp1 competencies while refining vocabulary and descriptors within the competencies
(Carretero et al., 2017)	DigComp2.1: maintains DigComp2.0 competencies while introducing eight proficiency levels and new use cases
(Vuorikari et al., 2022)	DigComp2.2: maintains DigComp2.0 competencies and 250 new examples of knowledge, skills, and attitudes.
(Law et al., 2018)	DLGF: seven core competence areas: devices and software operations, information and data literacy, communication and collaboration, digital content creation, safety, problem-solving, and career-related competencies

Each framework contributes uniquely to the assessment and enhancement of digital literacy, catering to various contexts and objectives. The motivations behind adopting and developing these frameworks are diverse. For instance, the DLGF is intended to monitor, assess, and further develop digital literacy, specifically for different levels of development (Law et al., 2018). Meanwhile, the Digital Competence Framework for Citizens (DigComp) aims to provide a common understanding, specifically within the European Union (EU), in defining digital competence and establishing a foundation for framing digital skills policy (Vuorikari et al., 2022). These examples of digital literacy frameworks are driven by distinct goals. They show various reasons for creating and applying them in the real world.

As shown in the Skills and/or Competences column in Table 3, commonalities across frameworks include foundational skills like operational, technical, and formal skills, alongside an emphasis on information, cognition, digital communication, and content creation skills (Van Deursen et al., 2014; Ferrari, 2013; Van Laar et al., 2017). While some frameworks prioritise comprehensive coverage (Ferrari, 2013; Van Laar et al., 2017), others maintain clarity with fewer competence areas (Eshet-Alkalai, 2004; Van Deursen et al., 2014). Each framework offers unique strengths and challenges, contributing to the diverse landscape of digital literacy assessment tools.

After considering various digital literacy frameworks, I chose the Digital Literacy Global Framework (DLGF). In the following section, I will provide some further background on the DLGF, then explain my rationale for choosing it for this research and acknowledge the limitations reported on it.

3.2.1 The Digital Literacy Global Framework (DLGF)

The DLGF encompasses seven core competence areas, covering devices and software operations, information and data literacy, communication and collaboration, digital content creation, safety, problem-solving, and career-related competencies (Law et al., 2018). Additionally, it introduces 26 competencies, expanding upon DigComp 2.0 by incorporating two additional areas: devices and software operations and career-related competencies (see Table 4).

Table 4: Digital Literacy Global Framework (DLGF) - Complete Framework (Law et al., 2018)

Digital Competence Area	**Digital Competence**
0. Devices and software operations	0.1 Physical operations of digital devices
	0.2 Identifying software to operate digital technologies
1. Information and Data Literacy	1.1 Browsing, searching and filtering data, information and digital content
	1.2 Evaluating data, information and digital content
	1.3 Managing data, information and digital content
2. Communication and collaboration	2.1 Interacting through digital technologies
	2.2 Sharing through digital technologies
	2.3 Engaging in citizenship through digital technologies
	2.4 Collaborating through digital technologies
	2.5 Netiquette
	2.6 Managing digital identity

Digital Competence Area	Digital Competence
3. Digital content creation	3.1 Developing digital content
	3.2 Integrating and re-elaborating digital content
	3.3 Copyright and licences
	3.4 Programming
4. Safety	4.1 Protecting devices
	4.2 Protecting personal data and privacy
	4.3 Protecting health and well-being
	4.4 Protecting the environment
5. Problem-solving	5.1 Solving technical problems
	5.2 Identifying needs and technological responses
	5.3 Creatively using digital technologies
	5.4 Identifying digital competence gaps
	5.5 Computational thinking
6. Career-related competences	6.1 Operating specialised digital technologies for a particular field
	6.2 Interpreting data, information and digital content for a particular field

Within the DLGF, digital literacy is defined as "the ability to access, manage, understand, integrate, communicate, evaluate, and create information safely and appropriately through digital technologies for employment, decent jobs, and entrepreneurship" (Law et al., 2018). It encompasses competencies commonly known as computer, ICT, information, and media literacy. The definitions for skills and competence in the DLGF were adapted from the European Commission (Law et al., 2018). According to the European Commission, skills refer to the ability and capacity to carry out processes and use existing knowledge to achieve results, while competence is characterised as a combination of knowledge, skills, and attitudes (European Commission, 2018).

3.2.2 Rationale for Choosing the DLGF

The DLGF is the appropriate theoretical lens for this research for many reasons. The first reason is the DLGF inherits the comprehensiveness of the DigComp framework's multiple revisions, which has a core strength in addressing the dynamic nature of technological advancements and is recognised as one of the most comprehensive and widely adopted digital skills frameworks globally (Bashir, 2020), but with one additional and important advantage - addressing contextual differences between developed and developing countries (Law et al., 2018). It provides a valuable methodology for mapping skills to diverse contexts, offering an advantage in adaptability. Given Nigeria's status as a developing nation without a specific digital literacy framework at the time, the DLGF offered a logical choice for adapting skills to this context.

Secondly, DLGF developed by the UNESCO Institute of Statistics was developed to establish a methodology supporting Sustainable Development Goal (SDG) thematic Indicator 4.4.2, measuring the "Percentage of youth/adults achieving at least a minimum level of proficiency in digital literacy skills." (Law et al., 2018).

Moreover, many frameworks often base assessments on ICTs in general or desktop computers, while the DLGF acknowledges the prevalent use of mobile devices in developing countries, particularly smartphones (African Union, 2020). Recognising that the required skill level can vary based on the device used, the DLGF provides guidelines to adapt the framework specifically to mobile devices (Law et al., 2018). This aligns with the research's focus on assessing digital skills on smartphones, especially in the contexts of mobile shopping and banking in developing countries.

Furthermore, the DLGF introduces a comprehensive guide for mapping digital skills to competencies, offering multiple accompanying use cases. This level of detail ensures transparency and replicability in the application and adaptation of the framework, which are crucial aspects of research. Notably, the DLGF has not been adopted in the HCI and HCI4D fields, making its application a novel contribution to this research. Leveraging the DLGF in this study not only combines usability and digital skills perspectives but also provides a structured approach for researching and evaluating specific digital competence areas through usability tasks.

3.2.3 Limitations of the DLGF

While the DLGF provides a comprehensive list of digital skills, challenges arise when converting digital literacy indicators into survey questions (Aesaert and van Braak, 2015). Additionally, concerns about the underrepresentation of indicators and issues of technological determinism in measuring digital skills have been raised in the literature (Van Deursen, 2010). However, this research does not rely on translating the framework into a traditional survey format. Instead, the study adopts alternative data collection methodologies involving screen interaction recording and think-aloud protocols, as detailed in the next section.

To address the challenge of possible complexities due to its comprehensiveness, the research will selectively test only those aspects of the framework that are directly relevant to the chosen mobile applications and align with the specific digital skills necessary for achieving the objectives of this study.

3.3 Summary

This literature section has highlighted theoretical backgrounds in HCI. The review on UI design patterns and their effectiveness for FXI users section underscored the necessity for alternative design considerations to understand their unique characteristics and design needs. While users share certain information processing traits, additional factors such as cultural background, life experiences, and literacy levels significantly influence their interaction with UIs. This means that the traditional 'universal' frame of the user is suboptimal. Additionally, it points out the static nature of UI design patterns since older devices and HCI methods, which are often applied without consideration for their appropriateness in diverse contexts. This may have contributed to the potential marginalisation of FXI users due to their likely alignment with earlier waves of HCI that overlooked such diversity. The context also being FXI users that are Nigerian indicates a double bill in terms of overlooking diversity. Much of this discourse aligns with the principles of decolonising design in HCI4D, involving decentralising the universal definitions of the user and advocating for the adaptation of HCI principles to suit the needs of developing contexts.

Building on this, this study integrates various HCI theoretical backgrounds, including usability, UX, and relevant models like mental and conceptual models, to assess current UI design patterns in mobile banking and shopping applications for Nigerian FXI users. Additionally, the choice to include a digital literacy perspective provides a structure towards evaluating essential skills required for proficient usage of the targeted applications within this thesis, such as banking and shopping, among FXI users. These evaluations inform the exploration of alternative UI design patterns tailored to better address this thesis's two primary research questions.

In summary, this section offered an overview of the existing literature, identifying relevant theories, methods, and research gaps. The subsequent section will leverage this understanding to discuss my approach to addressing the research questions in this thesis.

4 Methodology

This research addresses the critical need to understand how FXI user interaction can be improved through thoughtful design. Specifically, the focus is on investigating more inclusive UI design patterns tailored to the unique challenges faced by Nigerians FXI when using mobile banking and shopping applications on smartphones. As a reminder, the research questions underlying this study are:

1. What UI design patterns cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?
2. What design techniques can improve interaction for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

The findings will provide actionable insights and guidelines for designing more accessible and usable mobile applications for FXI users. This research employs a multifaceted philosophical approach, incorporating elements of positivism and interpretivism, but ultimately aligns most closely with pragmatism.

Aligned with the positivist philosophy, the study aims to measure user performance and satisfaction with different UI designs. Positivism emphasises the discovery of empirical facts and the establishment of objective knowledge through systematic and controlled research methods (Creswell, 2014). This philosophy is reflected in using hypotheses, quantitative measures, experimental design, and statistical tests within the study. Simultaneously, while positivism provides a framework for objective measurements, the study also embraces elements of interpretive philosophy. This approach recognises that knowledge is formed by understanding individuals' subjective experiences and socially constructed realities (Creswell, 2014). This is reflected in this study's objective of gaining insights into the challenges faced by FXI users when interacting with mobile banking and shopping applications on smartphones through exploring the context and personal experiences of participants using methods such as qualitative surveys and the think-aloud.

While positivism and interpretivism offer valuable insights, the pragmatic philosophy ultimately provides the most logical orientation for this research, effectively bridging the gap between these approaches. Pragmatism is centred on finding practical solutions to real-world problems and is not committed to any single system of philosophy or reality. This philosophy is particularly well-suited to the goals of this study, which aims to address the practical usability and UX issues faced by FXI using mobile applications for banking and shopping on smartphones.

Pragmatism supports using a mixed-methods approach, combining qualitative and quantitative research strengths. By integrating qualitative and quantitative methods, the research can provide a holistic analysis of user challenges and the effectiveness of the proposed solutions (Feilzer, 2009). This methodological flexibility is a hallmark of pragmatism, which values diverse methods to achieve practical and actionable outcomes. The data collection techniques, such as screen capture with keyloggers and structured interviews, further emphasise the pragmatic focus on detailed, accurate, and useful data collection.

Additionally, the pragmatic approach includes the use of triangulation, or "multiple operationalism," to validate findings through multiple methods (Johnson et al., 2007). This ensures that the research results are robust and reflect the underlying phenomena rather than being artefacts of the specific methods used. By employing both qualitative and quantitative methods, the research can produce well-rounded and reliable findings that are directly applicable to improving user interface design for marginalised populations.

Moreover, pragmatism aligns with the interdisciplinary nature of HCI4D research. This field often requires researchers to navigate different epistemologies and methodologies to develop contextually relevant and practically effective solutions. Pragmatism allows for this interdisciplinary flexibility, supporting developing, implementing, and evaluating interventions designed to improve user interactions with technology (Van Biljon et al., 2021).

By embracing pragmatism as the overarching philosophy, this research is well-positioned to address the complex challenges faced by FXI Nigerian users when interacting with mobile banking and shopping applications on smartphones. This approach will enable us to identify problematic UI design patterns and develop and evaluate effective design techniques that can significantly improve smartphone interaction for this marginalised population, directly addressing our core research questions and contributing to both academic knowledge and practical UI design improvements.

It is essential to note that all aspects of this research were conducted in the English language. Nigeria is a highly multilingual country, home to 515 languages (Ugwu, 2020). However, English serves as the sole official language and holds more functional roles than all indigenous languages combined. It is the primary language of governance, legislation, the legal system, education, mass media, and business transactions (Ugwu, 2020, p. 40). Given its dominance, English has the highest number of speakers in Nigeria and is widely used, particularly in urban areas. English is also the primary medium of instruction in schools, promoted over indigenous languages beyond early primary education (Ugwu, 2020).

Considering that the chosen mobile applications in Nigeria cater to financial and commercial services, i.e., sectors where English is the predominant language, most digital platforms are developed in English. This aligns with the broader digital landscape where English is the most commonly used language for business and technological interactions. Therefore, the decision to conduct this study in English reflects the realities of mobile usability in Nigeria and ensures that findings are applicable within the most common linguistic environment of digital services.

In the rest of this Chapter, I describe the techniques for data collection, sample selection, and data analysis to answer the research questions of this study. I have structured this section based on the three interconnected studies that aim to answer the above research questions. There were two primary data collection processes across two studies, and the methodologies for these are discussed in sections 4.1 and 4.3. Section 4.2 discusses further methodologies that bridge the two data collection studies. The details of these three studies are illustrated in Figure 2.

Figure 2: Three-Study Structure Overview

4.1 Study 1: Investigating the Problem Space

The reviewed literature revealed a general claim that FXI encounter difficulties interacting with mobile banking and shopping applications on smartphones. However, as limited research exists on this topic in Nigeria, I conducted a preliminary study to explore the state of functional illiteracy in Nigeria. Thus, the primary aim at this stage was to investigate how FXI interacted with mobile applications if they experienced difficulties, and which aspects proved to be more problematic. Therefore, the following objectives guided this stage of the research:

1. To explore the experiences and challenges of FXI and to assess the effectiveness of the current mobile applications' UI design in meeting the needs of FXI users.
2. To show the digital skills required to complete the essential mobile shopping and banking applications tasks.
3. To assess the UX of current mobile banking and shopping applications for FXI users.

I adopted a descriptive research design to fulfil these research objectives, as justified in the following subsection.

4.1.1 Research Design

HCI research designs are categorised into three (3) main groups: descriptive, relational, and experimental (Lazar et al., 2017). Each of these designs possesses distinct characteristics and necessitates different techniques to address the research objectives. Experimental design, for instance, provides the opportunity to investigate causal relationships, whereas relational investigations focus on uncovering connections between multiple events or variables (Lazar et al., 2017). In contrast, descriptive investigations, which emphasise the "what" question, serve as the foundational step in a research program, allowing researchers to identify noteworthy phenomena or events that lay the groundwork for subsequent research directions (Lazar et al., 2017). At this research stage, I explored the problem space, seeking answers to fundamental questions without drawing inferences or establishing relationships between factors. Consequently, I selected a descriptive design to align with my objectives.

The descriptive design was suitable for this research stage as it facilitated the discovery of accurate descriptions of what transpired during interactions. My intention was to investigate the proficiency of FXI users with mobile applications and, in doing so, reveal the difficulties they encountered. This approach enabled me to provide precise descriptions of these challenges, offering implications for UI design tailored to this user group.

4.1.2 Research Methods

HCI researchers have employed various methods for studying interfaces and applications, including observations, field studies, surveys, usability studies, interviews, focus groups, and controlled experiments (Shneiderman et al., 2017). Each of these methods has its strengths and weaknesses. For instance, unobtrusive observations in natural settings can reveal representative mobile phone usage patterns but can be time-consuming (Rogers et al., 2023). Surveys, on the other hand, allow researchers to reach many users quickly but may lead to misunderstandings, superficial data, and bias in participant samples (Lazar et al., 2017). Interviews permit in-depth exploration but demand more time and resources than surveys (Sharp et al., 2019). Usability tests quickly identify usability issues but cannot guarantee the discovery of all critical design problems (Lazar et al., 2017).

HCI4D research typically favours participatory and ethnographic methods (Van Biljon, 2020). Participatory approaches enable local communities to actively shape technology design (as discussed in section 3.1.5.2), while ethnography provides rich insights into users' cultural contexts (Blandford et al., 2016). These approaches are valuable for understanding contextual technology use but were less suited for this study's goal of systematically identifying and measuring specific UI interaction challenges faced by FXI users, which required controlled conditions to isolate and quantify these issues.

Ultimately, the choice of research method is context-dependent, influenced by factors such as the study's primary purpose, time constraints, funding, and participant pool (Lazar et al., 2017). Given the study's main objective, I opted for a mixed methods approach, which respects the unique strengths of different methodologies and accommodates diverse epistemological perspectives (Van Biljon, 2020). Moreover, it enables the triangulation and integration of findings from various methods (Van Biljon, 2020), mitigating the limitations associated with standalone methods. I selected a combination of the think-aloud technique, screen interaction recording, and surveys to systematically capture both qualitative and quantitative data, as detailed below.

4.1.2.1 Design of Survey

I chose surveys as one of the research methods due to their ability to yield relatively direct responses, which suited the collection of demographic data and user experience ratings. I conducted two versions of surveys verbally with participants at different stages of the study, both in English. The initial survey aimed to gather participants' background information before they engaged in assigned tasks on a smartphone (see Appendix A). The questions for this survey were based on the Programme for the International Assessment of Adult Competencies (PIAAC) due to its comprehensive set of background data questions.

The second survey was administered after participants completed their assigned tasks (see Appendix B). These post-study survey questions were adapted from the User Experience Questionnaire (UEQ-S) (Schrepp et al., 2017). The User Experience Questionnaire (UEQ-S) is a shorter version of the longer UEQ, measuring user experience with six items on a semantic differential scale (Astuti et al., 2021). Its brevity minimises potential reading fatigue among FXI participants while providing a benchmark for interpreting user experience and facilitating comparisons with other products (Schrepp et al., 2017). The benchmark currently contains data from 246 product evaluations using the UEQ, covering various applications.

To simplify the six items on the UEQ-S, I replaced the words and phrases with more straightforward alternatives to enhance understanding for FXI users. Although the initial developer of the questionnaire provided some options for words and phrases, some were still complex for FXI. Therefore, I made adaptations by selecting words from their word bank in some cases and, in another case, I chose the word that conveyed the same meaning within the Nigerian context (refer to Appendix C).

Additionally, I included one extra question that used a 7-point scale to gauge participants' self-assessed success. Lastly, I posed three open-ended questions to gain insights into user impressions of their interactions with mobile applications, enabling participants to articulate their thoughts retrospectively and providing richer data.

4.1.2.2 Design of Think-Aloud

The think-aloud technique, a well-established method in HCI research, is valuable for gaining insight into participants' cognitive processes and mental models (Sharp et al., 2019). It was originally developed by Anders Ericsson and Herbert Simon (1984) to investigate problem-solving strategies (Rogers et al., 2023). This approach encourages participants to verbalise their thoughts while completing each assigned task on a smartphone.

I opted for the think-aloud method due to its ability to yield rich, objective data in contrast to the subjective nature of researcher observations. Given the challenges faced by participants, as highlighted in the existing literature, the think-aloud method proved to be an interactive approach for obtaining and capturing participants' thoughts as they navigated the mobile applications.

However, it is essential to acknowledge that the think-aloud method has been criticised for its potential to influence participants' actions (Nagle and Zietlow, 2012). Despite this limitation, it remains a valuable tool for comprehending user mental models. Researchers can construct a comprehensive understanding of their mental models by having users articulate their thoughts, beliefs, and predictions during interactions with a user interface (UI) (Nielsen, 2010). Therefore, when employed in conjunction with other research methods, the think-aloud method is appropriate for comprehending participants' thought processes. More details on mental models in HCI research are in section 3.1.3.1.

4.1.2.3 Design of Screen Interaction Recording

The screen interaction recording method is a cornerstone of my research methodology, selected to address challenges posed by alternative approaches. While other methods, such as think-aloud and contextual inquiries involving direct observation and user activity recording, hold promise in unveiling usability issues, they bring complexities to the research process, especially when used alone.

Directly observing and recording user activities, although invaluable, demands considerable resources and introduces interpretation challenges (Rogers et al., 2023). Recording what happens as a user executes a series of complex tasks in the field can prove both time-consuming and error-prone (Lazar et al., 2017). Furthermore, interpreting the nuanced details of these activities and the context motivating them can often remain difficult to capture (Lazar et al., 2017).

Similarly, studies based on log files provide insights into the "what" and "when" of user actions but frequently fall short of explaining the "why" behind these interactions (Lazar et al., 2017). As such, comprehending the underlying motivations and cognitive processes driving user behaviour can present substantial difficulties when relying solely on this approach.

In contrast, combining screen interaction recording, complemented by audio recording from the think-aloud method, offers a holistic solution to these challenges (Lazar et al., 2017). It provides an encompassing view of smartphone interactions, capturing visual elements and users' vocalised thoughts. This integrated approach allows for precise scrutiny of user actions and provides critical context and insights into the "why" underpinning those actions (Lazar et al., 2017).

The user interactions within the screen capture tool are played back like a movie, illustrating the selection, movement, and opening of on-screen objects. This combination of data streams enhances our ability to interpret user behaviour in finer detail, offering a more comprehensive understanding of their interactions (Heath et al., 2010).

4.1.3 Sampling

I recruited twenty participants from an established adult literacy centre in Kaduna State, in the North-western region of Nigeria. I chose Kaduna State due to its accessibility to a literacy centre for adult students. Moreover, Kaduna State has an estimated population of 1.2 million in 2023 (World Population Review, 2023). According to available data, the states with the highest number of residents lacking basic reading and writing skills are typically found in Nigeria's Northeast, Northwest, and North-central regions (Amzat, 2023). This highlights the prevalence of limited literacy levels in the region, making Kaduna, a North-western state, a strategic choice for this study.

Moreover, the city is known for its commercial and industrial activities, which attract a constant influx of people seeking opportunities in industry (Bununu et al., 2015). The city's appeal as a residence for civil servants (Bununu et al., 2015) and the historical migration data

(Bununu et al., 2015) contribute to the vibrant and diverse population that makes it an ideal research location. This mix of backgrounds and experiences enhances the research environment.

The recruitment of FXI participants occurred in stages. Initially, I distributed printed copies of a call for participants, outlining the recruitment criteria, to the head teacher at the adult literacy centre to identify interested individuals (see call in Appendix D). This preliminary screening phase spanned approximately two weeks, from June 11 to 21, 2022. To be included in the study, participants were required to confirm the following criteria during the pre-screening stage verbally:

1) They must be motivated to engage with technology and self-assess that they require assistance using mobile applications for banking and shopping.
2) They must be capable of articulating their thoughts aloud while searching and reading on a smartphone.
3) They must have previous experience using a touchscreen smartphone.
4) They must be adults aged 18 or older.
5) Participants who could read proficiently in their native language but lacked sufficient English language skills to navigate the interface were excluded.

All participants in this study were able to speak English; however, they exhibited low reading and writing skills, particularly in comprehension. This aligns with the definition of functional illiteracy used in this study, where individuals can recognise words sparingly but have difficulties understanding extended text, making it difficult to fully comprehend meanings from what is read. The selection criteria ensured that participants were not excluded based on an inability to speak English but rather due to their low skills in processing written text.

The exclusion of non-English-speaking FXI participants was necessary to clearly distinguish between functional illiteracy and difficulties arising primarily from limited proficiency in English as a second language. This criterion prevents conflating FXI with other groups facing reading challenges due to fundamentally different reasons, such as individuals who are in the early stages of learning English as a second language or those already proficient in their native language but lacking sufficient English proficiency for mobile interfaces. Without this distinction, the research risks misclassifying language-acquisition barriers as functional illiteracy, a confusion highlighted by literature emphasising that proficiency in the study's language must be established before diagnosing functional illiteracy (Vágvölgyi et al., 2021). Otherwise, what appears as a fundamental reading challenge could simply reflect insufficient mastery of a foreign language.

Moreover, this methodological choice does not intentionally reinforce the digital divide. Instead, it ensures analytical precision by identifying usability issues specifically related to functional illiteracy. English, as the official language of Nigeria, is widely used in education, governance, and digital applications (Ugwu, 2020; Danladi, 2013). Additionally, the mobile applications in this study are in English, not native languages. Thus, proficiency in English aligns closely with realistic interactions Nigerian FXI users commonly encounter. Importantly, the usability principles and design recommendations emerging from this research remain applicable beyond English-language interfaces and could guide future inclusive designs addressing multilingual or native-language contexts.

Following this initial screening, I compiled a list of interested participants. A neutral third party was enlisted to verbally present a condensed version of the participant information sheet to secure their signed consent (see Appendix E for the form). Each participant received a paper-based version of the information sheet to follow along with the audio presentation.

I was available in a separate room to address the participants' questions before signing the consent form. Many participants raised concerns about being videotaped and the potential publicisation of their recordings. To alleviate these concerns, I clarified that I would not be recording their faces and showcased a pre-recorded video illustrating a person performing tasks on a smartphone following the study's procedure. I also emphasised that participants could withdraw from the data collection process at any point if they felt uncomfortable. This reassurance helped put participants at ease.

Upon obtaining participants' signed informed consent forms, I administered a paper-based assessment using the Dynamics Indicators of Basic Early Literacy Skills (DIBELS8) Maze Assessment (University of Oregon., 2023) to evaluate their textual capabilities and ensure their alignment with the criteria for classification as FXI (see Appendix F for the Maze Assessment). All the participants who agreed to participate in the study scored below the 50th percentile on Grade VII of the DIBELS8 Maze test, per the criteria outlined by Medhi et al. (2013) and Binder et al. (2012).

It is essential to acknowledge that despite the careful consideration applied to the method for identifying and recruiting FXI, this category may encompass a subset of the population, such as individuals with additional challenges, e.g., ADHD or dyslexia, who, in addition to literacy issues, might face further complications. However, separating these factors for control purposes would introduce complexity and necessitate extensive participant screening steps, as reviewed in the literature.

In addition to the 20 participants recruited as FXI, I recruited 5 LIT individuals from the staff of the adult literacy centre. These individuals scored above the 50th percentile on Grade VII of the DIBELS8 Maze test. While sharing similar attributes with FXI (e.g., adults, language, etc.), they possessed more developed reading skills. The LIT participants served as a comparison group to conduct an impartial usability assessment, ensuring the UI is not unnecessarily complex or problematic for all user groups. Engaging additional Nigerian users allowed for a more comprehensive evaluation.

4.1.4 Participants

The sampling process resulted in a total of 24 FXI volunteers. However, it excluded four participants due to their lack of experience with mobile touch user interfaces or insufficient proficiency in English for the study.

Of the 20 FXI participants I recruited, 55% of the FXI participants were male, while 45% were women. Most of the FXI participants (80%) had the educational level of senior secondary and came to the literacy centre to learn on their own (55%), job purposes (25%) and just a hobby (20%). Half of the FXI participants were aged 30-39; see Figure 3. Participants reported spending much time on their smartphones daily (22% spent more than 10 hours, 28% 6-9 hours, and 39% 3-6 hours). All 20 FXI participants reported social networking as one of the most frequent things they spend daily time on, followed by phone calls and messages (12 participants).

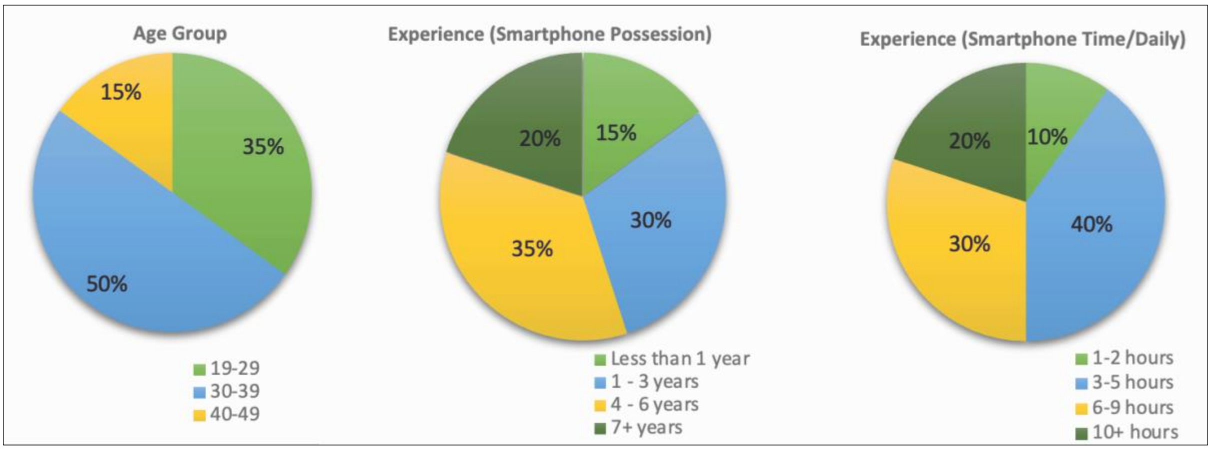

Figure 3: Participants Profile (FXI)

Although all FXI participants owned a smartphone and had experience with mobile applications for at least six (6) months, most participants reported that they had never used mobile banking and shopping applications (75% and 70%, respectively) because of issues relating to preconceptions on its usability (65%), trust issues (43%) and unawareness (22%). Also, 60% of FXI participants agreed they had difficulty achieving a smartphone task. To resolve challenges, 63% reported turning to family and friends for help, while 31% indicated using Google search.

Of the LITs recruited, 3 (60%) were female, while 2 (40%) were male. 60% of the LIT participants were aged between 40-49, while 40% were between 30-39. All LIT participants had at least a bachelor's degree. Most LIT participants (80%) reported that they had been using smartphones for more than seven (7) years. LIT participants reported a daily average time of 3-5 hours (40%), 6-9 hours (40%), and 10+ hours (20%) on their smartphones. 60% of participants used mobile banking apps. Of the 60% that used mobile banking apps, 80% reported their use frequency as often, while 20% reported rarely. Also, 80% agreed they use mobile shopping apps. Of the 80% that used shopping apps, 40% said they used them often, while 60% used them sometimes.

4.1.5 Data Collection

4.1.5.1 Mobile Application Selection and Tasks

To address the study objectives, I selected a set of digital skills to assess. I assigned them to the participants as tasks based on the Digital Literacy Global Framework (DLGF) by Law et al. (2018), refer to Table 5. I asked each participant to complete specific tasks on current Nigerian mobile banking and shopping applications (see Table 6). The rationale for this choice stems from the role of financial inclusion, specifically access to digital payments, as the key gateway in advancing Nigeria towards a digital economy (The World Bank Group, 2019; Federal Ministry of Communications and Digital Economy, 2019). Additionally, the choice of assessing digital skills in the context of shopping applications addressed a research gap identified in the reviewed literature (section 3.1.5.5), particularly concerning Nigerian FXI users. Given the growing prominence of e-commerce, it is imperative to ensure that FXI users are not marginalised, as highlighted by Chaudhry et al. (2021).

Table 5: Digital Literacy Global Framework (DLGF)

Digital Competence Area	**Digital Competence**
1. Information and Data Literacy	1.1 Browsing, Searching and Filtering Data, Information and Digital Content
	1.2 Evaluating Data, Information and Digital Content
	1.3 Managing Data, Information and Digital Content
2. Communication and Collaboration	2.1 Interacting through Digital Technologies
	2.2 Sharing through Digital Technologies
	2.6 Managing Digital Identity
3. Digital Content Creation	3.1 Developing Digital Content
4. Safety	4.2 Protecting Personal Data and Privacy
5. Problem-Solving	5.2 Identifying Needs and Technological Responses
Note: The table shows only the digital competencies relevant to this research study. For full details of the DLGF, refer to Table 4.	

The DLGF provides evidence that certain features are standardised across mobile applications in key sectors such as finance and commerce. These include searching for goods and services, comparing prices, managing user accounts, conducting in-app financial transactions, and evaluating providers. These functionalities are mapped across six economic sectors and are recognised as sector-independent digital competencies. They are typically supported by shared interface elements such as search bars, filters, product ratings, shopping carts, checkouts, login systems, and payment workflows.

Accordingly, while this study focuses on two specific applications, the research questions centre on interface design patterns and usability challenges that are widely applicable across mobile banking and shopping platforms. As confirmed by the Digital Literacy Global Framework (Law et al., 2018), features such as search, filtering, login, financial transactions, and product evaluations are standardised across sectors and typically supported by shared interface elements. Both mobile banking and shopping applications are built using established UI design conventions (e.g., navigation structures, iconography), and the usability issues encountered by FXI users often stem from common mobile interaction patterns rather than app-specific characteristics. Given this standardisation in mobile application development and UI conventions, the findings from this study have broader relevance for inclusive design.

The mobile banking application was selected due to its national reach and alignment with mainstream financial service use in Nigeria. Operated by one of the country's oldest and most established commercial banks, it serves over 42 million customer accounts through more than 820 branches and 100,000 banking agents nationwide (FirstBank, 2024). As of 2023, its digital platform reported 18.6 million active users, representing approximately 29% of Nigeria's banked adult population, based on EFInA's (2023) estimate of 58.3 million. Its widespread adoption and inclusion of standard mobile banking features such as fund transfers, airtime purchases, and bill payments make it a strong representative platform for studying FXI users' interaction with essential digital financial services. This is further justified by the Central Bank of Nigeria (CBN) Regulatory Framework for Mobile Money Services, which outlines standard e-banking features required across financial institutions (CBN, 2021). The researcher's existing user account also made it logistically feasible to conduct real-world testing on a live platform.

The selected shopping application was chosen based on its dominance in Nigeria's e-commerce market. In 2020, it recorded approximately 147 million website visits, far exceeding two other leading platforms, which received 54 million and 23 million visits respectively (Statista, 2021). This significant user base indicates not only popularity but also greater user familiarity, supporting the app's suitability for this research's aim. Additionally, the application operates in multiple African countries including, Egypt, Kenya, Morocco, and South Africa and has been described in media and academic sources as the 'Amazon of Africa' (Forbes, 2022; Ologunebi and Taiwo, 2023). Its core features, including search, filters, product reviews, cart, and mobile payment are standard across the e-commerce sector, making it an appropriate choice for studying mobile shopping interactions among FXI users.

Following the guidelines of the DLGF in adapting the framework to specific contexts, the specific smartphone functions were mapped out to the tasks relevant to mobile banking and shopping applications. This was further cross-referenced with each of the competencies of the DLGF. It is noteworthy that because testing all the items was unreasonable given the timeframe and resources available for this study and some tasks are more vital than others, not all competencies listed on the DLGF were tested. As such, I focused on the essential digital skills that are generalisable to other applications (e.g., searching and filling out forms). These digital skills are represented in Table 6, showing the relevant digital competencies from the DLGF for each skill.

Table 6: Tasks assigned to users, mapped out to the Digital Literacy Global Framework (DLGF)

Task ID	**Task Descriptions**	**Digital Literacy Competences**								
		1.1	1.2	1.3	2.1	2.2	2.6	3.1	4.2	5.2
	Banking Application									
T1	Transfer to another account	✓		✓				✓	✓	
T2	Buy airtime for a phone number	✓		✓					✓	✓
T3	Display transactions history	✓	✓	✓						✓
T4	Find an option to log a complaint	✓			✓					
	Shopping Application									
T1A	Edit the name on the account			✓			✓	✓		
T1B	Add a new address			✓			✓	✓		
T2A	Search for a product	✓								
T2B	Filter search results by price	✓	✓							
T2C	Filter search results by rating	✓	✓							
T2D	Add products to the cart		✓	✓						
T3A	Search for a product	✓								
T3B	Sort search results	✓	✓							
T3C	Add to wish list			✓						
T4A	Locate the wish list	✓								
T4B	Share products with a saved contact					✓				
T5A	Locate the cart	✓								✓
T5B	Checkout	✓	✓							✓

4.1.5.2 Procedure

The study used a Samsung Fold 2 smartphone with a (HxWxD, mm of 159.2 x 68.0 x 13.8-16.8) running Android v12 and a touchscreen user interface. The device's microphone recorded the participants' audio during the think-aloud and survey responses. The smartphone's built-in screen recording capabilities captured users' keystrokes while they completed each preassigned task. It is important to note that the playback of participants' think-aloud audio and the screen recording (including keystrokes) were synchronised into a single recording, allowing for simultaneous playback. This synchronisation provided valuable context for analysing participants' think-aloud and enabled examining users' tapping behaviour, a topic explored in the data analysis section.

The data collection occurred at the literacy centre in Kaduna state, Nigeria, from June 22 to July 7, 2022. Initially, I administered a background data survey to collect demographic information from each participant, audio recording their responses. Subsequently, I conducted 25 individual evaluation sessions, each lasting approximately 20 minutes for the shopping application and 9 minutes on average for the banking application. Throughout the data collection process, participants were individually engaged. To summarise, the process for each participant included the background survey, orientation, evaluation session, and post-study surveys. To ensure replicability and data reliability, I read from an orientation script (see Appendix G for the script).

During the orientation, I emphasised that the study focused on evaluating the usability of mobile applications among Nigerian smartphone users. I deliberately avoided labelling the participants as FXI, as it might carry a negative connotation. Instead, I referred to them as typical Nigerian smartphone users. I stressed that mobile applications are meant to be user-friendly and that any difficulties they encountered were indicative of design issues rather than their abilities. Next, I reminded the participants about the recording process.

To provide a clear understanding of expectations, I played a pre-recorded video demonstrating similar tasks performed on a mobile application by a Nigerian user. This video served as a practical example and helped participants comprehend the study's objectives better. After the orientation, I administered a sample task to ensure that participants were familiar with the think-aloud process. This initial task involved opening the messaging interface, typing a message to "John," and using the "Message edit box" on the Messaging application.

Following the orientation, I provided participants with a list of tasks, as detailed in Table 6, and encouraged them to ask any questions or seek clarification. To make the tasks more relatable, I supplied contextual scenarios that described the tasks, a technique adapted from (Elling et al., 2012). Participants were then reminded to think aloud while they completed the tasks, beginning with the first on the list and proceeding to the last. They completed the tasks for one mobile application before transitioning to the other. I remained in the same room during the study but allowed participants some space to avoid undue pressure.

After participants completed all the tasks for one mobile application, I conducted a post-study survey. This timing allowed participants to recall the details of the issues they encountered while the experiences were still fresh in their minds. I encouraged participants to share specific details they remembered, and I encouraged them to look at the task list and mobile applications if they needed a refresher. Participants were also informed that they could take a break if they felt fatigued, although none of them requested a break during the study.

Throughout the study, participants were encouraged to verbalise their thoughts, especially if they fell silent for extended periods, which occurred occasionally. To ensure data collection efficiency, I trained a research assistant to assist in recording background data during the survey and conducting some evaluation sessions on the mobile banking application following the prescribed script and procedure. When the research assistant collected data for the mobile banking application, they also handled the post-study survey. This approach ensured that the survey was conducted by someone familiar with the context, allowing for more effective probing of participants to gather details about their interactions.

After the final survey, I thanked the participants and provided a small fee for transportation and meal.

4.1.6 Data Analysis

The data analysis aimed to examine the experiences and challenges faced by FXI users and evaluate the effectiveness of the current mobile application user interface (UI) designs in meeting their needs. Notably, the data from each mobile application underwent separate analysis, aligning with the objective of testing two distinct mobile applications. The data analysis process consisted of several stages, with a predominant focus on quantitative analysis.

4.1.6.1 Data Recording

In the initial stage, I reviewed the audio recordings of the background data section of the survey and participants' responses on Microsoft Forms. This provided a quick summary of the data's characteristics. Subsequently, I examined the screen recordings, keystrokes, and audio transcriptions associated with each digital skill and participant. Throughout this stage, I remained attentive to the challenges encountered by all participants. Because all the data sources could be replayed simultaneously due to the smartphone synchronising the screen interaction recordings with participants' audio, I reviewed one video recording at a time.

During this phase, my primary objective was to record user performance for each participant per digital skill in a Microsoft Excel spreadsheet. Transcribing verbalisations would occur in later stages. As noted in the literature section on usability assessments (see section 3.1.3.2), HCI studies often employ varying criteria to describe the usability of mobile UIs. Performance times and the number of different types of activities done by users are the two main performance measures in evaluating UIs (Sharp et al., 2019). Getting these two measures entails recording the time it takes users to do a task (e.g., finding out medical information using Google Chrome) and the number of errors made by the users (e.g., selecting the wrong menu options). These metrics are widely adopted in HCI research, as outlined by Wixon and Wilson (1997), cited in Sharp et al. (2019).

To quantify user performance and measure difficulties, I incorporated the aforementioned two usability measures into my analysis, along with two additional metrics: the number of taps required to complete each task and whether or not the task was successfully completed (Islam et al., 2020). These usability metrics are further described below.

1. Error Rate – Recorded as dichotomous data following (Hollinworth and Hwang, 2009). This category encompassed instances of (i) multiple attempts to complete a task, (ii) mid-task delays requiring external assistance, (iii) incorrect actions taken, and (iv) requests for verbal confirmation. In my observations, I noticed that some participants inaccurately reported successful task completion, which was taken as an indication of an error. Consequently, I introduced an additional category to account for this phenomenon, denoted as (v) a false perception of success.
2. Task Completion Rate - Recorded as dichotomous data in line with ISO 9241-11, 1998. This category involved counting the number of participants who successfully completed each task. If a participant rediscovered the option to perform a previous task during a subsequent one, this wasn't considered a successful completion of the prior task, and the initial metrics remained unchanged.
3. Tapping Count – Recorded as count data following ISO 9241-11, 1998. I tallied the number of taps for each task and recorded them as the minimum number of taps based on a task analysis of the interfaces. The number of taps for users was subtracted from the minimum number required to complete each task to measure difficulty. In cases where multiple methods existed to accomplish a task, the longer process was recorded as the 'minimum number of taps.' Both scrolls and taps were counted as indicators of interaction with the user interface. The counting for each task is initiated from the home page, with exclusions for closing ads or alerts. All tasks involving typing were counted as a single tap in the field to account for variations in word length (e.g., addresses or search terms).
4. Time Elapsed – Recorded in seconds, following Wixon and Wilson (1997), cited in Sharp et al. (2019). 'Time elapsed' was calculated by noting the start time of each task and the completion time. Adjustments were made for periods when participants sought clarification between tasks, and a new timing was initiated once they fully grasped the task requirements.

By the end of this stage, I had recorded these four user performance measures for each participant and task in the Microsoft Excel spreadsheet.

4.1.6.2 Rank Analysis

Following the above method, I computed the average for each difficulty category across all tasks. The averages of each task were taken and summarised in a table for each user performance measure. Afterwards, for each user performance measure, an average rank was assigned to each task, with the highest number indicating the most challenging tasks and the lowest number showing the most accessible tasks. For example, for the user performance measure' *error occurrence'*, the average time it took to complete tasks T1, T2, T3, etc., was taken, and a rank was assigned to each task. This means that the task with the highest average for '*error occurrence'* was given the highest rank and vice-versa. This was repeated for '*task completion*. For *'time elapsed'*, the ratio compared with LITs was taken for all tasks, and the task with the highest ratio will be assigned the highest rank, and so on. Similar logic is applied to '*taps'* -only the ranking is done based on a difference in the minimum taps required (based on task analysis of each task) and the taps done by FXI.

The average ranks for each task and user performance measures were calculated to tally up the results. This average was used as a rating to find the most difficult tasks. The tasks with the highest averages were the most difficult, while the lowest average scores were indicative of more manageable tasks.

Throughout this analysis, equal weight was assumed for all user performance measures.

4.1.6.3 Statistical Analysis

In the next data analysis step, I explored the results from all four (4) user performance measures between FXI and LIT users. This analysis aimed to distinguish tasks that were universally challenging from those primarily challenging for FXI. It is important to emphasise that my study's core focus was not directly comparing FXI and LIT users. Rather, my objective in evaluating LIT users' performance was to conduct an impartial usability assessment, ensuring that the UI was not unnecessarily complex or problematic for all user groups. While I could have performed a usability walkthrough, I involved other Nigerian users to provide more objective data from a similar context for comparison.

To facilitate this exploration, I used statistical analyses, such as the Fisher's exact test and independent samples t-test, using IBM SPSS Statistics. Additionally, I leveraged descriptive frequencies to illustrate performance differences between both user groups. Descriptive analysis involves generating frequency and relative frequency distributions of data (Weiss, 2012), which were then presented using charts. This approach offered the advantage of uncovering and recognising patterns within the summarised data.

For assessing the task completion and error occurrence user performance categories, I employed Fisher's exact test, which is used to establish the independence of two dichotomous variables (Kateri, 2014). If the two variables are not independent, there is an association between them (Laerd Statistics, 2015). Fisher's exact test rests on two (2) main assumptions: (1) The data has two dichotomous variables (i.e., they both have two categorical, independent groups), and (2) observations are independent (Kateri, 2014). Given that the data met both required assumptions, this choice was appropriate for analysing task completion and error occurrence difficulties. Moreover, Fisher's exact test is suited to handle cases where more than 20% of expected cell counts are less than 5, which was the case of the study's design due to the unequal sample sizes (i.e., 20 FXI vs. 5 LIT users).

The analysis was carried out based on the following hypotheses for each task:

Hypothesis 1

Ho: There is no association between the number of errors and user group.

Ha: The number of errors and literacy group are not independent.

Hypothesis 2

Ho: There is no association between the task completion rate and the user group.

Ha: The rate of task completion and literacy group are not independent.

To compare the time elapsed difficulty category, I employed the independent samples t-test. I aimed to determine whether the observed difference between the two-sample means was a result of random variation or represented a genuine population difference (Laerd Statistics, 2015). This test allowed me to consider whether the population means of the groups (i.e., FXI and LITs) differed, not just the sample means (Sheskin, 2011). I chose the independent samples t-test because it aligned with the first three basic assumptions of my study design (Laerd Statistics, 2015):

(1) The dependent variable is continuous,

(2) There is one independent variable that is measured on a dichotomous scale,

(3) The independent variable displays the independence of observations.

Notably, assumptions 4 (the data is approximately normally distributed with no significant outliers in any cell in the design) and 5 (there should be homogeneity of variances, particularly when sample sizes are not equal) were based on the nature of the data. As such, I interpreted the Welch test for some analyses that failed these assumptions, as recommended in Howell (2010).

The analysis for the time elapsed difficulty category was based on the following hypothesis:

Hypothesis 3

Ho: FXI and LITs' mean time elapsed scores are equal in the population.

Ha: FXI and LITs' mean time elapsed scores are not equal in the population.

Notably, no statistical analysis was conducted for the tap user performance measure due to the nature of the count data and the small sample size in the LIT group. However, I employed visualisation results from descriptive analysis and frequencies to explore performance differences between the two user groups. For instance, when examining differences between LIT and FXI, I considered a ratio of 1:2 or greater as a substantial difference in tapping counts between the two user groups.

4.1.6.4 UEQ-S Survey Analysis

The UEQ-S had six (6) questions to assess the user experience of the mobile banking and shopping applications on a 7-point Likert scale based on the UEQ-S benchmark developed by (Schrepp et al., 2017). There are five categories of feedback based on the user experience benchmark (i.e., Excellent, good, above average, and so on). See Appendix H for details. To compute the Likert items, the values above 0 represent a positive evaluation of the quality aspect; values below 0 represent a negative evaluation. Answers to an item, therefore, range from -3 (fully agree with the negative term) to +3 (fully agree with the positive term). Half of the items start with the positive term, and the rest with the negative term. Computing the values results in data that fits one of the five feedback categories established by (Schrepp et al., 2017).

By the conclusion of this stage, I had obtained the results from rank analysis, outlining a scale ranging from the most challenging to the least challenging digital skills. Additionally, I acquired results from descriptive frequencies and statistical analyses, shedding light on which digital skills posed difficulties exclusively for FXI, which ones were universally manageable, and which were challenging for FXI but manageable for LIT. I also obtained UX results from the post-study survey. These results ultimately led to the identification of three specific digital skills, which will be the primary focus of the remaining portion of this Chapter.

4.2 Study 2: Designing Conceptual Models for Improvement

Study 1: Investigating the Problem Space narrowed down the focus of this thesis. In this study, I conducted a qualitative analysis of the top three digital skills I had identified in Study 1. As a reminder, the data I collected in the previous stage included think-aloud verbalisations, screen videos, and open-ended post-study survey recordings. I aimed to answer the first research question, which is as follows.

> RQ1: What design patterns of the user interface specifically cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

With this in mind, I reviewed the screen recordings of FXI participants in the three difficult digital skills and their responses to the open-ended sections of the survey. My objectives at this stage included:

1. To identify the specific challenges and associated UI patterns related to the challenges faced by FXI users.
2. To provide insights into the reasons behind these observed difficulties, focusing on the users' mental model.
3. To investigate the techniques that can improve the initial mobile banking interface in terms of learnability, ease of use, and users' understanding of the underlying conceptual model.

In this subsection, I describe how I analysed the data collected in the previous study.

4.2.1 Task Analysis

I conducted a hierarchical task analysis of both mobile applications for the three digital skills. Task analysis "provides a model for task execution, enabling designers to envision the goals, tasks, subtasks, operations, and plans essential to users' activities" (Crystal and Ellington, 2004). Effective task completion relies on a sufficient understanding of the task model, an accurate interpretation of the visual cues in the user interface (Norman, 1986, cited in (Sharp et al., 2019), and the ability to recall and execute the correct sequence of activities (Hollinworth and Hwang, 2009).

A critical aspect of this task analysis was the assignment of a unique screen ID to each screen from the mobile applications, alongside noting the respective UI patterns in use (see section 6.1.1 Results for a sample of the output for the task analysis). This screen ID became the foundation of my subsequent analysis, providing a crucial reference point for tracking user interactions and identifying problematic UI patterns and elements.

Breaking down the challenging tasks using task analysis was pivotal as it allowed me to comprehend the steps involved in each digital skill, revealing interdependencies between these steps. This was essential for redesigning improvements that support users in completing tasks efficiently and without unnecessary complications. Moreover, it facilitated an in-depth analysis of the competencies required for each step, enabling a thorough examination of the specific issues affecting user performance.

Beyond these, task analysis further served three purposes:

1. Indexing events for the verbalisation units are discussed further in the content analysis section.

2. Identifying the specific goals users aimed to achieve when using the UI.
3. Enabling a thorough examination of UI design patterns across screens, highlighting areas in need of improvement.

This approach, centred on the screen ID system, laid the groundwork for the detailed analysis that followed, ensuring that user interactions could be accurately mapped to specific UI patterns and stages of task completion.

4.2.2 Content Analysis

In the initial stage of reviewing the video recordings for this study, I aimed to create a high-level narrative of the events observed. This narrative was designed to highlight interesting occurrences and common patterns while not attempting to capture every detail (Blandford et al., 2016). I noted relevant screen IDs and participant IDs to provide context for these high-level observations. An excerpt from my researcher narrative, including researcher notes, relevant UI patterns, and participant IDs, is presented in Figure 4.

Researcher note ↓

Screen ID → <3> *The participants did not follow a top-bottom approach in filling out the bank details* [Form. P1, P2, P4, P11, P18].

↑ UI pattern ↑ Participant ID

Figure 4: Excerpt from the researcher narrative, including researcher notes, relevant UI pattern, and participant ID.

Following this initial narrative phase, I transcribed the participants' verbalisations from the think-aloud recordings. Qualitative data analysis can employ an inductive or deductive approach to categorising and interpreting data (Rogers et al., 2023). Each approach has its merits and is guided by specific analytical frameworks. The choice between them hinges on the research's nature and objectives.

The inductive approach is characterised by allowing categories and themes to emerge directly from the data. It fosters an exploratory design, capitalising on the emergence of patterns from the data itself. This approach is particularly well-suited for studies with an exploratory design. Analytical frameworks like thematic analysis, interaction analysis, and grounded theory align with this approach, facilitating the emergence of novel themes and patterns (Rogers et al., 2023).

Conversely, the deductive approach relies on pre-existing frameworks and a predetermined set of categories, often derived from relevant theories (Rogers et al., 2023).

This approach employs these predefined categories as a lens through which to interpret the data. The deductive approach is fitting when the research goals are more descriptive and focused, as it provides a structured system for organising data into categories that are directly relevant to the research question (Rogers et al., 2023).

Given that my research focused on revealing usability issues and understanding UI patterns, the deductive approach, particularly content analysis, offered an organised system to classify data into meaningful categories. This system included essential categories such as screen types, participant information, and UI patterns.

Ultimately, my selection of content analysis with an existing categorisation scheme was underpinned by the need to efficiently organise data that was directly relevant to my research question. This allowed for a more targeted examination of usability problems and UI patterns, aligning with the study's overarching goals. Therefore, the deductive approach was the logical and pragmatic choice and the primary approach used in the transcription process. While the deductive approach was the primary method, I later incorporated inductive elements towards the final stages of analysis to allow for discovering unexpected patterns and themes.

Content analysis combines qualitative and quantitative aspects, enabling descriptive and quantitative analysis (Vaismoradi et al., 2013). This analysis categorises data into various groups, and the frequency of category occurrences is calculated (Krippendorff, 2013). For my content analysis, I adopted the categorisation scheme and procedure from the Concurrent Think-Aloud (CTA) framework developed by Cooke (2010). Cooke's framework encompasses five categories: reading, procedure, observation, explanation, etc.

While tools are available for the automatic transcription of qualitative data, I opted for manual transcription using Microsoft Excel. This choice was motivated by the limitations of automated tools in recognising participants' non-western accents and non-standard syntax. However, given that manual transcription is time-consuming and resource-intensive, I selectively transcribed relevant portions of verbalisations. To guide this decision, I revisited the study's objectives, which primarily centred on investigating the reasons for UI difficulties as recommended by Rogers et al. (2023). Consequently, this study explicitly focused on detecting user interaction problems, as similarly undertaken by Haak et al. (2003).

Therefore, the two following CTA categories were of particular interest:

1. Observation: Making observations about the website or the participant's behaviour (e.g., "The checkout icon is not working because I did not input the voucher code").

2. Explanation: Providing explanations, using the present or future tense, for the participant's behaviour; offering insight into their motivations (e.g., "I expect to see an option that says 'buy now on this page'").

Consequently, I identified the above two (2) distinct CTA categories in my transcripts. However, I did not assign different weights to these categories when interpreting the data. This approach was chosen because my research objectives necessitated focusing on the screen ID where these verbalisations occurred rather than the specific CTA category they belonged to. The primary goal was to understand usability issues concerning specific UI patterns (identified by screen IDs), regardless of whether the insight came from an observation or explanation

As a result, contrary to the use of verbalisation unit or time as the unit of analysis employed by Cooke (2010), the screen IDs were used in my study. This choice provided context for each verbalisation's reference to specific UI patterns, aligning with the analysis' objectives. Also, it ensured that insights into participants' mental models were analysed within the natural flow of the UI, facilitating the understanding of participants' expectations and the familiar knowledge they applied to complete the steps for each digital skill.

Following the categorisation schemes, I transcribed each participant's verbalisations into protocols for each relevant screen, dividing them into units that included phrases and sentences. The borders of verbalisation units were determined based on pauses between verbalisations and the content of the verbalisations, following Cooke's method (Cooke, 2010).

To ensure reliability, a member of the supervisory team coded one of the videos to verify the accuracy of verbalisations. In some cases, participants used words like 'this' or 'there' to refer to specific aspects of the screen in their verbalisations. In such instances, I utilised the context of their verbalisation (e.g., the goal they were trying to achieve) and cursor movements on the screen, providing descriptions in brackets. An excerpt is shown in Figure 5.

Participant verbalisation ↓

Screen ID → <1> *I think the basket will be under this page*, *and* '*deliver*' *will be written* [Basket icon. Scrolling through the product details page].

↑ UI pattern ↑ User action

Figure 5: Excerpt from the annotated transcript, including verbalisation UI pattern and user action.

The same approach was applied to the open-ended section of the post-study survey. Subsequently, the frequencies of the most frequently noted issues were categorised into difficulty units. As the study focused on each of the top three digital skills, the analysis concentrated solely on interview responses related to that aspect.

While adhering to Cooke's approach (Cooke, 2010) in conducting the content analysis, I organised the data in Microsoft Excel with columns denoting screen IDs and UI patterns within and rows representing each participant. Each sheet was dedicated to the relevant digital skill.

At the final content analysis stage, I used an inductive approach to discover novel patterns from the data. For every screen ID, the verbalisations were grouped based on how frequently participants made similar difficulties, as exemplified in the following example:

> Screen ID → <3c> Difficulty encountered while entering text in the destination account field due to omission of a previous step [6 participants]

This methodological approach to content analysis facilitated a comprehensive examination of the study's objectives. By organising difficulties by screen ID and frequency, I could systematically analyse users' mental models concerning specific UI design patterns. Consequently, in the results section, I present the findings regarding the difficulties experienced in the UI task sequence while highlighting relevant UI patterns. This presentation method allows for a clear connection between the observed user behaviours, their underlying mental models, and the specific interface elements that posed challenges, directly addressing the research questions established at the study's outset.

4.2.3 Designing the Conceptual Improvement

In the previous stage, 4.2.2 Content Analysis, the analysis revealed problematic UI patterns along with detailed explanations for the difficulties encountered. In this phase, I began developing a conceptual model to address these identified issues and improve user interaction. I drew inspiration from various theories and concepts within the HCI field to construct this conceptual model for an improved user interface. These theories, as elaborated in the literature section 3.1.3 Theoretical Backgrounds, served as valuable frameworks for guiding my design decisions. The theory that particularly influenced my approach included the theory of "mental models" in the literature section 3.1.3.1.

The initial stages of my design process involved creating paper prototypes, utilising only pencil and paper for sketching. This design process followed an iterative approach, allowing me to continually refine and enhance the designs. As my designs progressed, I transitioned to using Microsoft tools to create low-fidelity prototypes that captured the envisioned improvements.

By the conclusion of this phase, I had developed design blueprints for the three digital skills that required improvement, which can be found within each dedicated Chapter (see Figure 21, Figure 33 and Figure 40). These blueprints served as the foundation for the subsequent study, where these designs were transformed into interactive prototypes. The forthcoming section will explore the specifics of designing this custom user interface and outline the process of evaluating it with users in Nigeria.

4.3 Study 3: Designing and Evaluating Custom User Interfaces

The preceding study concluded with a conceptual design that proposed improvements for FXI users in Nigeria. In this study, I translated this concept into a custom UI that would undergo evaluation with both FXI and LIT users. This study aimed to conduct a comparative analysis, pitting the custom (redesigned) interface against the original mobile banking and shopping interface introduced in Study 1: Investigating the Problem Space. The primary aim here was to gauge whether the techniques applied in the custom interface design had indeed enhanced interaction for FXI users. This endeavour addresses the second research question:

> RQ2: What design techniques can improve interaction for FXI Nigerians while interacting with mobile banking and shopping applications on smartphones?

To answer this research question, I conducted this study at the same adult literacy centre between January and February 2023. I conducted 25 individual evaluation sessions, with each session lasting about 2 minutes on average for each application. In this section, certain elements covered in Study 1: Investigating the Problem Space overlap with the current study. These aspects include 4.1.2 Research Methods, 4.1.3 Sampling, 4.1.5.2 Procedure, and 4.1.6.1 Data Recording. This overlap arises from the need to replicate research processes, facilitating a comparison between data collected in the custom UI and data from the initial study. To avoid redundancy, I will refrain from discussing these aspects in detail here. Instead, I will make references to them as appropriate within the Chapter. However, I will first describe the development of the conceptual model proposed in section 3.2. Following this, I will examine the details of the research design, participants, and data analysis in this study more deeply, as these elements differ from those in Study 1.

4.3.1 Designing the Custom UI

Transitioning from the conceptual model to the actual interface demanded a careful shift to practically implement the intended mental model. This process began by translating the conceptual models into a high-level prototype, replicating the responsiveness of genuine mobile applications. Consequently, two interactive prototypes emerged: one for mobile banking and another for shopping. At this stage, I recruited a UI designer to implement the low-fidelity prototypes I had developed in the previous stage. I specifically engaged a Nigerian designer and emphasised the importance of adhering precisely to the designs depicted in the low-fidelity prototypes.

The high-level interactive prototypes were developed using Protopie[6]. Similar to the design of the conceptual model, I adopted an iterative evaluation approach, testing the prototypes at various stages. This iterative process was facilitated by the UI designer, who provided real-time access to the prototypes throughout the design phase. The final version underwent multiple usability walkthroughs conducted by the UI designer, the supervision team, and me to ensure robust usability and a seamless user experience before commencing the experiment with users.

4.3.2 Design

The research design for this study is experimental because it allows for causal relationships to be evaluated between entities. An experimental design enabled the assessment of relationships and influences between independent variables (e.g., custom interface) and dependent variables (e.g., number of errors made). The dependent variables were based on the user performance metrics from the initial study, including error rate, task completion rate, tapping count and time taken. Further details on the user performance metrics are in section 4.1.6.1 Data Recording.

These variables can also be manipulated to see if different outcomes result from the experiment. All experiments have three major components: treatments/conditions, units, and assignment methods (Lazar et al., 2017). In this research, the treatment is the type of interface (initial or custom), the units represent the participants recruited for the study, and non-randomisation was used for assignment. The non-randomised assignment method was used to recruit new participants for the custom interface evaluation, aligning their characteristics with the initial group in the first study. This approach enabled controlled, purposeful comparisons between the groups and interface conditions, considering the timing constraints inherent to the research. Furthermore, the deliberate selection of participants based on functional literacy status was essential for understanding the impact of these characteristics on interactions with mobile phone interfaces.

Following the experimental design and my research aim, my focus centred on testing two aspects of hypotheses. The first aspect aimed to assess whether FXI users encountered fewer difficulties in the custom UI compared to the initial UI in the three focal digital skills.

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[6] The Protopie prototyping tool is available at: [ProtoPie | High-Fidelity Prototyping for Mobile, Desktop, Web & IoT])

Meanwhile, the second aspect sought to determine if the custom UI mitigated performance disparities between the two user groups (FXI vs. LIT).

To elaborate further, my goal was to compare the performance of FXI users across both UIs. I sought to establish whether FXI users encountered fewer difficulties in the custom UI compared to the initial UI. Due to the partial nature of the custom UI, direct comparison of metrics such as time and number of taps was challenging. Differences in functionality between the two interfaces could influence exploration possibilities, making a fair comparison difficult. However, I considered error and task completion rates comparable, especially because the tasks are standardised and can be completed in both UIs, offering a basis for a direct user performance evaluation despite differences in functionality. Thus, the analysis focused on comparing error and task completion rates in each of the 3 focal digital skills, as articulated in Hypotheses 1 and 2 below.

Hypothesis 1

> Ho: proportion of errors made by FXI in the initial UI = proportion of errors made by FXI in the custom UI.
>
> Ha: proportion of errors made by FXI in the initial UI ≠ proportion of errors made by FXI in the custom UI.

Hypothesis 2

> Ho: proportion of task completion by FXI in the initial UI = proportion of task completion by FXI in the custom UI.
>
> Ha: proportion of task completion by FXI in the initial UI ≠ proportion of task completion by FXI in the custom UI.

In hypothesis 3 that follows, I investigated whether the custom UI successfully minimised the performance disparities between the FXI and LIT users. In this case, I avoided direct comparisons of the UIs themselves. Instead, I analysed if there were significant performance differences between the user groups for the custom UI by replicating the same analysis methods used on the initial UI. Subsequently, I determined whether the performance differences observed in the initial UI remained significant or otherwise. This allowed me to make comparisons despite the custom UI being a partial UI. To reiterate, a tapping count ratio greater than 1:2 (LIT: FXI) was considered a significant difference, as the data nature and the small LIT groups did not facilitate a statistical test for this measure.

Following the above explanation, the third hypothesis I focused on in this study includes the following for each of the top three digital skills.

Hypothesis 3

> Ho: The custom UI led to a reduction in performance disparities between FXI and LIT users in terms of error rate, task completion rate, and time taken.

Ha: The custom UI did not result in a reduction of performance disparities between FXI and LIT users in terms of error rate, task completion rate, and time taken.

4.3.3 Methods

The research methods employed in this experiment were consistent with those used in the initial study. These methods included the think-aloud technique, screen interaction recording, and a survey (as detailed in section 4.1.2 Research Methods). I asked the participants to complete the tasks that tested their proficiency in the 3 focal digital skills following the same procedure as the first study, as outlined in section 4.1.5 Data Collection. To ensure the integrity of the study and limit the introduction of new variables, the data was collected and recorded using identical equipment and the same research assistant as in the initial study.

4.3.3.1 Participants

I recruited FXI and LIT following the same recruitment criteria as the initial study from the same adult literacy centre (see section 4.1.3 Sampling). Twenty-five (25) participants were recruited for the study, twenty (20) of whom were FXI, while the rest (5) were LIT. For the FXI, 60% of the participants were female, while 40% were male. 55% of the participants were aged 30-39, 25% between 19 – 29 and 20% between 40 – 49 years. Half of the participants (55%) had the educational level of senior secondary, while 25% had a national diploma, and 20% had vocational training. Participants attended the literacy centre because of self-learning needs (45%), job purposes (40%) and just a hobby (15%).

The FXI participants reported spending much time on their smartphones daily (25% spent more than 10 hours, 10% 6-9 hours, and 40% 3-5 hours). FXI reported smartphone possession of 4 - 6 years (55%), 7+ years (15%), and 1 - 3 years (15%). However, there was a low report of experience with shopping and banking applications; 65% had never used banking apps, and 75% had never used shopping apps. Instead, USSD was reported as a widely used mobile banking medium (85%). Table 7 summarises the FXI participants' demographic information from the initial study (4.1.4 Participants) and this current study.

Among the LIT participants, three were females (60%), and two were males (40%), with 60% aged 19-29 and 40% aged 40-49. Two participants had a bachelor's degree (40%), two others had a diploma (40%), and one had a senior secondary certificate (20%). Most participants (60%) had used smartphones for over seven years, spending 3-5 hours (60%) or 10+ hours (40%) daily. Of those, 80% used mobile banking apps, with 40% frequent users, 20% rare users, and 20% occasional users. Contrastingly, 80% had never used mobile shopping apps.

Table 7: Comparing FXI users' demographics and smartphone usage patterns from the first to the second data collection study.

	Study 1: Investigating the Problem Space (n = 20)		Study 3: Designing and Evaluating a Custom UI (n = 20)	
	Number	**%**	**Number**	**%**
Gender				
Male	11	55	8	40
Female	9	45	12	60
Age				
19 - 29	7	35	5	25
30 - 39	10	50	11	55
40 - 49	3	15	4	20
SP* Experience Years				
Less than a year	3	15	2	10
1 – 3 years	6	30	4	20
4 – 6 years	7	35	11	55
7+ years	4	20	3	15
SP* Experience: Daily Time				
1 – 2 hours	2	10	4	20
3 – 5 hours	8	40	8	40
6 – 9 hours	6	30	3	15
10+ hours	4	20	5	25
SP* Experience: Banking				
Never	15	75	13	65
Rarely	1	5	1	5
Sometimes	2	10	2	10
Often	1	5	2	10
Always	1	5	2	10
SP* Experience: Shopping				
Never	14	70	15	75
Rarely	6	30	4	20
Sometimes	0	0	1	5
Often	0	0	0	0
Always	0	0	0	0
*SP is used as an abbreviation to represent 'Smartphone'				

4.3.4 Data Analysis

I reviewed the data collected following the same data recording technique described in the initial study (see section 4.1.6.1 Data Recording). Following this data recording stage, I compiled a spreadsheet containing details for each of the three digital skills tested, including the recordings of four user performance metrics (e.g., task completion rate) for each participant.

To analyse Hypotheses 1 and 2, which sought to assess whether the proportion of FXI users successfully using the custom UI was significantly greater than those using the initial mobile banking application, I chose the exact McNemar's Test (McNemar, 1947). This choice was appropriate as my data met the assumptions for this test, including:

1. Having one categorical dependent variable with two categories (e.g., "errors" and "no errors") and one independent variable with two related groups (interface type with two groups: "Initial UI" and "custom UI"). This design reflects a pre-test vs. post-test or matched pairs study.
2. Ensuring that the two groups of the dependent variable were mutually exclusive. In this context, participants could only have "errors" or "no errors" when analysing the initial UI. Similarly, they could only have "errors" or "no errors" when assessing the custom UI.

For Hypothesis 3, as previously mentioned, I analysed potential performance differences between user groups for the custom UI, replicating the same analysis methods applied to the initial UI. This involved utilising the Fisher's Exact Test and Independent Samples T-test, with data analysis conducted using IBM SPSS Statistics. Descriptive frequencies were also employed to facilitate result comparisons. Additional information on my rationale for these methods is available in section 4.1.6.3 Statistical Analysis.

4.4 Ethical Considerations

This study received ethical approval from the Aston University College of Business and Social Sciences Ethics Committee (see Appendix Q). This research adhered to strict ethical standards to safeguard participant well-being, ensure data confidentiality, and maintain the utmost ethical conduct throughout the study. Participants were selected based on specific inclusion criteria, including proficiency within a literacy benchmark, a demonstrated interest in technology interaction, and additional prerequisites outlined in section 4.1.3 Sampling. Exclusion criteria involved participants who displayed strong literacy in their native language but lacked English proficiency for interface usage or those failing to meet the criteria detailed in section 4.1.3 Sampling.

Potential risks identified encompass stress, anxiety arising from literacy levels, and the risk of undue influence due to compensation. These risks were evaluated as low to medium and were effectively managed through robust measures. To mitigate potential stress, a condensed participant information sheet was used, verbally communicated by a neutral third party. Verbal consent options were offered to participants to alleviate fatigue before the study, authorised by the literacy centre's deputy head teacher, and participants were informed of their right to withdraw at any stage.

Addressing potential anxiety due to literacy levels, participants received no performance feedback and were assured the study focused on mobile applications rather than individual performance. Verbal explanations and simplified materials facilitated comprehension for participants facing communication challenges. Participants also belonged to pre-existing adult literacy programs, indicating their familiarity with their literacy levels and proactive steps towards improvement, creating a more natural setting conducive to participant well-being.

Regarding the risk of undue influence, the researcher maintained a balanced approach between offered incentives and any perceived inducements projected by participants. Every participant received 3000 Nigerian Naira[7] regardless of study completion, covering transportation and meal costs.

Strict confidentiality, data security, and anonymisation protocols were followed throughout the research. Data collected was password protected, stored securely, and solely utilised for research purposes. Anonymisation was implemented during data collection, granting access to data only to the researcher and the main supervisor. Audio recordings were discarded after transcript verification, while video recordings were eliminated post-analysis to answer the research question.

4.5 Summary

In summary, this methodology chapter has provided a comprehensive overview of this study's research design and methods. The careful recruitment of participants, data collection, and rigorous analysis methods were detailed to ensure the validity and reliability of my findings. In the subsequent chapters, I will apply these methods to answer my research questions and gain deeper insights into the intricacies of usability issues and user interface patterns in the context of Nigerian smartphone users. The methodology outlined here is the foundation for my research findings and conclusions.

In the next section, I discuss my implementation of the methods in Study 1: Investigating the Problem Space. A detailed examination of the results obtained will follow this. Subsequently, I will engage in an in-depth discussion of these results, drawing meaningful insights and conclusions from the data.

[7] Equivalent to about 1.5 GBP as of October, 2024.

5 Investigating the Problem Space

Chapter 5 investigates the problem space to better understand how FXI interact with mobile banking and shopping applications on smartphones. This chapter presents the findings of Study 1, which was described in section 4.1. Refer to the thesis flow map in Figure 6 to see how this study fits into the overall research structure.

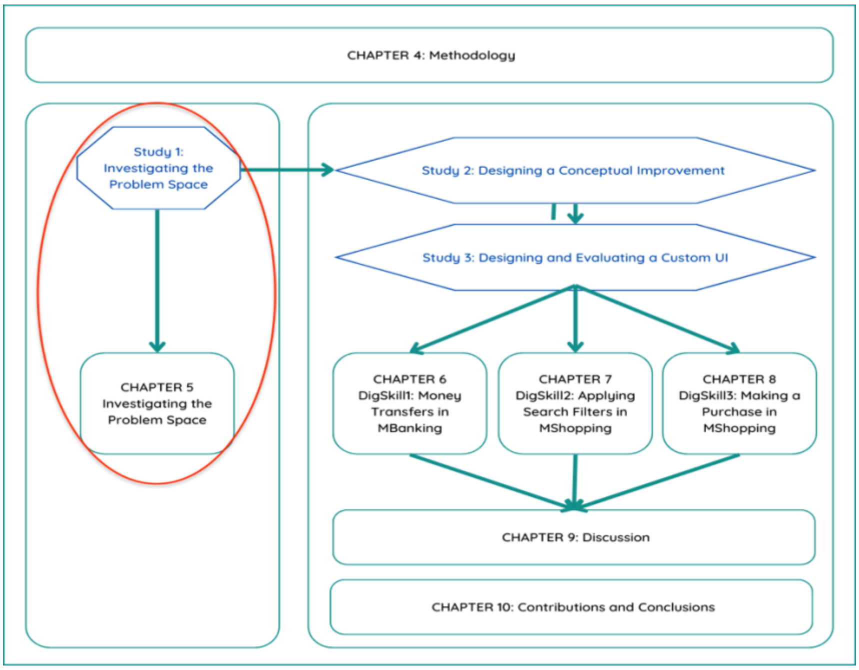


Figure 6: Thesis Flow Map – Chapter position in research structure.

5.1 Introduction

While research shows FXI users often need help to effectively use mobile applications to complete many basic tasks that are easier for other users (see Chapter 3), limited studies exist in the Nigerian context. A better understanding of the reasons behind the challenges experienced by FXI can help inform better interactions suited to these users. Consequently, I conducted this study to learn more about how FXI do everyday tasks on mobile applications, thereby obtaining empirical data on the challenges they face while carrying out basic tasks on mobile applications. This research serves as a starting point towards answering research question 1, which is:

> RQ 1: What design patterns of the user interface specifically cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

Results from this study provide a basis for exploring the factors that contribute to the challenges faced, providing information on what specific design patterns on the user interface are challenging for FXI users.

5.2 Method

This study employs a mixed methods approach, including the following methods: screen interaction recording, think-aloud, and surveys (see section 4.1 for details of methods related to this chapter). The data analysis methods employed in this study stage are predominantly quantitative. I employed Fisher's exact test and independent samples t-test to assess performance differences across FXI and LIT user groups. The focus is to use quantitative measures to explore and identify the most challenging digital skills, narrowing down the scope of the thesis. The objective is to investigate "what" digital skills are difficult. Subsequent chapters (i.e., Chapters 6, 7, and 8) will further investigate each case study, addressing the underlying "why" questions.

To evaluate digital skill challenges, participants completed 17 tasks across mobile banking and shopping applications (see Section 4.1.5.1. for task selection criteria). Each task was designed to assess specific digital literacy competencies required for successful interaction with these applications. The following sections detail each task, outlining the expected user interactions and the necessary digital literacy competencies.

5.2.1 Mobile Banking Tasks

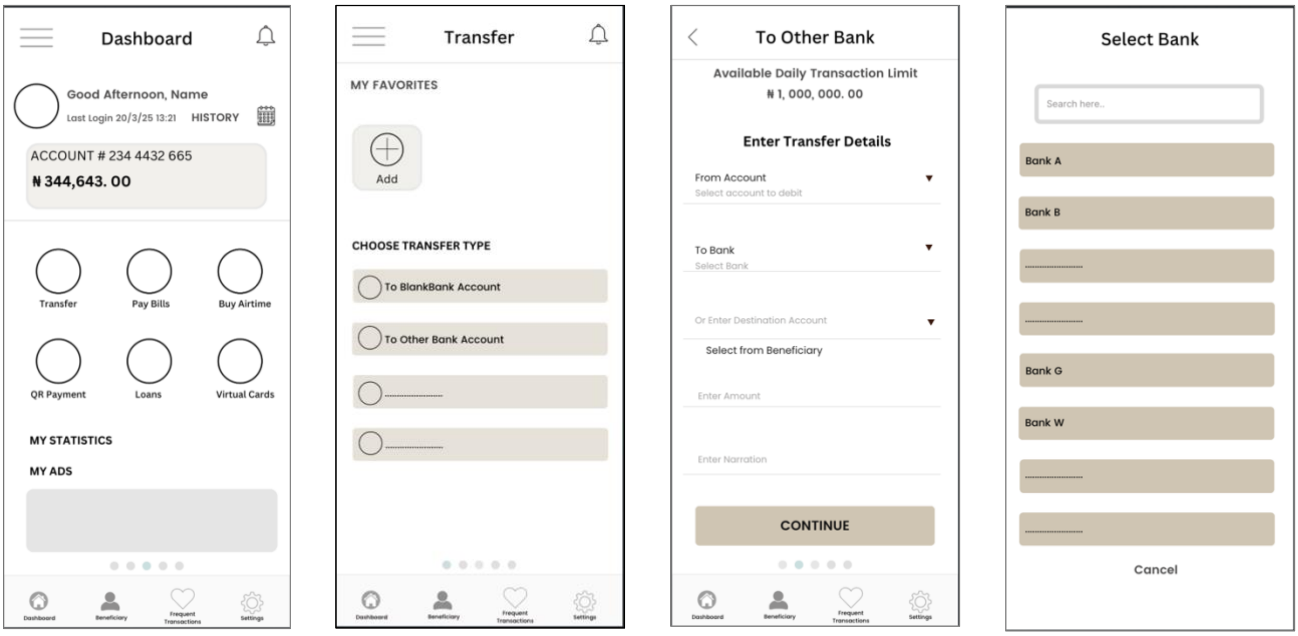
The following tasks evaluate user interactions with a mobile banking application, focusing on key financial transactions such as money transfers, airtime purchases, transaction history review, and customer support features.

5.2.1.1 Task T1 – Transfer to Another Account

Description: Users completed a money transfer using the mobile banking application.

Interactions: As shown in Figure 7, users navigated to the **Transfer** feature, selected the transfer type, entered transfer details into the form and authenticated the transaction.

Digital Literacy Competencies: 1.1 (Browsing UI), 1.2 (Evaluating transactions), 3.1 (Data entry), 5.2 (Confirming actions).



(a) (b) (c) (d)

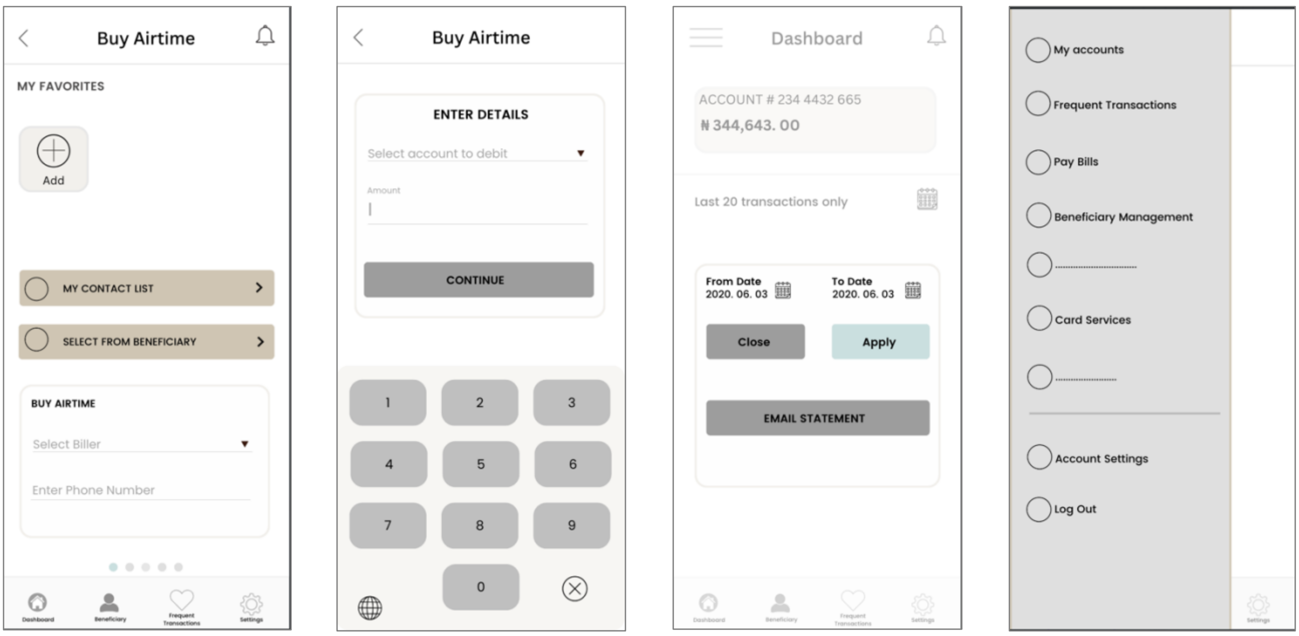
Figure 7: Mobile banking transfer interface

5.2.1.2 Task T2 – Buy Airtime for a Phone Number

Description: Users purchased mobile airtime via the banking application.

Interactions: As shown in Figure 8 (a-b), users navigated to the **Buy Airtime** feature, entered the recipient's phone number, network carrier and amount, and confirmed the purchase.

Digital Literacy Competencies: 1.1 (Browsing UI), 1.2 (Evaluating input data), 3.1 (Processing digital transactions), 5.2 (Verifying correct details).



(a) (b) (c) (d)

Figure 8: Screens of the mobile banking application for buying airtime (a-b), viewing transaction history (c), and (d) accessing the support menu

5.2.1.3 Task T3 – Display Transactions History

Description: Users accessed and reviewed their transaction history.

Interactions: As shown in Figure 8c, users opened the **History** con from the main menu, chose a history timeframe, scrolled through previous transactions, and selected an entry to view details.

Digital Literacy Competencies: 1.3 (Managing financial data), 4.2 (Understanding data privacy).

5.2.1.4 Task T4 – Find an Option to Log a Complaint

Description: Users located the banking app's complaint submission feature.

Interactions: As shown in Figure 8d, users navigated to the **Share Experience** section in the collapsable menu, selected a complaint category, and submitted a message.

Digital Literacy Competencies: 1.1 (Browsing menus), 2.1 (Interacting with digital customer support), 5.2 (Identifying the right technological response).

5.2.2 Mobile Shopping Tasks

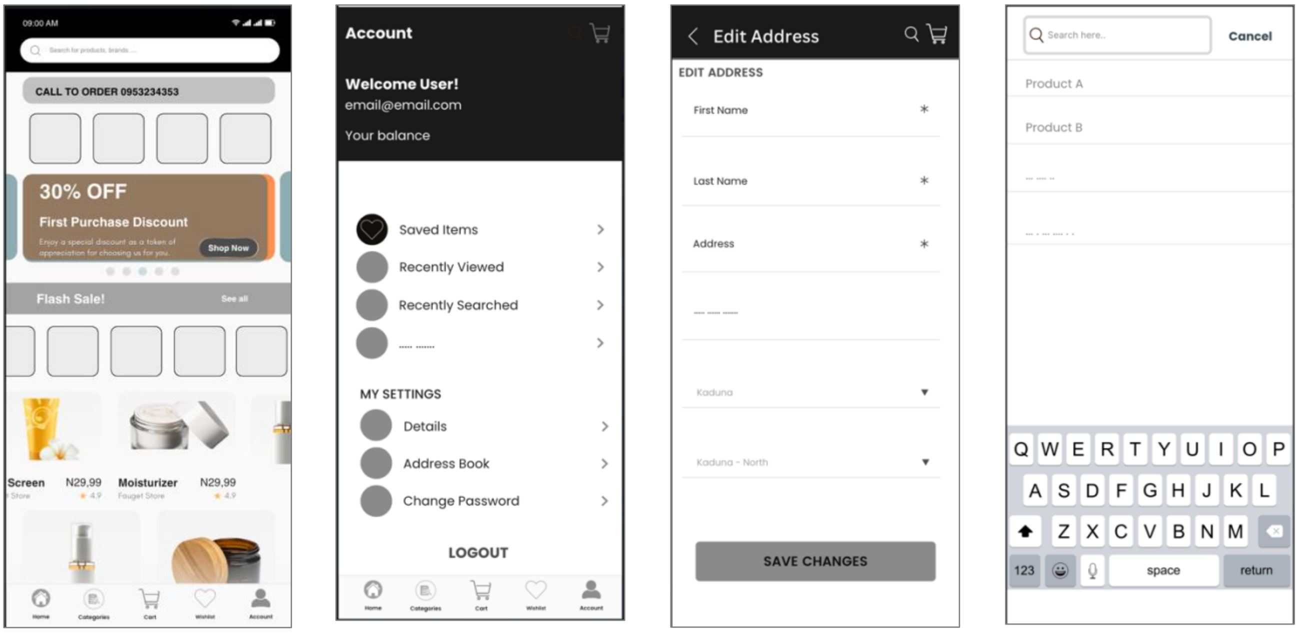
The following tasks assess user interactions with a mobile shopping application, focusing on product search, filtering, cart management, and transaction processes.

5.2.2.1 Task T1A & T1B – Edit Account Name & Add a New Address

Description: Users updated their account details by editing their name and adding a new delivery address in the shopping application.

Interactions: As shown in Figure 9 (a-c), users navigated to the **Account** section, selected the **Details** option to modify their name, and accessed the **Address Book** feature to add a new address.

Digital Literacy Competencies: 2.1 (Interacting through digital technologies), 2.6 (Managing digital identity).



(a) (b) (c) (d)

Figure 9: Mobile shopping application: (a) product search, (b) account details, (c) address editing, (d) search bar.

5.2.2.2 Task T2A & T3A – Search for a Product

Description: Users searched for a product in the shopping application using the search bar.

Interactions: As shown in Figure 9a and Figure 9d, users accessed the **Search** feature, entered a product name (tea). Subsequently, users viewed the search results list, as shown in Figure 10a.

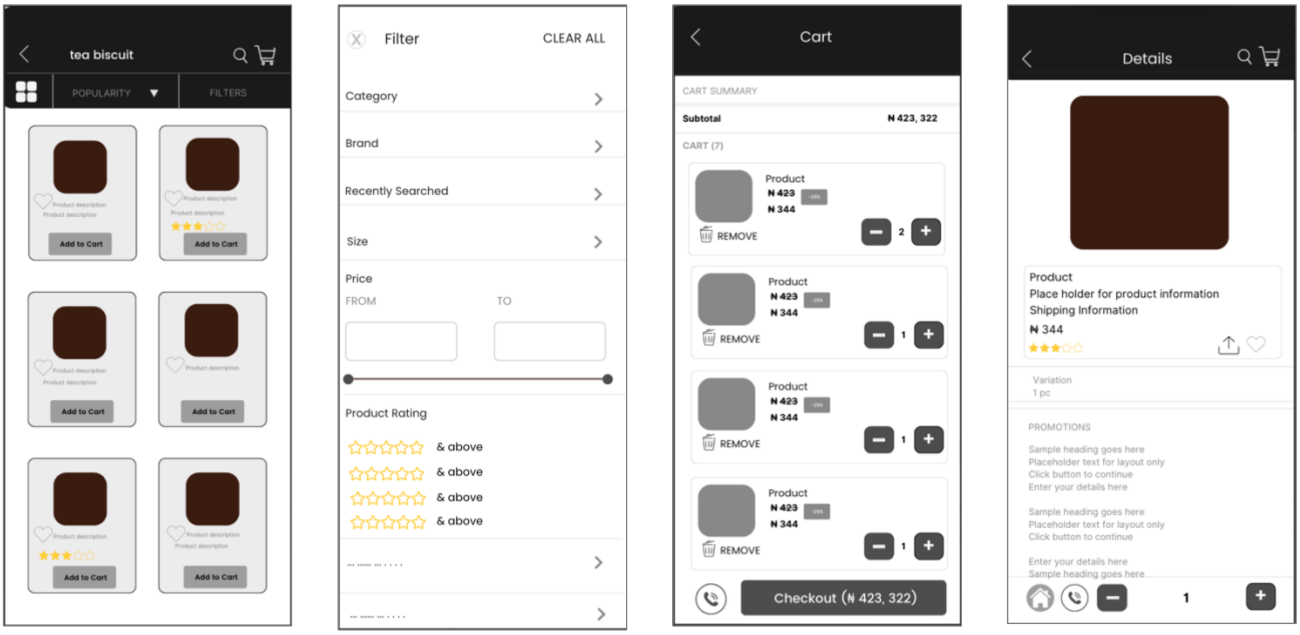
Digital Literacy Competencies: 1.1 (Browsing, searching, and filtering data), 5.2 (Identifying needs and technological responses).

5.2.2.3 Task T2B & T2C – Filter Search Results by Price & Rating

Description: Users applied filters to refine their product search based on price and customer ratings.

Interactions: As shown in Figure 10 (a-b), users chose **Filters** option from their search results screen, selected the **Price Range** and **Ratings** filters, and applied them to refine their search results.

Digital Literacy Competencies: 1.1 (Browsing, searching, and filtering data), 1.2 (Evaluating digital content).



(a) (b) (c) (d)

Figure 10: Mobile shopping application views for searching (a), applying filters (b), reviewing cart (c), and (d), product details.

5.2.2.4 Task T2D – Add Products to the Cart

Description: Users added selected products to their shopping cart before proceeding to checkout.

Interactions: As shown in Figure 10a, users clicked on **Add to Cart** for a product from the search results or each individual product details screen.

Digital Literacy Competencies: 1.3 (Managing digital content), 5.2 (Identifying technological responses).

5.2.2.5 Task T3B – Sort Search Results

Description: Users sorted search results to arrange products based on criteria such as price, popularity, or relevance.

Interactions: Users accessed the sort feature, which by default is set to **Popularity** within the search results page and selected a sorting option, as shown in Figure 10a.

Digital Literacy Competencies: 1.1 (Browsing, searching, and filtering data).

5.2.2.6 Task T3C & T4B – Add to Wishlist & Share a Product

Description: Users saved a product to their wish list and shared product details with a saved contact.

Interactions: As shown in Figure 10d, users selected the **Wishlist** icon (represented as a heart icon) on a product detail page to save the item for later and used the **Share** feature (represented as an upward arrow) to send the product details via the messaging application.
Digital Literacy Competencies: 1.3 (Managing digital content), 2.2 (Sharing through digital technologies).

5.2.2.7 Task T4A & T5A – Locate the Wishlist & Cart

Description: Users accessed their wish list and shopping cart to review saved and selected products.
Interactions: As shown in Figure 9b, users navigated to the **Account** section and selected **Saved Items** to view their wish list and accessed the Cart section (represented as an icon on the top of the screens) to review products before checkout.
Digital Literacy Competencies: 1.3 (Managing digital content).

5.2.2.8 Task T5B – Checkout

Description: Users completed the checkout process, selecting payment and delivery options.
Interactions: Users reviewed their cart, selected a payment method, confirmed the delivery address, and placed an order.
Digital Literacy Competencies: 1.1 (Browsing UI), 1.2 (Evaluating transactions), 3.1 (Data entry for payments).

5.3 Results

This section presents two subsections (5.3.1 and 5.3.2), which are written based on each mobile application. Further exploration into the results for FXI and LIT is done in the following section, with the main aim of exploring whether the measured tasks are complex for other users or only FXI. The user performance measures are used to structure the subsections per user interface. The results of the averages and sums for each task per user performance metric are presented in Appendix I.

5.3.1 Exploring Results Between Two User Groups in Mobile Banking

This section focuses on the results of the banking user interface. I examined the data to determine if the two user groups (i.e. FXI and LIT) are identical concerning the difficulty parameters (i.e. error rate, task completion rate, tapping count, and time elapsed). Twenty-five (25) participants were recruited for the study, twenty (20) of whom were FXI, while the rest (5) were LITs.

5.3.1.1 Error Rate

Of the FXI recruited, 13 (65%) experienced errors compared to LIT, 2 (40%) on average of the four tasks measured. Compared to LIT, FXI experienced errors up to two times (2x) more across the four (4) tasks measured, as shown in Figure 11. These tasks include T1, T3 and task 4. In T2, FXI experienced 40% fewer errors than the other tasks, indicating less difficulty in doing this task. However, compared to LIT, FXI experienced 40% more errors on T2.

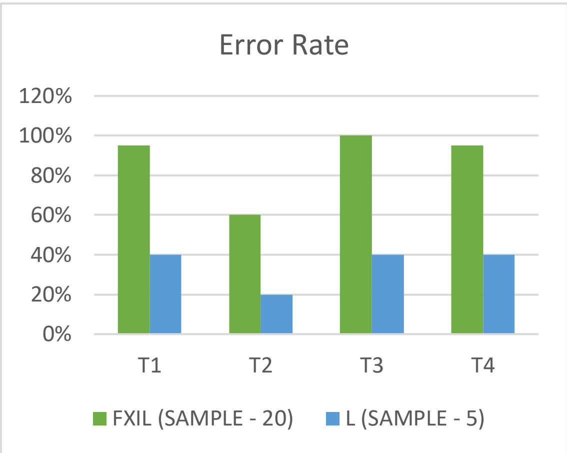
To further analyse this, Fisher's exact test was run as follows (see 4.1.6.3 Statistical Analysis for more details)

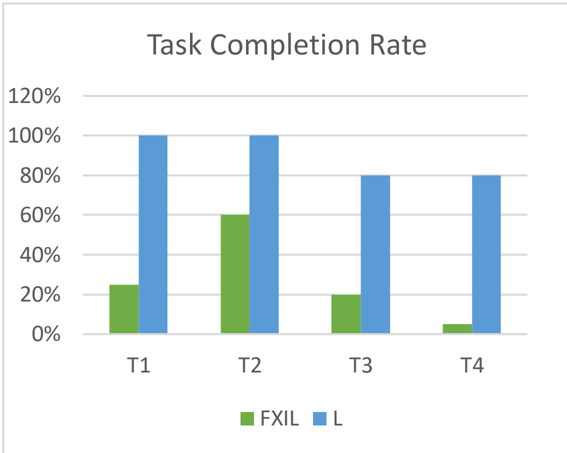
Hypothesis 1:

Ho: There is no association between the number of errors and user group.

Ha: The number of errors and user group are not independent.

The results showed a statistically significant association between the user group and error occurrence as assessed by Fisher's exact test for Tasks T1 (p = .016), T3 (p = .004), and T4 (p = .016). No statistically significant association was found for T2 as assessed by Fisher's exact test (p = .160).





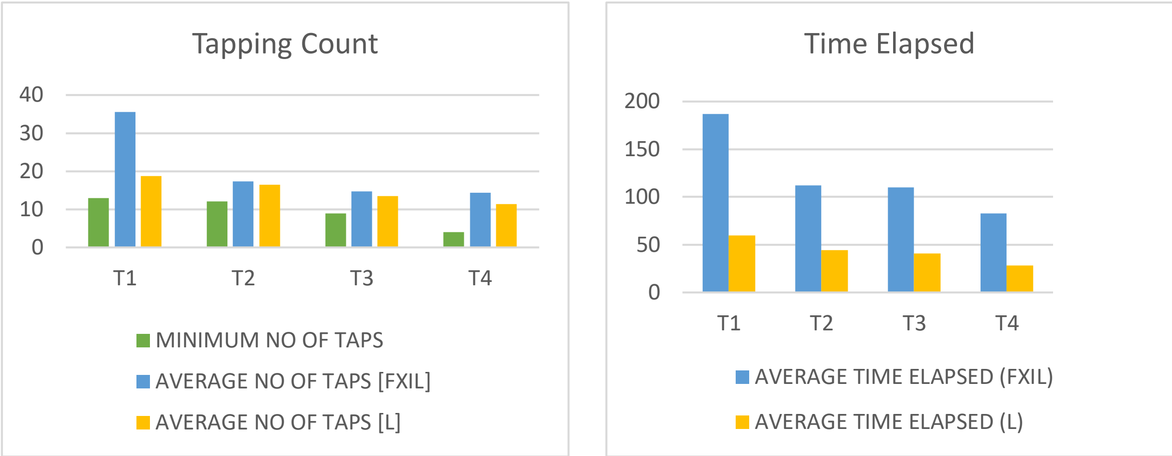


Figure 11: Study 1 Results – Mobile banking user performance metrics (error rate, task completion, taps, time).

5.3.1.2 Task Completion Rate

Of the FXI recruited, 28% completed the assigned tasks compared to LITs, 90% on average of the four tasks measured, see Figure 11. In T2, 60% of FXI were successful compared to LIT (80%). Therefore, task T2 was less difficult for FXI compared to other tasks (T1, T3 and T4) and LIT. On average, one-fourth of FXI completed all four tasks (mean 5.5). Fisher's exact test was conducted based on the task completion rate to determine if both user groups were identical in their task completion rates for each task with the following hypothesis (see 4.1.6.3 Statistical Analysis for more details).

Hypothesis 2:

> Ho: There is no association between the task completion rate and the user group.
>
> Ha: The rate of task completion and user group are not independent.

The results displayed a statistically significant association between the user group and error rate as assessed by Fisher's exact test for tasks T1 (p = .005), T3 (p = .023), and T4 (p = .002). No statistically significant association was found for T2 as assessed by Fisher's exact test, p = .140).

5.3.1.3 Tapping Count

The minimum taps required to do tasks T1, T2, T3 and T4 were 13, 12, 9 and 4, respectively. The results showed that FXI averagely tapped 36, 17, 15, and 14 times to do T1, T2, T3 and T4, respectively. On the other hand, LIT tapped on average 19, 16, 3 and 11, respectively, for the same sequence of tasks (as shown in Figure 11).

On average, FXI took 22.5, 5.3, 5.75 and 10.35 more taps to do tasks T1, T2, T3 and T4, respectively, compared to the minimum number of taps for the tasks (as shown in Figure

11). Compared to LIT, FXI took 17, 1, 1, and 3 taps more to do T1, T2, T3 and T4, respectively. Because LIT did 6, 4, 4, and 7 taps more than the minimum taps for T1, T2, T 3 and T4, respectively, it is reasonable to assume that T1 was difficult for FXI. It is also likely that both FXI and LIT found T4 somewhat challenging.

5.3.1.4 Time Elapsed

FXI took longer to complete all four (4) tasks, as shown in Figure 11. On average, FXI took 127 seconds, 68 seconds, 69 seconds, and 55 seconds longer in doing tasks T1, T2, T 3 and T4, respectively, compared to LIT in the time taken to do the four tasks. This means that FXI took three times longer to do all four tasks.

An independent samples t-test was conducted with the dependent variable as time elapsed to find out if the difference in time elapsed between both user groups was statistically significant. The independent variable was the two independent user groups (FXI and LIT). The test was run with the following hypotheses (see 4.1.6.3 Statistical Analysis for more details).

Hypothesis 3:

Ho: FXI and LITs’ mean time elapsed scores are equal in the population.

Ha: FXI and LITs’ mean time elapsed scores are not equal in the population.

There were two outliers in the data, which had a studentised residual value of 3.61 and 3.63. An assessment of the normality of the data distribution by Shapiro-Wilk's test of normality (p >.05) showed that five out of the eight combinations of the levels of literacy group factors were normally distributed. Variances were homogeneous (p > .05), as assessed by Levene's test of homogeneity of variances.

The time elapsed was higher for FXI in tasks T1, T2, T3 and T4, respectively than for LITs (see Appendix J for the statistical results table). A statistically significant difference was observed in tasks T1, T3 and T4 with t (38) = 3.678, 3.827, and 2.904, p = .001, 0.27 and .008, respectively. No statistical significance was found for T2 with t(38) = 1.932, p = .066.

There was a statistically significant difference between mean time elapsed (p < .05) for T1, T3 and T4, and therefore, we can reject the null hypothesis and accept the alternative hypothesis. No statistically significant difference between means was found for T2; therefore, we accept the null hypothesis.

5.3.2 Exploring Results Between Two User Groups in Mobile Shopping

This section focuses on the results of the mobile shopping application. I examined the results to determine if the two user groups (i.e., FXI and LIT) are identical concerning the user performance metrics (i.e., error occurrence, task completion, taps, and time elapsed). Twenty-five (25) participants were recruited for the study, twenty (20) of whom were FXI, while the rest (5) were LITs.

5.3.2.1 Error Rate

FXI experienced more errors than LITs in most of the tasks measured. As shown in Figure 12, no errors were recorded for LIT participants in 70% of the 13 tasks measured. FXI experienced a relatively lower number of errors in tasks T3a (10%) and T2d (35%) compared to the other tasks. Tasks T1a, T1b, T2c, and T5b had a percentage of error occurrence of at least 80%, compared to LITs who were recorded to experience no errors for the same tasks.

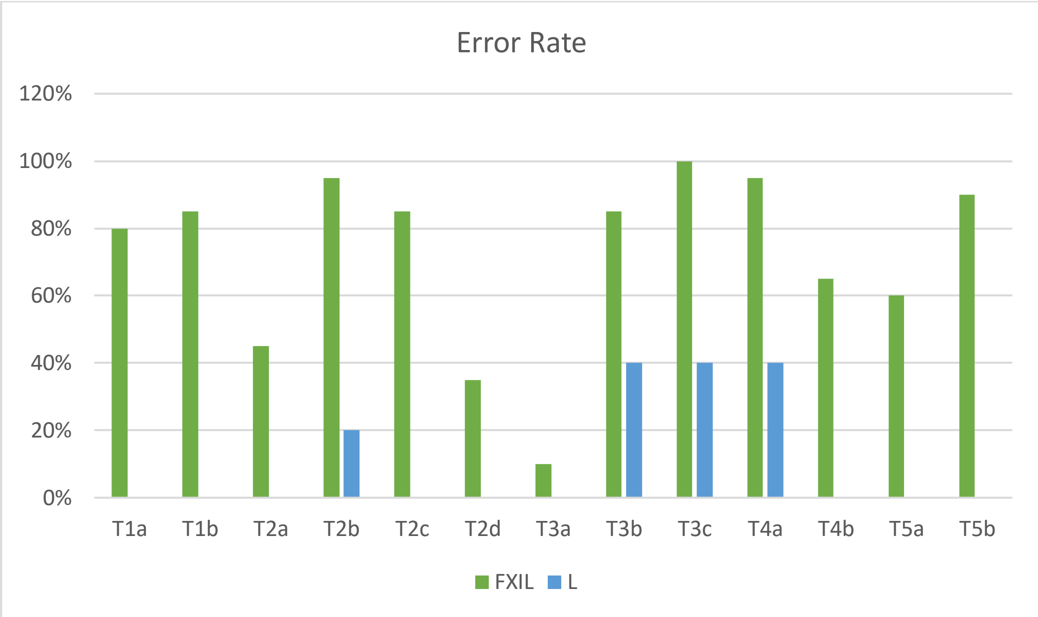


Figure 12: Percentage of error rate by FXI vs LITs

Further analysis was carried out on each task to examine whether FXI and LITs are identical concerning error occurrence across the 13 tasks tested using the Fisher's exact test. In other words, if the proportion of errors is equal in both groups. This test was chosen due to the categorical nature of the data and the relatively small sample size in the LIT group, which made it more appropriate (Kateri, 2014). Fisher's exact test evaluates whether the proportion of errors differs significantly between FXI and LIT participants (see Section 4.1.6.3 Statistical Analysis for more details). Fisher's exact test was run with the following hypotheses for each of the 13 tasks.

Hypothesis 1:

Ho: There is no association between the number of errors and user group.

Ha: The number of errors and user group are not independent.

There was a statistically significant association between the literacy group (i.e., FXI or LIT) and error occurrence as assessed by Fisher's exact test for some tasks. These tasks include Task T1a (*p* = .002), T1b (*p* = .001), T2b (*p* = .002), T2c (*p* = .001), T3c (*p* = .004), T4a (*p* = .016), T4b (*p* = .015), T5a *(p* = 0.039) and T5b (*p* = <.001).

No statistically significant association was found for T2a (*p* = .123), T2d (*p* = .274), T3a (*p* = 1.000), and T3b (*p* = .070), as assessed by Fisher's exact test. Therefore, we **reject** the null hypothesis and accept the alternative hypothesis for Tasks T1a, T1b, T2b, T2c, T3c, T4a, T4b, T5a and T5b and **cannot accept** the alternative hypothesis for Tasks T2a, T2d, T3a and T3b.

5.3.2.2 Task Completion Rate

Of the FXI recruited, 43% completed the assigned tasks compared to LITs, 85% on average of the four tasks measured. As depicted in Figure 13, more than 60% of FXI completed tasks T1b, T2a, T2d and T3a (65%, 80%, 85%, and 90%, respectively) compared to LITs who had a 100% completion rate on the same tasks. The tasks with the lowest completion rate for FXI were tasks T2c, T3b, T3c, and T4a, with below 25% recorded as the average completion rate. On the other hand, tasks T3c and T4a recorded a 60% completion rate for LIT participants, which might indicate that these two tasks were also somewhat challenging for LIT participants. None of the participants was able to complete task T2b.

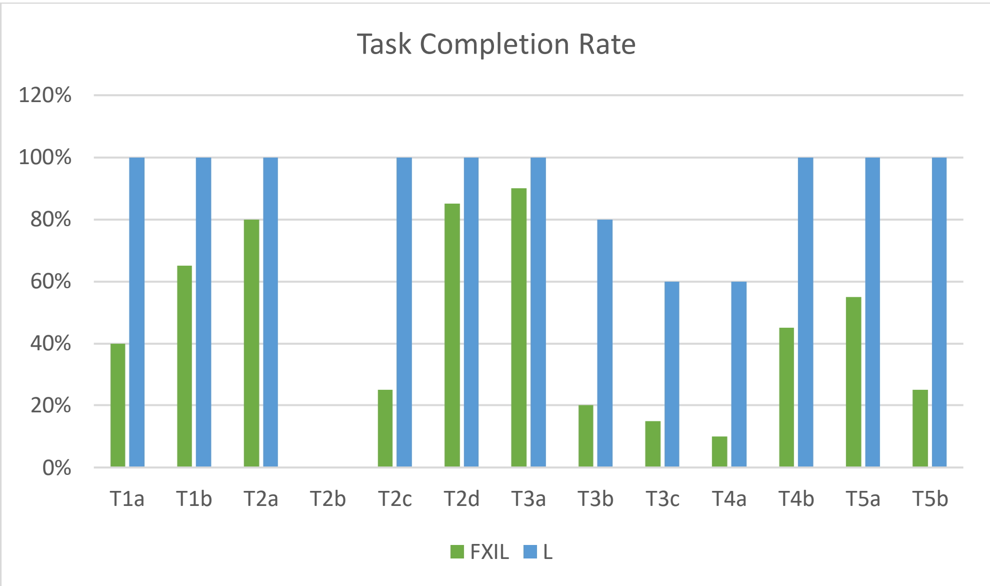


Figure 13: Percentage of task completion rate by FXI vs LIT

We conducted Fisher's exact test on each task to determine if both literacy groups had identical task completion rates. The test was selected due to the small sample size, which makes it suitable for analysing categorical data where expected frequencies are low (Kateri, 2014). Given the unequal sample sizes (FXI: 20, LIT: 5), this test ensured reliable estimations without violating statistical assumptions (Laerd Statistics, 2015). See Section 4.1.6.3 Statistical Analysis for more details. The test was run with the following hypotheses.

Hypothesis 2:

> Ho: There is no association between the task completion rate and the user group.
>
> Ha: The task completion rate and user group are not independent.

There was a statistically significant association between the literacy group (i.e., FXI or LIT) and error occurrence as assessed by Fisher's exact test for tasks T1a (p = .024), T2c (p = .005), T3b (p = .023), T4a (p = .038), T4b (p = .039), and T5b (p = .005).

No statistically significant association was found for tasks T1b (p = .274), T2a (p = .549), T2d (p = .1.000), T3a (p = .549), T3c (p = .070) and T5a (p =.123), as assessed by Fisher's exact test. Therefore, we reject the null hypothesis for Tasks T1a, T2c, T3b, T4a, T4b, and T5b and accept the null hypothesis for Tasks T1b, T2a, T2d, T3a, T3c and T5a. No statistic was computed for T2b because it is a constant.

5.3.2.3 Tapping Count

As shown in Figure 14, FXI tapped at least two times (2x) more when compared to LIT and the minimum taps required for the tasks for a considerable number of tasks (6 tasks: T1b, T2c, T2d, T4b, T5a and T5b). This indicates that FXI took longer and made more attempts (whether successful or unsuccessful) to do these tasks than LITs.

In some other tasks (T2b, T3b, and T4a), both FXI and LITs had roughly similar taps, which was relatively higher than the minimum number of taps required to do those tasks. It is reasonable to assume that tasks T2b, T3b and T4a were challenging for both user groups to complete.

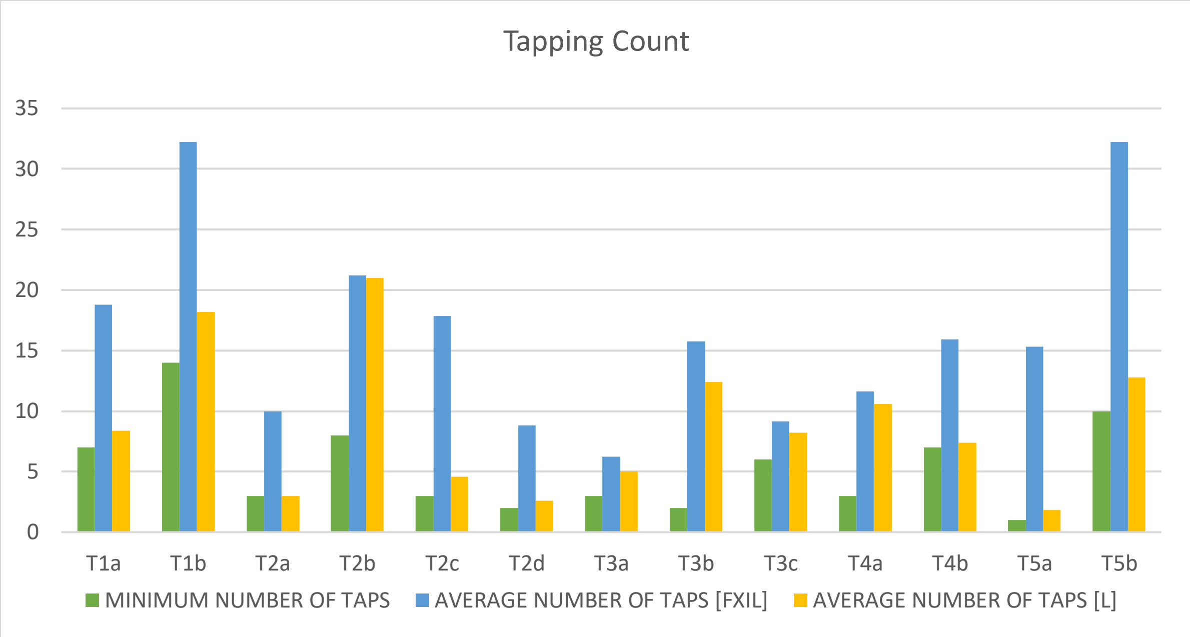


Figure 14: Average number of taps for both user groups and all tasks

Further details on the figures for minimum taps and the number of taps for both literacy groups can be found in Table 36 in Appendix I.

5.3.2.4 Time Elapsed

On average, FXI took relatively longer to complete all thirteen (13) tasks on the mobile shopping application than the time for LITs, as shown in Figure 15. For some tasks (2 tasks: T3c and T4a), although FXI took longer than LITs, the difference between both users was not more than 21 and 24 seconds on average. Other tasks showed a more considerable difference in time. For example, in tasks T1b and T5b, FXI took (105 seconds and 114 seconds, respectively) longer than LITs.

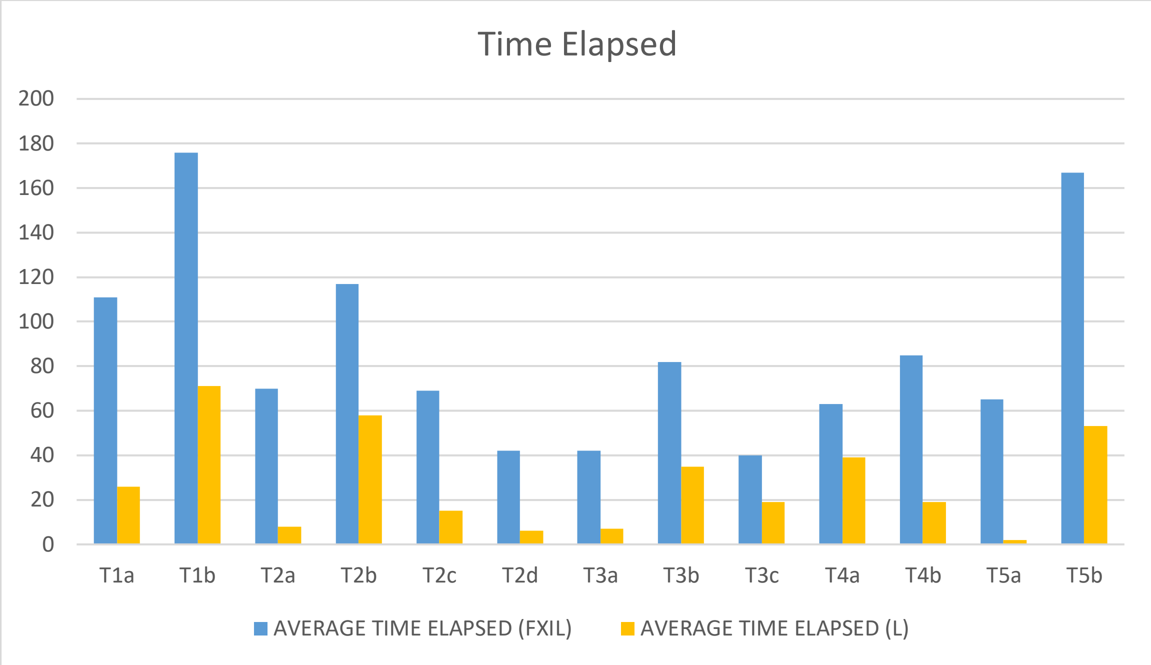


Figure 15: Average time elapsed (seconds) for both user groups and all tasks.

Further analysis was conducted to determine whether the difference between both user groups was significant. An independent samples t-test was run with the dependent variable as time elapsed. The independent variable was the two independent literacy groups (FXI and LITs). This test was chosen as it evaluates whether the observed differences in sample means reflect true differences in population means, rather than being due to random variation (Sheskin, 2011). Given the unequal sample sizes and potential differences in variance, the Welch correction was applied where homogeneity of variance assumptions were not met (Howell, 2010). See Section 4.1.6.3 Statistical Analysis for more details. The test was run with the following hypothesis.

Hypothesis 3:

Ho: FXI and LITs' mean time elapsed scores are equal in the population.

Ha: FXI and LITs' mean time elapsed scores are not equal in the population.

There were three outliers, which had a studentised residual value of 3.07, 3.30 and 3.94. An assessment of the normality of the data distribution by Shapiro-Wilk's test of normality (p >.05) showed that eighteen combinations out of the twenty-six levels of literacy group factors were normally distributed. Variances were homogeneous ($p >$ .05), as assessed by Levene's test of homogeneity of variances for some of the tasks (T1a, T1b, T2b and T3b).

The time elapsed was 85, 105, 60, and 46 seconds (CI 95%) higher for FXI in T1a, T1b, T2b and T3b, respectively, than the time elapsed for LITs (see Appendix J for the statistical results table). A statistically significant difference was observed in T1a, T1b, T2b and T3b with *t*(38) = 3.453, 4.614, 2.146 and 2.308, *p* = .002, <.001, .043, and 0.30 respectively.

Since the homogeneity assumption is violated for the other tasks, the Welch t-test is used, as recommended in Howell (2010). The Welch test is interpreted for T2a, T2c, 2d, T3a, T3c, T4a, T4b, T5a, and T5b (see Appendix J for mean difference and t-statistic value in the statistical results table). A statistically significant difference was observed in T2a (*p* = <.001), T2c (*p* = <.001), T2d (*p* = .001), T3a (*p* = <.001), T3c (*p* = .005), T4a (*p* = .008), T4b (*p* = <.001), T5a ((*p* = <.001) and T5b (*p* = <.001).

There was a statistically significant difference between mean time elapsed (*p* < .05) across all 13 tasks. Therefore, we can reject the null hypothesis and accept the alternative hypothesis for all 13 tasks.

5.3.3 User Experience Ratings

According to the UEQ-S benchmark, a product that ranks in the 'excellent' category for any usability aspect (e.g., enjoyability, efficiency) performs better than 90% of evaluated products. Products in the 'good' category have 10% of products performing better and, 75% performing worse, and so on. For more details, see Appendix H. For example, as shown below, FXI rated the application as above average in terms of enjoyability, meaning 25% of the results in the benchmark are better than the mobile banking application, and 50% are worse.

Following the UEQ-S benchmark, the results show that FXI rated the mobile banking application as follows: see Figure 16.

1. Enjoyability: above average (mean 1.21)
2. Understandability: below average (mean 0.79)
3. Efficiency: below average (mean 0.79)
4. Meets expectations: bad (mean 0.63)
5. Exciting: good (mean 1.31), and
6. Leading-edge: bad (mean 0.05).

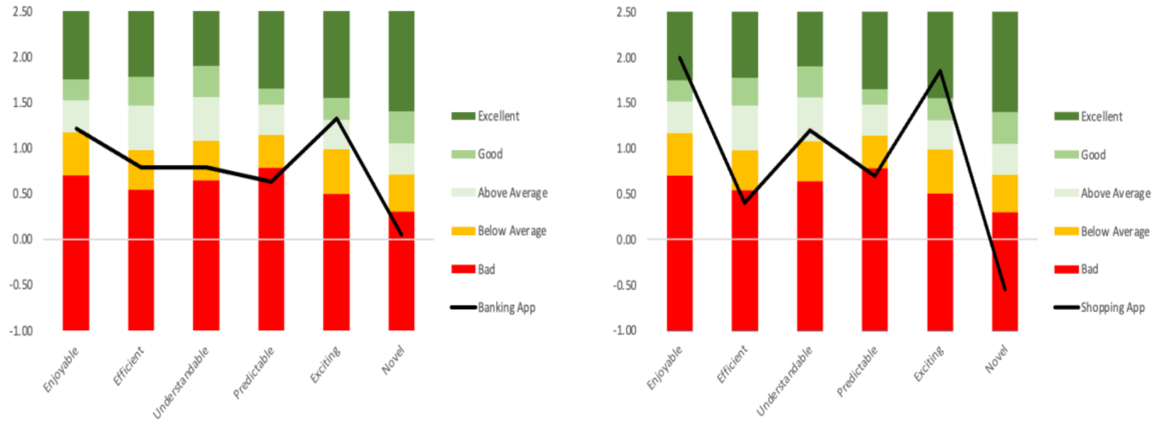


Figure 16: UEQ-S Survey Results – FXI user ratings of mobile banking and shopping applications..

Users were also asked to rank their success in completing all four assigned tasks. FXI ranked their success rate as relatively high (64.7%) compared to their average total task completion rate (27.5%) for all four tasks measured.

For the mobile shopping application, FXI rated it as follows (see Figure 16).

1. Enjoyability: excellent (mean 2.0)
2. Understandability: above average (mean 1.2)
3. Efficiency: bad (mean 0.4)
4. Meets expectations: bad (mean 0.7)
5. Exciting: excellent (mean 1.85) and
6. Leading edge: bad (mean -0.55).

Users ranked their success in completing all thirteen (13) assigned tasks. On average, FXI participants ranked their success rate as relatively high (75%) compared to their average total task completion rate (42%) for all thirteen (13) tasks measured.

5.3.4 Rank Analysis

A descriptive rank analysis was conducted to summarise both user interfaces' most challenging tasks for FXI users. The results of this analysis are presented in Table 8 and Table 9.

Table 8: Summary table - rank analysis for mobile banking application

Performance measures	**Task IDs**			
	T1	T2	T3	T4
Error Rate	2	1	3	4
Task Completion Rate	2.5	1	4	2.5
Tapping Count	4	1	2	3
Time Elapsed	4	1	2	3
Average Rank	3.1	1.0	2.8	3.1

In Table 8, T1 ranks 3.1 out of 4 overall, while T2 shows 1.0 out of 4. This means that T1 was relatively more difficult because it ranks more than twice in difficulty. The same logic applies to Table 9, where T5b ranked 9.25 out of 13 (indicating the most difficult task), while T3a ranked 3.5 out of 13 (indicating the least difficult task). The rankings in the mobile shopping application are out of 13 because there were 13 tasks measured overall.

Table 9: Summary table - rank analysis for mobile shopping application

PM	Task IDs												
	T1a	T1b	T2a	T2b	T2c	T2d	T3a	T3b	T3c	T4a	T4b	T5a	T5b
ER	7	4	3	13	8	2	1	10	11	12	6	5	8
TCR	6	7	3	11	7	2	1	7	13	11	5	4	10
TC	7	5	12	2	9	11	10	4	3	1	8	13	6
TE	7	12	4	8	11	3	2	9	1	5	6	10	13
AR	6.75	7	5.5	8.5	8.75	4.5	3.5	7.5	7	7.25	6.25	8	9.25

*Note: PM represents performance measures,
ER represents Error Rate,
TCR- Task Completion Rate,
TC- Tapping Count,
TE- Average Rank, and
AR- Average Rank

5.3.5 Summary

This section presents a summary of the results section.

5.3.5.1 Most Challenging Tasks for FXI

As shown in Table 8, the ranking averages for each task were taken for the mobile banking interface. Based on these rankings, the most difficult tasks were those with the highest average ranked scores, i.e., Task 1 (bank transfer via the mobile application) and Task 4 (Search through the banking application for an option to log a complaint). The easiest task was task 2 (purchase airtime for a phone number).

Similarly, Table 9 shows the most difficult tasks for FXI users using the mobile shopping application. These are tasks T5b (*Checkout until the summary page*), T2c and T2b (both '*filter the search results so that it displays specific results*'), and T5a (*Locate the shopping cart*). Tasks T1b (*Add a new address to the current* account), T3c (*Add any two products to the wish list*), T1a (*Edit the account name to include your first and last name on the shopping application*), and T4b (*Share any product with a contact saved on the phone via the messaging application*) were relatively less challenging for FXI users. Meanwhile, tasks T2a and T3a (*Search for a product on the shopping application*) and T2d (*Add any two products to the cart*) proved easy for FXI users.

Based on the above analysis, we focus on the following tasks as the most challenging for FXI.

1. Transferring funds from one account to another [Task 1, banking application]
2. Searching through the banking application for an option to log a complaint [Task 4, banking application]
3. Completing a purchase [Task 5b, shopping application]
4. Filtering search results [Tasks 2b and 2c both, shopping application]
5. Locating the shopping cart [Task 5a, shopping application]

5.3.5.2 Statistical Analysis Results (FXI vs LIT Users)

Table 10 and Table 11 summarise the statistical analysis results from sections 5.3.1and 5.3.2 for the mobile banking and shopping applications. Because different statistical tests were used to compare the user performance measures, p-values were not used in the summary tables below. Instead, "x" denotes a significant difference in the observations between FXI and LIT participants. There is no data for the *tap* user performance measure because it is count data. However, to aid the discussion, a ratio of 1:2 or above is considered a notable difference in tapping count between both user groups.

Table 10: Summary of statistical analysis results for mobile banking. *Note that 'x' in bold represents the tasks rated as the most difficult in 4.3.5.1

	Performance Measures			
Task IDs	**Error Rate**	**Task Completion Rate**	**Tapping Count**	**Time Elapsed**
T1	**x**	**x**	**2:1**	**x**
T2			1:1	
T3	x	x	1:1	x
T4	**x**	**x**	**1:1**	**x**

Table 11: Summary of statistical analysis results for mobile shopping. *Note that 'x' in bold represents the tasks rated as the most difficult in 4.3.5.1

	Performance Measures			
Task IDs	**Error Rate**	**Task Completion Rate**	**Tapping Count**	**Time Elapsed**
T1a	x	x	2:1	x
T1b	x		2:1	x
T2a			3:1	x
T2b			**1:1**	**x**

	Performance Measures			
Task IDs	**Error Rate**	**Task Completion Rate**	**Tapping Count**	**Time Elapsed**
T2c	**x**	**x**	**4:1**	**x**
T2d			3:1	x
T3a			1:1	x
T3b		x	1:1	x
T3c	x		1:1	x
T4a	x	x	1:1	x
T4b	x	x	2:1	x
T5a	**x**		**9:1**	**x**
T5b	**x**	**x**	**3:1**	**x**

5.4 Discussion

This study was done with a group of FXI users to learn more about how they perform tasks on a smartphone. LIT users were also studied to establish that the interfaces were not complicated for all users. The objective was to gain insight into what people did and what they found most challenging. The research question was as follows.

> RQ1: What design patterns of the user interface specifically cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

To answer the research question, I had to establish whether there were difficulties in the tasks we assigned to FXI. The results from this research have demonstrated that while FXI found some tasks easy, FXI experienced challenges in other tasks when interacting with smartphones. Section 5.3.5 highlights the summary of the easy-difficult tasks.

This section is structured in four (4) sub-headings. In section 4.4.1, we discuss the results of the user experience survey. In the next section (5.4.1), we focus on our findings for FXI and discuss whether this is the same for LIT. Section 5.4.3 discusses the results based on the Digital Literacy Global Framework (DLGF). Because the research question is focused on assessing difficulties, sections 5.4.2 and 5.4.3 focus more on discussing the tasks that were classified as difficulties for FXI. Finally, section 5.4.4 discusses other more general findings.

5.4.1 User Experience

A new product should reach at least the '*good'* category on all scales to match user expectations of quality user experience based on the data already obtained from established products to form the basis of the benchmark (Schrepp et al., 2017). The user experience rating of both interfaces was assessed and compared to the UEQ benchmark to allow for conclusions regarding the relative strengths and weaknesses of the applications.

The results showed that FXI thought both mobile applications were bad in terms of whether they met their expectations and leading edge. This means that in these user experience aspects, both mobile applications were among the worst 25% of the results based on the benchmark. However, crucial quality aspects of user experience depend on an application's nature and goal (Sharp et al., 2019; Schrepp et al., 2017). For instance, efficiency and understandability are relatively more critical user experience aspects for a banking application than enjoyability and exciting elements. However, for shopping applications, the latter will be equally important in addition to efficiency and understandability.

FXI users rated the banking application below average regarding understandability and efficiency, indicating that 50% of the applications in the benchmark are better than the banking application. On the other hand, the mobile shopping application was rated above average in understandability and bad in efficiency. FXI users rated the shopping application as excellent compared to the user experience benchmark in terms of enjoyability and excitement.

FXI were also asked to rate their success in completing tasks at the end of their interaction with each interface. Interestingly, FXI had a perceived success rate considerably higher than their actual success rate. FXI participants ranked their success rate as relatively high (64.7%) compared to their average total task completion rate (27.5%) for all four tasks measured in the Banking application. For the mobile shopping application, FXI participants ranked their success (75%) vs average total task completion rate (42%) for all thirteen (13) tasks measured. This is thought to be either because they had trouble recognising whether their actions were correct in attempting the tasks or because they were anxious about admitting that they had difficulty completing them.

5.4.2 Exploring Results of Difficult Tasks between Two User Groups

Based on our analysis, FXI experience the most difficulties in tasks that involve the following: transferring funds from one account to another (T1; banking), finding an option to log a complaint (T4; banking), completing a purchase (T5b shopping), filtering search results (T2c, T2b; shopping), and locating the shopping cart (T5a; shopping). This subsection discusses whether only FXI experienced difficulties in these tasks.

Transferring funds to another account (T1 banking) was among the most challenging tasks. This task showed considerable differences against the LIT participants on all four user performance measures. FXI participants had significantly more errors, time spent, taps, and the lowest completion rates for this task, while the LITs found this task easy. Similar results were found for completing a purchase (T5b; shopping) and one of the filtering search tasks (T2c; shopping).

However, the opposite was found in the other filtering searches task (T2b; shopping). The only significant difference in difficulty between FXI and LITs was the time it took to do the task. There was no difference in the number of errors, taps, and whether the task was completed. Also, no participant could complete this task. This indicates that although two tasks measured sorting searches, one (T2c; shopping) was difficult for only FXI, while the other (T2b; shopping) was difficult for both FXI and LITs. Since both tasks require arguably similar mental models and digital skills, this raises the question of whether there is a difference in the user interface design patterns between both tasks, which causes difficulties in only one task.

In finding an option to log a complaint (T4; banking), FXI made considerably more errors and took longer than LITs. A significant difference in completion rate was also found, as LITs could complete the tasks more than FXI. No difference was found in the number of taps required to do the task between FXI and LIT, although both users tapped at least twice more than the minimum taps required. Further review of the screen interaction logs will provide more details on this, although my current observation indicates that both FXI and LITs searched through the interface to find the option to do the task. Because there is a significant difference in time, this indicates that although both user groups had to tap more than necessary, LITs could assess whether they had found the right option faster than FXI.

On the other hand, there was no significant difference in the task completion rate between FXI and LIT participants in locating the shopping cart (T5a; shopping). FXI could complete the task even though it took considerably longer and had more errors and taps than LITs. This shows that although FXI found it challenging to find the option for the cart, they explored the interface until they found it.

Based on the analysis of both user groups, significant differences were found in all four user performance measures for half of the complex tasks (T5b; shopping; T2c; shopping; T1; banking). In the other half, there were significant differences in three out of the four user performance measures for all (T4; banking; T5a shopping) except one task (T2b; shopping). We can conclude that *only* FXI had difficulties with five out of the six complex tasks, as only one task (T2b; shopping) presented a strong indication of difficulty in both user groups.

5.4.3 Digital Literacy Global Framework (DLGF)

Mapping the most complex tasks for FXI to the Digital Literacy Skills Framework (DLGF) showed that the digital competencies required to complete those difficult tasks are in the following areas: Information and Data Literacy, Communication and collaboration, Digital content creation, and Problem-solving on the Digital Literacy Skills Framework (DLGF). See the methodology chapter for mapping. This sub-section aims to see whether FXI users are more skilled in some digital competencies than others.

As shown in section 4.1.5.1, most of the tasks measured were mapped out to more than one digital competency. For example, in completing a purchase (T5b; shopping), problem-solving is also required as a digital competency, in addition to information and data literacy. The user needs to be able to identify the needs and technological response of the user interface, which is a problem-solving competence area. As a result, because multiple steps are required to complete a purchase (T5b; shopping), the challenge for FXI may be in only one of the digital competencies, which appears within one or two steps of the task.

Even when similar digital competencies are needed across tasks, the interface may offer a wider range of operations, making it more comprehensive and complex (Law et al., 2018). Consequently, the level of competence and proficiency required for one task might be higher than others. For example, (i) searching for products and adding them to the cart (T2a, T3a and T2d; shopping) and (ii) filtering search results and completing a purchase (T2b and T5b; shopping) are all dependent on the information and data competence area of the DLGF. However, these two categories are at the far end of our results; FXI found it easier to do the former (i) than the latter (ii). One difference between both comparisons is that filtering search results and completing a purchase requires many more steps than searching for products and adding to a cart. This shows that although both comparisons measure the same DLGF competency, higher proficiency is required in those with multiple steps. Moreover, the greater a task's complexity, the higher the demand for cognitive processing, meaning that tasks with multiple steps could be too complex for users with low literacy (Medhi, 2015).

However, purchasing airtime for a phone number (T2; Banking) also required multiple steps, but this task was easy for FXI. No difference was observed compared to the performance of the LIT in any user performance measures (i.e., time, taps, completion rate and error occurrence). This challenges the judgement that complex steps are the reason for the finding that tasks that measure the same DLGF competencies are accessible in some tasks while challenging in others. This leads to two possible questions: (i) Are there differences in the user interface design patterns between both cases? If so, this will indicate that some user interface design patterns are easier for FXI than others, and (ii) Is the user interface design identical to the mental model of FXI users in the case of the easy tasks? If so, this means that FXI users found this task easy because they are used to doing the same tasks and following a similar process.

Nevertheless, for a user to complete a task effectively, there needs to be a sufficient understanding of the task model, an accurate interpretation of visual cues and the recollection and ability to translate the model into a correct sequence of activities on the user interface (Sharp et al., 2019; Hollinworth and Hwang, 2009). As a result, the design of the user interface (design elements and patterns) is likely misunderstood in the more challenging tasks. As complex tasks can be too cognitively demanding on FXI, what user interface design patterns exacerbate this, and what can make it more manageable for these users?

5.4.4 Other Findings

The results show that FXI took longer to complete all but one task in both interfaces tested: purchasing airtime for a phone number (T2; Banking). Both user groups found this task easy, as there was no significant difference between both user groups for any of the four user performance measures. Although FXI took longer in all other tasks (regardless of the interface), there was no significant difference in the number of errors and task completion rate against LITs in the tasks classified as easy. However, even with the easy tasks, FXI tapped significantly more than the LITs, indicating some sort of challenge with the interfaces.

Since most FXI participants reported that they had never used mobile banking and shopping applications before this study, we can assume that their lack of experience contributed to their challenges. Prior exposure is correlated with competence in achieving tasks on a mobile application for users with low literacy, albeit specific to only that application (Thatcher and Ndabeni, 2005). Consequently, FXI took longer to complete tasks not only due to reading and writing challenges but also because they were becoming acquainted with the interface. This learning curve is presumed to impact all tasks equally, emphasising the notable differences observed between tasks.

Also, as mentioned earlier in the data recording protocol section 4.1.6.1, errors were classified into four categories: several attempts, delaying mid-task, wrong action and request for confirmation. This was based on research by (Hollinworth and Hwang, 2009), which was conducted on older users. This research discovered that the perception of success for FXI users was not always accurate. FXI thought they were successful in completing tasks when they were not, in fact, successful. This was added as a new error category in the analysis of results for FXI.

5.5 Summary

Interacting with ICTs requires cognitive skills, which are trained by literacy. As these skills are less present in people with lower literacy, FXI users often need help effectively using smartphone applications to complete many basic tasks that are easier for other users. As a result, there is a need to examine methods to interact with smartphones that can utilise existing skills and place lower cognitive demands on FXI users.

This research was a starting point towards finding out what specific user interface design patterns are problematic to FXI users. To achieve the research question, we had to determine the most difficult tasks for FXI. We also compared the performance of FXI against LITs to assess whether the tasks challenging for FXI are the same for other users. This analysis was not aimed to be a direct, rigorous comparison between FXI and LIT but rather an exploration that acknowledges (if) some tasks are more challenging than others inherently.

The results indicate that within the set of seventeen (17) measured tasks, six (6) were identified as the most challenging. Among these six (6) tasks, *only* the FXI users encountered difficulties with five (5) out of the six (6), while both the FXI and LIT users faced difficulties with one (1) particular task out of the six (6). The most challenging tasks measured the following digital competence areas: 1) Information and data literacy, 2) Communication and collaboration, 3) Digital content creation, and 4) Problem-solving. However, as these digital competencies overlap across the different tasks measured, we also found that the same competencies were easy to do in other tasks. These findings have led us to consider the following.

In the case of tasks that measure the same digital skills with multiple steps and are found easy in some tasks while difficult in others (case: task T2 buy airtime for a phone number vs T1 transfer money to another bank; banking), *(i) is this because of a difference in the user interface design patterns, or/and (ii) because the users' mental models are already pre-developed for the easy tasks*? In another case of tasks that measure the same digital skills and require the same mental model (case: filtering searches; tasks T2b and T2c shopping), *(iii) is there a difference in user interface design patterns which results in FXI being able to complete one task and not the others?*

The results also showed that tasks involving multiple steps are among the most challenging, likely because they place too many cognitive demands on FXI users. As this study was limited to finding the most difficult tasks, further analysis is required to address these questions. In the next stage of this research, we examine what user interface design patterns exacerbate the challenges for FXI users and what can make these challenges more manageable.

In the next chapter, data collected from the think-aloud will provide insight into the users' mental model, allowing us to discover what FXI users expected while interacting with the interfaces. The screen recording data will provide more information that will serve as observation data, while task analysis will provide a breakdown of the steps to complete each task - thereby providing further insights into the user interface patterns and specific digital literacy competencies required for each step. This can then show why the problems arise and what specific user interface design patterns are explicitly challenging.

6 Digital Skill 1: Transferring Money in Mobile Banking

Chapter 5 revealed that specific digital skills presented significant challenges for users. Among them, Chapter 6 focuses on a particular skill: transferring money between accounts on a mobile banking application. This chapter explores this skill in-depth by presenting two interconnected studies (Study 2 and Study 3, as outlined in Chapter 4). See Figure 17 for a thesis flow map that shows how this chapter fits into the overall research structure.

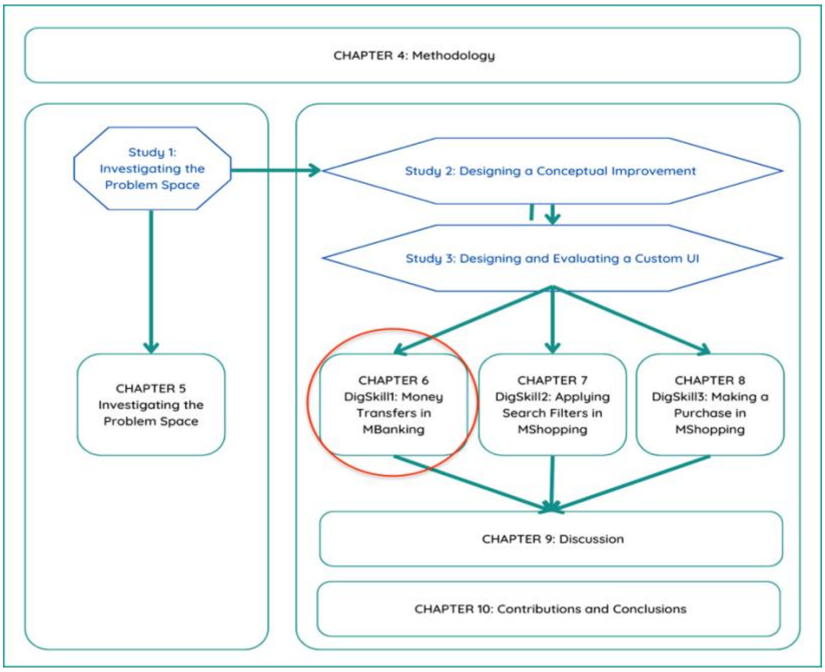


Figure 17: Thesis Flow Map – Chapter position in research structure.

These studies aim to gain insights into the challenges faced by FXI users and to develop and assess a potential solution. Following that, I summarise the results to determine whether the evidence supports improvements in user performance, particularly focusing on error and task completion rates, tapping count, and the time taken by FXI users in the custom UI.

6.1 Designing a Conceptual Model for Improvement

Transferring money between accounts is a fundamental digital skill that should be accessible to anyone using a mobile banking application for their financial needs. However, FXI users often encounter difficulties in this area. As demonstrated in Chapter 5, FXI users had a completion rate of 25%, with 95% experiencing errors compared to 100% and 40% respectively, for LIT users. Additionally, FXI spent three times longer and used twice as many taps as their LIT counterparts. Furthermore, FXI ranked the mobile banking application among the worst 25% in UX quality compared to current benchmarks (Schrepp et al., 2017).

The aim of this study is to investigate why FXI users face challenges in transferring money between accounts on a mobile banking application. This investigation addresses the first research question.

> RQ1: What design patterns of the user interface specifically cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

This study has two main objectives: firstly, to identify the specific challenges and associated UI patterns, and secondly, to provide insights into the reasons behind these observed difficulties.

This study builds upon the initial data collection conducted in Chapter 5 of the research, where FXI and LIT users performed tasks while their screen data (including keystrokes) and think-aloud protocol data were collected. While Chapter 5 focused on quantifying the difficulties in identifying the most challenging digital skills, this study goes further by exploring the underlying causes of these challenges.

Qualitative analysis is employed using the same dataset as Chapter 5, involving content analysis of screen observations, think-aloud, and user feedback from the post-experiment interview's open-ended section.

6.1.1 Results

The task analysis of the mobile banking application showed that the users needed to interact with the screens in Figure 18. As shown in Figure 18, the screens involved include (a) transfer type, (b) transfer details forms, (c) 'select account to debit screen', and (d) 'select bank' screen. The UI patterns used in the design of these screens include the following.

a) Figure 18a: Vertical list with buttons.
b) Figure 18b: Form with text/character input indicators and confirmation/control patterns built into the required fields and error messages.
c) Figure 18c: Form selection with a button as the design pattern indicator.
d) Figure 18d: Sort and filter, including a vertical list with a search and scroll.

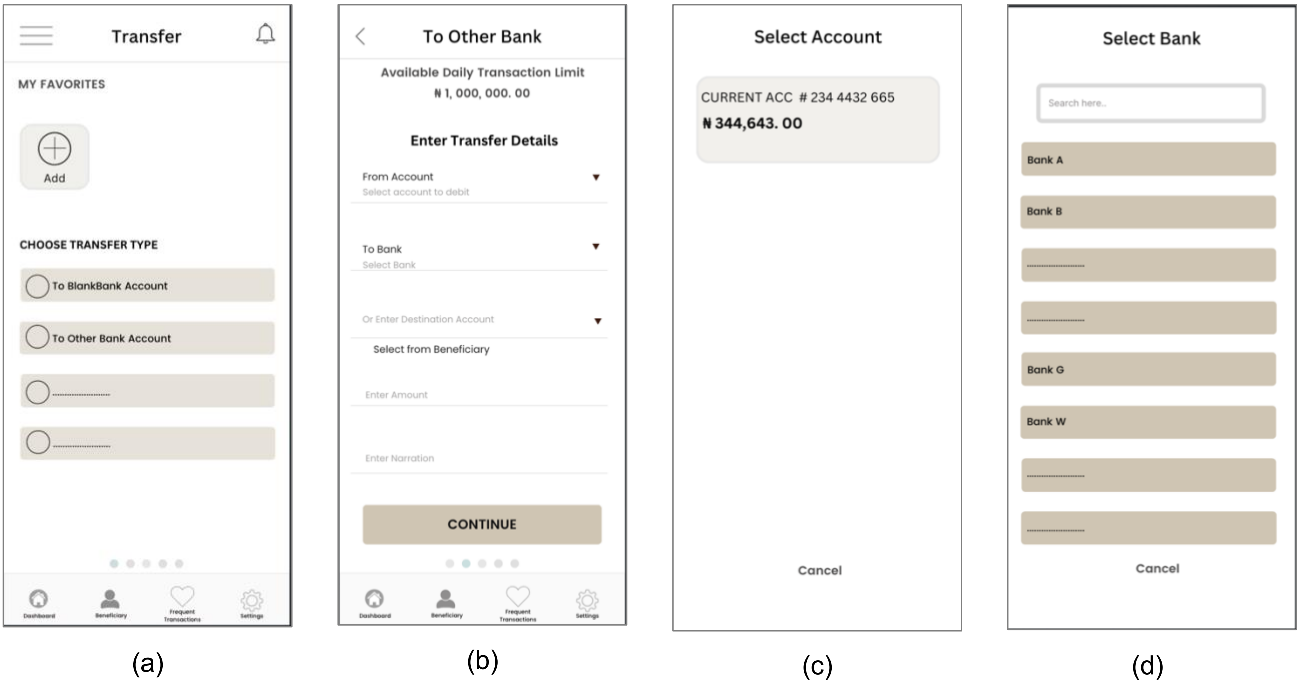


Figure 18: Mobile Banking Interface Screenshots – Transfer process. .

A review of the screen recordings and verbalisations showed that the common errors made by participants include the following.

a) Screen ID → <Figure 18b> Difficulty finding the destination bank details (10 participants)
b) Screen ID → <sample screen, Figure 19> Difficulty understanding the error messages (9 participants)
c) Screen ID → <Figure 18c> Difficulty in knowing that the text presented in the select accounts page must be clicked (7 participants)
d) Screen ID → <Figure 18b> Difficulties when searching or scrolling through the list of banks (7 participants)
e) Screen ID → <Figure 18b> Skipping selecting the option to select an account to debit (6 participants)
f) Screen ID → <Figure 18b> Difficulty in entering the text field for destination account because a previous step was missed (6 participants)
g) Screen ID → <Figure 18a> Difficulty finding the correct option in selecting whether to transfer to the same bank or other banks (5 participants)
h) Screen ID → <Figure 18b> Difficulty in progressing to the next page after inputting all fields (4 participants)
i) Screen ID → <Figure 18b> Difficulty in understanding the meaning of the required field' 'destination account' (1 participant)

j) Screen ID → <Figure 18b> Difficulty in knowing whether the option chosen has been updated (1 participant)

The difficulties are further analysed by comparing the context of mental models with the underlying conceptual model on the respective user interface screens. For instance, in the mental model of FXI users, the first step is to select the option to transfer from the main menu without differentiating whether the destination bank is the same as their bank or different. However, the application differentiates these and presents two additional options, as shown in Figure 18a. Participant 4 expressed their confusion about Figure 18b, stating the following.

> I am not sure what this is asking me, so I will just choose the first option and see. (P4)

The FXI users' mental model suggests that the second step is to enter the account details to transfer to, including the bank name, account number, and amount. However, the system presents a form with three additional entry options: selecting the account to transfer from, transferring to a beneficiary, and adding a narration (Figure 18b). Moreover, FXI users' mental model assumes that entering the transfer details into the form does not require sequential steps. However, the system requires the user to follow the form sequentially, leading to pop-up error messages if data from prior fields on the form is missing. One participant expressed their frustration with this step, stating:

> I am trying to enter the account number you gave me to send the money to, but it is giving me an error message showing that I have to select the account to debit, but I do not understand. (P5)

Furthermore, upon selecting the first two options on the form, FXI users were directed to other screens (Figure 18c and Figure 18d). This led the users to believe they were progressing, but the system eventually returned them to the same form (Figure 18b) after interacting with the screens in Figure 18c and d. Moreover, FXI's mental model indicated that some terms in the form were unfamiliar, including the first two fields that asked the user to 'select account to debit,' enter 'destination account,' and 'narration,' as seen in Figure 18b. The participants explained their thoughts on this, stating:

> I do not know the purpose of this transfer narration, so I will just stop here. (P7)

> I know that I have to put the account number I am transferring to, but I am not sure where I can put that here. Maybe if I click continue, it will then take me somewhere so that I can enter it. (P15)

Regarding the interaction with the button to select accounts to debit (Figure 18c), FXI's mental model was unclear as they did not realise they were required to click the button. They assumed this did not make sense because they were already within their bank accounts. However, the system requires the user to choose which of their accounts to initiate the transfer from, considering the possibility of having multiple accounts, such as a current and savings account.

Regarding Figure 18d, FXI's mental model assumes using the abbreviation for the destination bank name, as the bank and its customers commonly use it. However, the system only provides the bank's full name, causing users to have difficulties when searching or scrolling through the list of banks. Some users also encountered issues with spelling in the search bar.

Furthermore, in FXI's mental model, the meaning of the error messages they received from the application when trying to progress to the next stages without entering all the required information was unclear. For instance, one of the error messages is depicted in Figure 19. FXI users expected the system to visually indicate the missing information on the form when they clicked 'OK' after the error message. However, the system returned the users to the transfer details form (Figure 18b), expecting them to understand the error and make the necessary corrections.

> I have clicked on OK on the error message, but it is not taking me anywhere. I am thinking that it will show me where to go, but I am just back to the same form, and I don't see any error here. (P6)

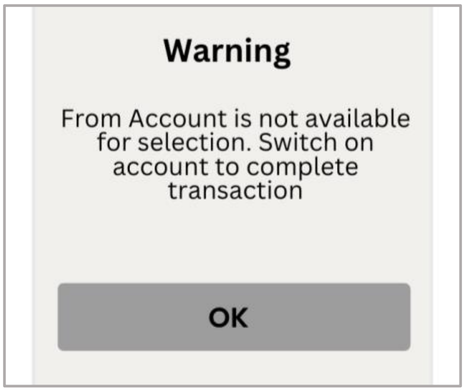


Figure 19: Screen depicting an example of error message received by users.

6.1.1.1 Post-Study Interview

Based on coding verbalisations into observations and explanations, some themes emerged from the open-ended section of the interview. Since the focus is on the digital skill of money transfer, the analysis concentrates solely on interview responses related to that aspect. These are presented below.

Complexity: Five participants mentioned that the numerous steps and processes made the mobile banking application challenging. Some participants mentioned that the necessary steps differed from real-life experiences. Additionally, six participants expected the application's process to be like the USSD mobile system, leading to confusion. Participant 20 expressed their frustration, commenting as follows.

> Transferring money was very hard. I thought it would be like USSD -like the application will be asking me questions. (P20)

User Interface Design: FXI participants explicitly mentioned certain user interface patterns as being difficult. Four participants suggested that the navigation between pages should be more straightforward. Additionally, six participants pointed out that certain entry fields and buttons on the form (Figure 18) were not visible, leading them to skip those fields.

> There are too many pages and navigation to get results. That is why I got confused and got many errors to do the transfer. (P8)

> I did not see the first 'select account to debit' place when I opened the page, so that was why I had problems. Even the 'select destination account' should be [clearer] because I did not see it. (P5)

User Interface Vocabulary: Five participants stated challenges related to understanding the phrases and terms used in the mobile application. Participants recommended that the language used should be easier to reduce confusion. Some excerpts depicting these issues are as follows.

> I thought the first option, 'first bank transfers', would mean where I am transferring from, so that was why I chose that option, but I think that was why when I entered the transfer details on the form, the application showed me many errors that the account details are wrong. (P15)

> I think the application was easy for me, but the English made it hard for me to understand where to put the information you gave me about the transfer. Like this, 'select account to debit' now should be changed to something simpler to understand. (P15)

6.1.2 Key Findings

In line with the reviewed literature, the design of user interfaces requires a keen understanding of usability and user experience design. An essential usability concern arises from the mismatch between designers' and users' mental models, as users assume how a system functions based on their mental models (Hartson and Pyla, 2012). Our analysis revealed a noteworthy mismatch between the mental model of FXI users and the mobile banking application in doing money transfers, especially related to the task sequence and banking vocabulary. This discrepancy led to unmet user expectations and erroneous sequences of actions.

Specific UI patterns proved particularly challenging for FXI users, especially those related to forms, navigation, and search/filter features. When interacting with the form, FXI users tended to behave as if they were dealing with paper-based forms, entering information into familiar fields rather than following a top-bottom sequence. Notably, FXI users have been observed to minimise reading or skip form instructions altogether (Colter and Summers, 2014), leading to errors and the unintended omission of input fields. Additionally, the lack of affordance in the interface for required fields further hindered their ability to recognise them.

A lack of affordance on some symbols, especially not graphical ones (e.g., buttons), also caused issues with recognising visual cues. Affordances serve as interface hints for users (Sharp et al., 2019). For a user to interact with UI patterns, there needs to be a characteristic of the object that lets the user know what it can do. This influenced FXI's inability to recognise that a selection of buttons was required from them.

The navigation process also posed obstacles, with users encountering new screens before being brought back to the original form. Consequently, users were under the impression that they were making progress, but the system ultimately brought them back to the same form, leading to confusion and a sense of being stuck in a loop. Although the process involved only about five steps, FXI users perceived the interface as complex, aggravated by the lack of specified required fields and incomplete input information.

Furthermore, the presence of a lot of information on the interface, as expressed by the users, coupled with users' limited textual abilities, hindered their ability to find relevant functions for completing tasks. The challenge of retaining information while navigating between screens also indicated FXI users' potential limits in working memory, which is the cognitive system that allows us to work with information without losing track of what we are doing.

Regarding the search and filter patterns, FXI users faced difficulties utilising them effectively, often preferring to scroll through the list instead. Others encountered issues with misspelling and misunderstanding the full bank names provided. Hence, these challenges were influenced by additional issues stemming from limited textual abilities, impacting FXI's interaction with the search and filter patterns.

Limited textual abilities further complicated the challenges, leading to confusion about terms like 'account to debit,' 'destination account,' and 'beneficiary,' which are common banking vocabulary. As highlighted in (Medhi et al., 2009), unfamiliarity with such banking terminology posed difficulties for users with limited literacy.

Additionally, error messages, intended as corrective feedback, proved ineffective for FXI users due to their complexity and lack of visual cues. After dismissing an error message, users were uncertain about which input fields on the form caused the errors, as there were no clear visual cues to highlight the problematic fields among the five on the form.

These findings provide us with important information regarding user expectations and abilities regarding the current banking interface. As seen in Chapter 5, most users have problems completing a transfer on the application. This section has given us the reasons why these challenges occurred. With this understanding, a conceptual model is proposed to address the issues discovered.

6.1.3 Proposed Conceptual Model for Improvement

The main objective of the redesign was to leverage the existing skills that FXI users have already acquired and apply them to mobile banking applications. Since FXI users frequently mentioned the use of USSD, I examined the USSD system's interface to understand the user's familiar knowledge better so that it can inspire a new design that takes the user's mental model into account while addressing other identified issues.

Upon examining the USSD interface, it became evident that although both interfaces required the same information, differences were observed in the presentation of information and interaction styles. The USSD interface utilised a conversational interaction style and displayed information on a single screen, while the mobile application utilised a form-based pattern with instructive interaction. These observations were considered while designing the conceptual model for the novel interfaces. The goal was to enhance discoverability, allowing users to find functions independently without external assistance.

Figure 20 depicts an initial paper-based sketch of the conceptual model, which was refined through multiple revisions to effectively address the identified issues while avoiding correlations with previously reported problems from the literature.

Figure 20: Design Iterations for Money Transfers - from the paper-based conceptual sketch to the design of the custom UI.

The paper-based sketch evolved into a final conceptual model design, as depicted in Figure 21. The flow in Figure 21 from L-R includes (a) initial transfer screen to enter an amount, (b) select an account to debit screen, (c) select the receiver of the payment, and (d) enter new payee details. The model was designed using Microsoft tools, serving as a visual representation of the new interface design.

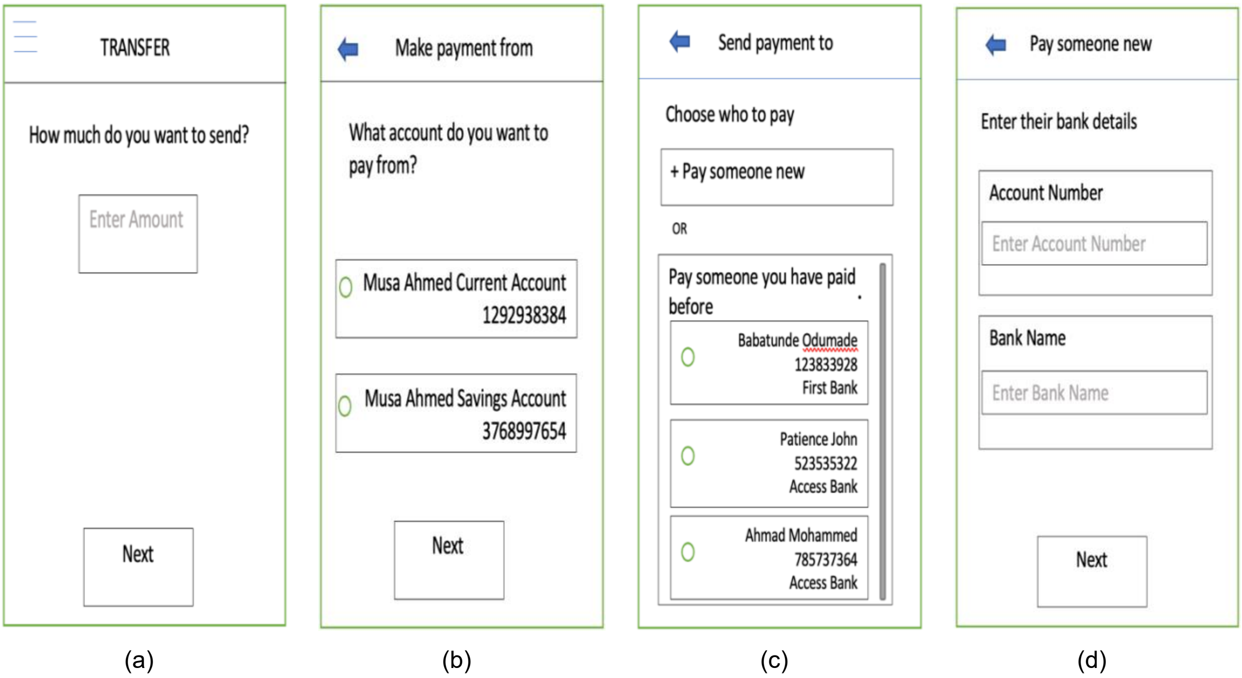


Figure 21: Low fidelity prototype of the conceptual model for the banking custom UI.

As depicted in Figure 21, I adjusted the sequence of user inputs based on an analysis of their mental models, which led to eliminating problematic screens to achieve improved designs. The redesigned model prompts users to input only one or two pieces of information at a time. Notably, in the initial UI, the users' mental model did not account for the initial step of distinguishing between transferring to the same or a different bank. We recognised this as an unnecessary redundancy and consequently removed this step. This redesign enables users to input transfer details and specify their choice of bank, whether it is the same or different in later stages. The result is a streamlined process that allows users to make relevant decisions about bank type.

In the new design, upon selecting the transfer option on the homepage, users' initial encounter is with a screen prompting them to input the desired transfer amount (Figure 21a). This decision stemmed from two primary considerations. Firstly, there's a desire to alleviate the burden of memory retention for users during the transfer process. Secondly, this approach enforces sequential data entry, unlike when data is presented in a form where users are prompted to provide information all at once. Additionally, the language used at this stage adopts a day-to-day conversational tone, resembling a dialogue between the user and the interface.

Once this data is entered and users proceed to the next screen, they are prompted to select the account from which they wish to transfer (Figure 21b). This option, which previously posed significant challenges in the initial interface (Figure 18b and c), was simplified both in the screen title and question formulation, clarifying the required information. Furthermore, we included the account holder's name alongside the account number to emphasise ownership – a detail absent in the initial UI (Figure 18c).

Subsequently, users are asked to choose between paying a new recipient or someone they have paid before (Figure 21c). In the initial UI, this option was presented in two places as a beneficiary selection (Figure 18a and b). Besides changing the sequence, here we replaced complex banking vocabulary with simpler, everyday language relevant to the Nigerian context. We opted for concise terms where possible, facilitating ease of comprehension. This, in turn, helps to preserve users' cognitive space by reducing the load from decoding and comprehension of the written information. Opting to pay a new recipient leads to a screen for entering transfer details, while choosing a past payee directs users to a confirmation screen.

For new recipients, users are prompted to enter the recipient's account number and bank name. In the initial interface, the process involved selecting the payee bank (Figure 18b), which then opened a separate screen (Figure 18d). We streamlined this in the new design, displaying the bank name within the same screen (Figure 21d). Additionally, we modified 'enter destination account' to 'account number' to reduce ambiguity since the former was hard for users to understand.

The next step displays a confirmation screen, allowing users to verify information accuracy (Figure 22a). Upon confirmation, a summary screen displays transfer details, with an option to add a commentary (Figure 22b). The language here has been simplified to 'add a reason for payment,' eliminating confusion about the meaning of 'narration' from the initial UI. Also, the term 'optional' has been enclosed in brackets, clarifying that this field is not mandatory. This addresses the issue from the initial UI where users assumed 'narration' was obligatory. Finally, users are prompted to enter a transfer PIN (Figure 22c), and a dialogue confirms the transaction's success.

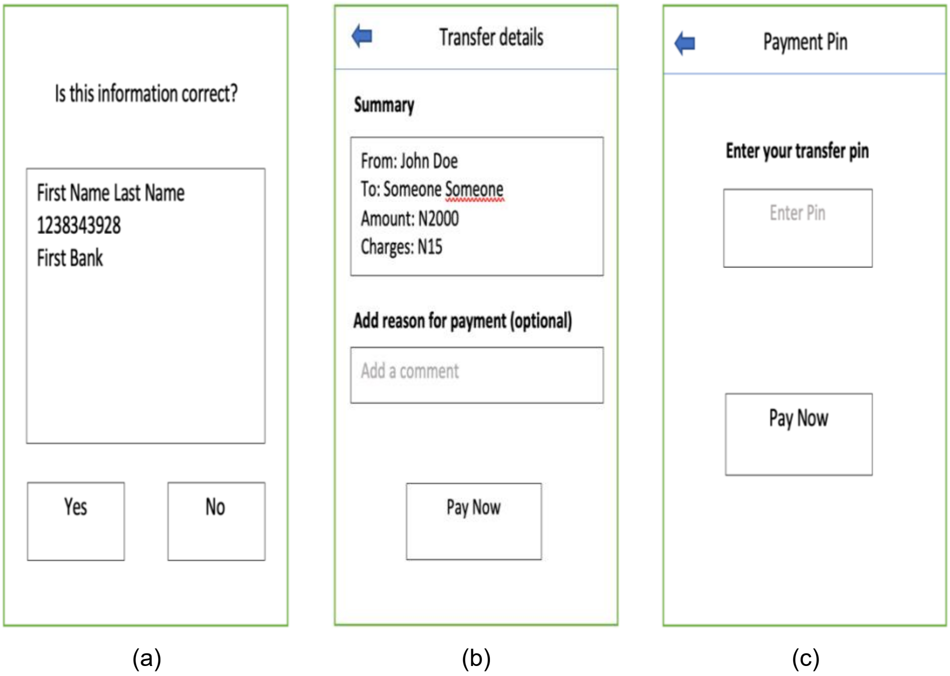


Figure 22: Low fidelity prototype of the conceptual model for the banking custom UI.

This version of the conceptual model served as a basis for communicating custom design requirements with the third-party UI designer. In the upcoming study, this enhanced conceptual model will be translated into a custom UI, which will be evaluated for its impact on user performance with FXI users in Nigeria.

6.2 Designing and Evaluating a Custom UI

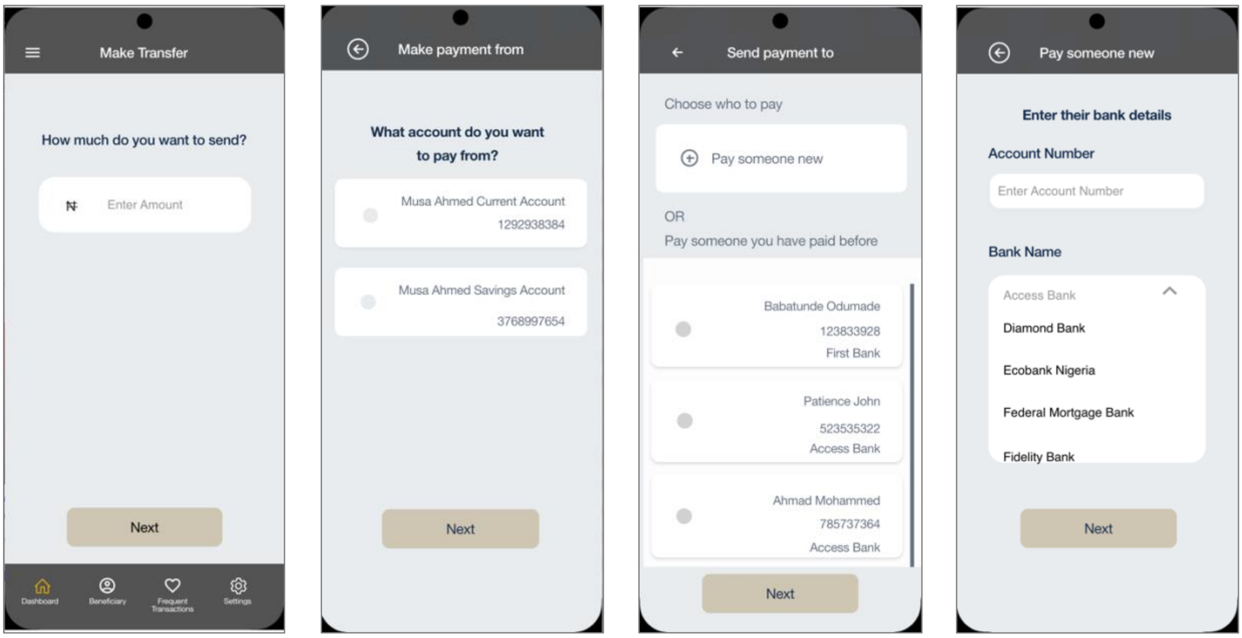
This section focused on an experimental study, where I designed and evaluated a novel money transfer mobile interface based on the findings from the previous section. The preceding study identified specific UI patterns, such as forms, navigation, and search/filter features, as significant challenges for FXI users. The way they interacted with forms on the mobile banking interface resembled paper-based forms, leading to errors and overlooking certain input fields. Moreover, the lack of affordance in the interface hindered their recognition of required fields and buttons. Additionally, information overload and limited textual abilities made it challenging for FXI users to find relevant functions. At the same time, potential limits in working memory affected their ability to retain information during navigation. Furthermore, ineffective error messages without visual cues added to the confusion. This section aimed to answer research question 2:

> RQ2: What design techniques can improve interaction for FXI Nigerians while interacting with mobile banking and shopping applications on smartphones?

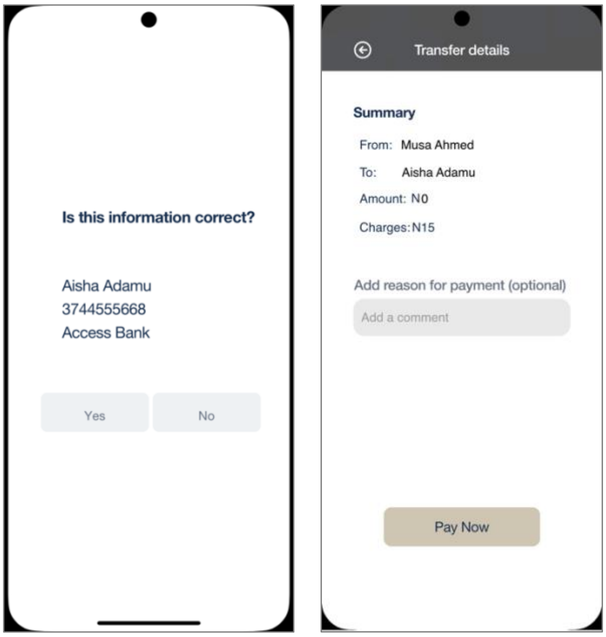
The rest of this section discusses the design of the custom user interface and subsequently an experiment with FXI and LIT users to evaluate the improvements' effectiveness in terms of user performance.

6.2.1 Custom UI

Transforming the conceptual design resulted in an interactive prototype depicted in Figure 23. Each screen within this representation conveys the operational aspects of the conceptual model with screens depicting the following process: (a) Enter the transfer amount screen. (b) Debit account selection screen. (c) Payee selection screen. (d) Entering new payee details. (e) Payee information confirmation dialog. (f) Transfer summary screen..



(a) (b) (c) (d)



(e) (f)

Figure 23: Custom UI for mobile money transfers, illustrating various screens in the sequence.

When transitioning from the conceptual model to the custom UI, the choice of design patterns and principles assumes a pivotal role. Therefore, the choices in elements such as screens, buttons, visual cues, and more were important to convert the abstract concept into a practical and navigable artefact. However, certain enhancements initially envisioned in the conceptual model were unattainable due to constraints posed by prototyping tools. For instance, the original concept for selecting the payee bank name involved a search input field pattern that auto-suggests matches from a database with all bank names. Due to technical limitations, I chose an alternative approach involving an embedded drop-down within the UI.

Notably, I preserved the aesthetic design in terms of the colour theme from the initial user interface, ensuring consistency in the theme. This strategic choice aimed to prevent the influence of distinct colour theme designs on the comparison between both user interfaces. Since this study's focus is not on interface colours and our data from the initial interface did not highlight it as an issue, maintaining thematic similarity served our objective. Throughout this section, I discuss further my choices of the design patterns and principles that shaped the custom design.

In terms of design patterns related to input modes, I moved away from the traditional form pattern. Instead, we divided the form questions into separate input fields spread across multiple screens. The approach focused on presenting users with a single piece of information at a time. This strategy aimed to avoid overwhelming users' working memory and to accommodate challenges associated with reading and writing.

Concurrently, we removed the sort and filter patterns (see Figure 18d) in the new design while preserving the vertical list and scroll patterns in selecting the payee bank. We introduced a drop-down pattern equipped with a control element that locks information within the relevant input area. This augmentation is shown in Figure 24. The aim was to address complex navigation concerns and avoid a potentially confusing flow of interaction, eliminating the issue encountered in the initial design. Specifically, this adjustment eliminates the issue of users being led back to a previous dialogue after reaching a new one, thus preventing confusion and maintaining user orientation.

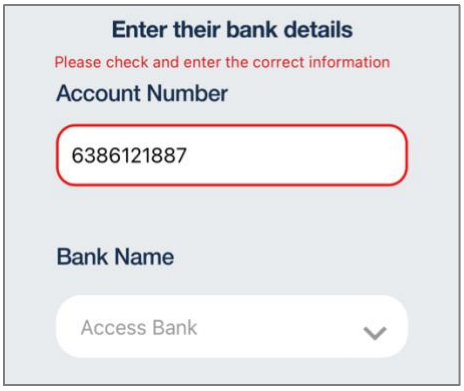


Figure 24: Implementing the affordance design principle to signify fields that require modification.

This enhancement further prevents users from losing track of their current location within the application. Throughout the new design, we maintained similar control patterns that lock information within relevant panes. For instance, in Figure 23c, while navigating through past payees, only the content within the pane changes. The topmost pane containing details of a new payee remains unaffected by the scrolling action.

Furthermore, when entering payee details (see Figure 24), we hardcoded the account details provided to participants. This tactic serves a dual purpose: to trigger an error message if the entered information does not align with hardcoded details and to emulate the experience of a genuine banking application. Such applications typically cross-reference entered details with their database to verify accuracy.

Moreover, we replaced the previous pop-up error message pattern with prompts on the relevant screens in red font (Figure 24). This enhancement reduces complex navigation and prevents screens from looping users back to the initial screen. Anticipating users' desire to pinpoint error locations based on their mental models, we integrated an affordance measure highlighting problematic input fields with a red hue. This design principle was maintained throughout the new interface design to provide feedback on user errors.

Additionally, we integrated visual cues to signal interactive elements and acknowledge user actions. For instance, Figure 25 illustrates a visual cue where font colours alter and an introduction of radio buttons, which are filled with the same colour to signify user actions being recognised by the interface. This design principle was lacking in the initial UI, which caused users to overlook the need to tap and select the account for payment.

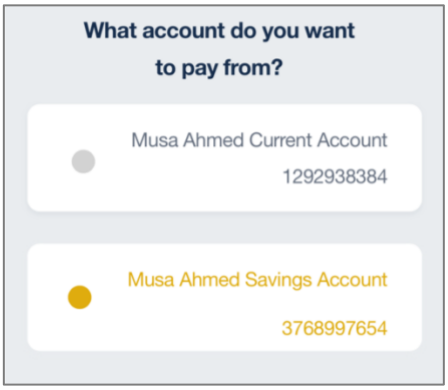


Figure 25: Visual cues enhancing user understanding of interface interactions.

In summary, up to this point, we have outlined the design enhancements incorporated into the custom UI, as depicted in Figure 23. These enhancements encompass modifications to UI patterns, including user inputs, forward navigational direction, on-screen prompts, drop-down, and control patterns. Additionally, design principles such as visual feedback through colour hues and error highlighting were introduced. Furthermore, simplification of language and elimination of complex banking vocabulary were implemented. The changes were motivated by the initial study's findings, aiming to align the conceptual model with users' mental models. This alignment also influenced the application's information architecture and reordering of required inputs. In the next section, our focus shifts towards evaluating the impact of these changes on enhancing usability and user experience.

6.2.2 Experiment

This research section discusses the experiment conducted with FXI and LIT users. The aim of the experiment was to evaluate whether the design solutions in the custom UI enhanced usability and user experience (UX) for FXI users compared to the initial UI. It is important to note that the data for the initial UI is derived from Chapter 5 Investigating the Problem Space. As a reminder, participants were asked to do one task, as shown in Table 12. Participants were also told to assume the name of the account holder as their identity for the experiment.

Table 12: Participant money transfer task description

Use this Mobile Banking Application to transfer ₦2000 to the following account details. Account Number: 3744555668 Account Name: Aisha Adamu Bank Name: Access Bank. Transaction Pin: 0000

6.2.3 Results

This section presents the findings from the experiment with FXI and LIT on the custom UI. The rest of this section is organised according to the analysis of the hypotheses and the results related to user experience. See section 4.3.2 Design, for further discussion on the rationale for the hypotheses and analysis in this section. The results are shown below.

6.2.3.1 Hypothesis 1

Twenty (20) FXI participants were recruited to participate in a custom UI redesigned to reduce the number of errors experienced by FXI users. An exact McNemar's test was run to determine if there was a difference in the proportion of errors pre- and post-intervention, as shown in the hypothesis below.

> Ho: proportion of errors made by FXI in the initial UI = proportion of errors made by FXI in the custom UI.
>
> Ha: proportion of errors made by FXI in the initial UI ≠ proportion of errors made by FXI in the custom UI.

The proportion of lack of errors increased from a pre-intervention value of 5% to 45% post-intervention, a statistically significant difference, $p = .008$.

6.2.3.2 Hypothesis 2

Twenty (20) FXI participants were recruited to participate in a custom UI redesigned to improve the task completion rate for FXI users. An exact McNemar's test was run to determine if there was a difference in the proportion of task completion pre- and post-intervention. The hypothesis is as follows.

> Ho: proportion of task completion by FXI in the initial UI = proportion of task completion by FXI in the custom UI.
>
> Ha: proportion of task completion by FXI in the initial UI ≠ proportion of task completion by FXI in the custom UI.

The results showed that the proportion of task completion increased from a pre-intervention value of 25% to 100% post-intervention, a statistically significant difference ($p = .000$).

6.2.3.3 Hypothesis 3

Similar data analysis methods from the preliminary study were replicated to test the hypothesis for the custom UI. Fisher's exact test was used for error and task completion rates, while the independent samples t-test was used for the time taken. Meanwhile, a tapping count ratio greater than 1:2 (LIT: FXI) was considered a significant difference. The results are as follows for the four user performance measures (error rate, task completion, taps and time taken):

> Ho: The custom UI led to a reduction in performance disparities between FXI and LIT users.
>
> Ha: The custom UI did not result in a reduction of performance disparities between FXI and LIT users.

Error Rate: As shown in Figure 26, the difference in error rates between the two user groups in the initial UI was 55% (95% for FXI vs 40% for LIT), whereas, in the custom UI, it decreased to 15% (55% for FXI vs 40% for LIT). The results from Fisher's exact test revealed that in the custom UI, there was no statistically significant association between the user group and error rate (p = 0.645). However, in the initial UI, a statistically significant association between the user group and error rate existed (p = 0.16).

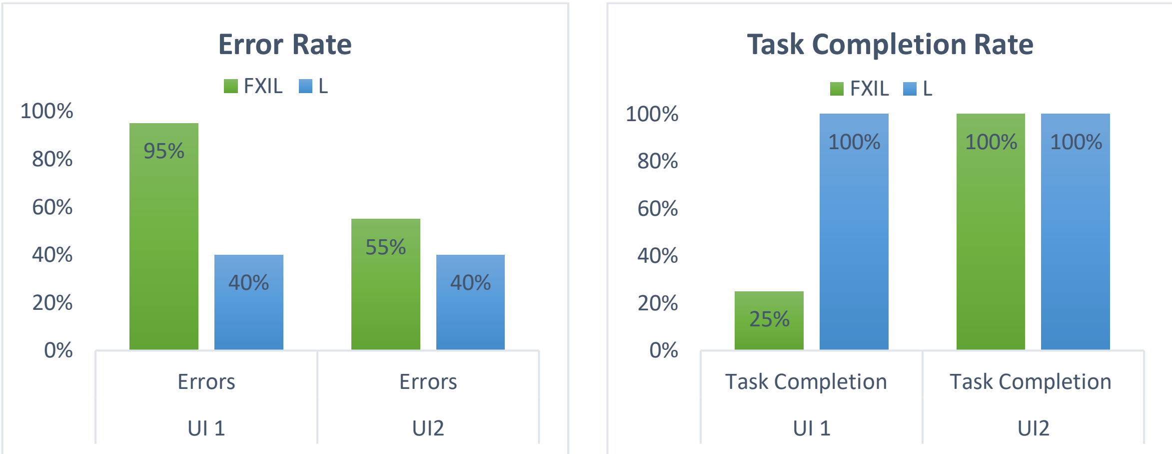


Figure 26: Transferring money to another account ((FXI v LIT) (Initial UI v Custom UI)).

Task Completion Rate: The difference in task completion rate when using the initial UI was 75% (25% for FXI vs 100% for LIT), as shown in Figure 26. In comparison, the task completion rate increased by 75% (100% for both FXI and LIT). Fisher's exact test for the initial UI showed a significant association between the user group and task completion rate (p= 0.005). In contrast, no statistics were computed for the custom UI, as FXI and LIT users had a 100% task completion rate.

Time Elapsed: As shown in Table 13, the ratio in the time taken to complete the assignment between FXI and LIT using the initial UI was 3:1 (FXI: LIT). Meanwhile in the custom UI, the ratio was 1:1. The results from the independent sample t-test revealed that in the custom UI, the difference in the mean was not statistically significant (p = 0.439, t(38) = 0.788). However, in the initial UI, a statistically significant association between the user group and meantime was observed (p = 0.001, t(38) = 3.678).

Table 13: Comparing average time taken in seconds and ratios to complete money transfers in the initial UI vs custom UI

	Study 1: Investigating the Problem Space		Study 3: Designing and Evaluating a Custom UI	
Time*	**Number**	**Ratio**	**Number**	**Ratio**
FXI (n = 20)	187	3:1	143	1:1
LIT (n = 5)	60		121	
*The time was measured in seconds and represented in the number column as such.				

Tapping Count: The initial UI showed a tapping count ratio of 2:1 (FXI: LIT) with FXI tapping 36 times vs LIT 19 times, whereas it decreased to 1:1 in the custom UI (FXI 18 vs LIT 17); see Table 14.

Table 14: Comparing the average number of taps in numbers and ratios to complete money transfers in the initial UI vs custom UI.

	Study 1: Investigating the Problem Space		Study 3: Designing and Evaluating a Custom UI	
Tapping Count	**Number**	**Ratio**	**Number**	**Ratio**
FXI (n = 20)	36	2:1	18	1:1
LIT (n = 5)	19		17	

6.2.3.4 UEQ-S

Similar to the method used in Chapter 5, FXI users were asked to rate their UX based on the UEQ-S in the post-study interview. The mean values of the UEQ scales in the benchmark data set for the banking UI2 include the following:

- i Novel: 1.68
- ii Exciting: 2.32
- iii Predictable: 1.95
- iv Efficient: 2.21
- v Understandable: 2.00
- vi Enjoyable: 2.21

The values reflecting these UX scales are illustrated in Figure 27, showcasing the results of the UEQ-S assessment for both the initial UI (UI1) and the custom UI (UI2). The coloured bars represent the ranges for the scales' mean values. **where the value '3' represents a positive experience, while '-3' represents a negative one. Meanwhile, the line represents the results for the banking interface, showing the initial UI (UI1) vs custom UI (UI2).

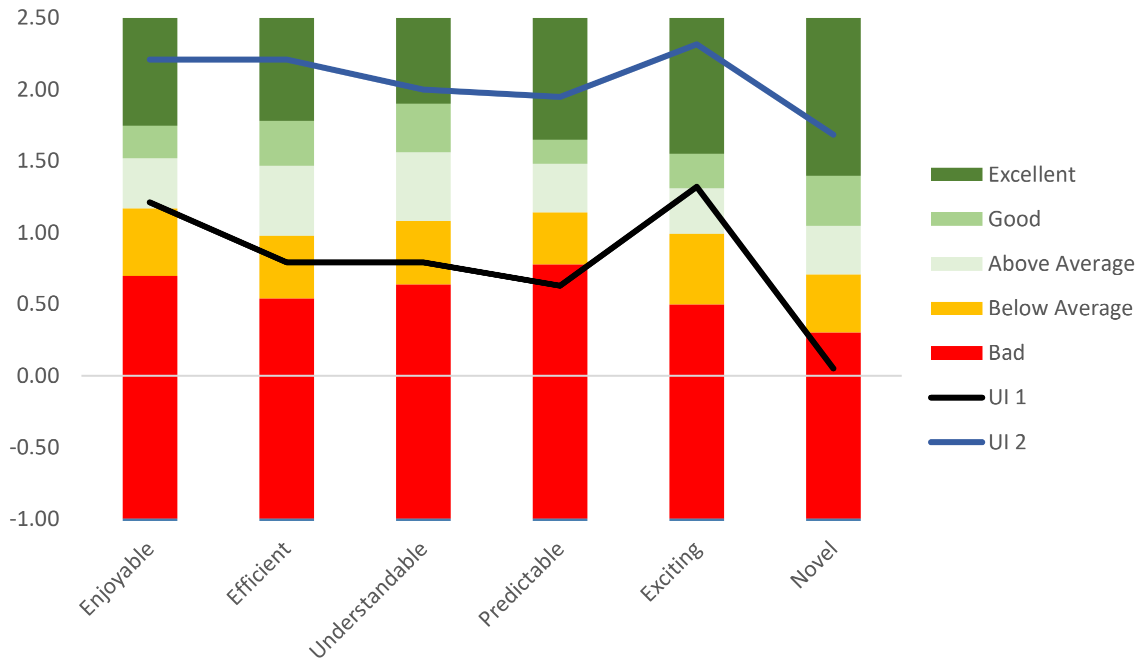


Figure 27: UEQ-S Benchmark – Banking UI (Initial vs. Custom).).

6.2.4 User Performance Evidence: Custom UI vs. Initial UI

The study's focus on improving the challenges faced by FXI during mobile money transfers brought to light significant issues in the initial interface. The study compares the initial banking application to a custom UI that was designed to align with FXI users' mental models and capitalise on their existing skills. The interface design was guided by insights from both the conceptual model and the observed interactions of FXI users, introducing several strategic changes to enhance usability and user experience. The discussion of the results is presented in the rest of this section based on user performance metrics.

6.2.4.1 Error Rate

Half of the FXI users encountered money transfer errors on the custom interface, in contrast to nearly all FXI users who encountered errors on the initial interface. Some users (frequency: 6) encountered some challenges with understanding the 'account to pay from' option (Figure 25b), with one user mistakenly perceiving it as the recipient's account. Later, most participants realised that it sought information about their own accounts. This confusion could have been circumvented by personalising the account name to each participant, but this was unfeasible due to time and resource constraints.

FXI users also had challenges with the screen prompting them to select the payee (Figure 23c). Some participants only viewed the lower half of the page, leading them to search past payees for matching information (frequency: 4). This observation provides insight into how FXI users scan through interfaces. Like in the initial interface, FXI users adopted a visual search approach that began at the middle of the screen. This could explain why they missed the initial option to pay a new recipient, which was the first option on the screen.

Nevertheless, the results showcased a significant 40% decrease in FXI user error rates on the custom UI. Furthermore, the custom interface yielded no significant difference between FXI and LIT users, contrary to the initial UI, where a statistically significant difference existed between user groups in error rates. Remarkably, the error rate among LIT users remained consistent between both interfaces. In the custom interface, one LIT user inputted account details inaccurately, while the other overlooked the on-screen error prompt pattern (replacing the previous pop-up) designed to correct their entry details.

6.2.4.2 Task Completion Rate

The custom interface significantly improved, with all FXI users successfully completing money transfers. This was a significant enhancement compared to the initial interface, which had a completion rate of 25%. Conversely, the completion rate of LIT users remained consistent between the initial and custom interfaces, with total completion maintained among them. These findings show that the custom UI meets user performance needs across various literacy levels. Thus, it highlights the critical role that interface design plays in shaping user interaction and task success.

6.2.4.3 Tapping Count

The tapping count ratio evolved to a balanced 1:1 ratio, with FXI and LIT users tapping significantly fewer times. This transformation implies that the custom UI managed to bridge the tapping behaviour gap between the two user groups despite introducing two additional screens to the money transfer process in the custom interface.

The custom UI's introduction of two additional screens to replace the form pattern and a reduction in information per screen contradicts the conventional belief that simplifying tasks by minimising steps inherently improves usability. While FXI users initially expressed difficulties with navigation and interface complexity, this longer sequence of steps in the custom UI surprisingly improved performance. This observation sparks a noteworthy discussion about the relationship between task complexity and usability, especially in the context of FXI users. The finding suggests that the optimal design for usability may not always align with minimising steps and challenges the notion that more than five (5) steps in a task inherently complicate it (Kodagoda et al., 2009).

6.2.4.4 Time Elapsed

Analysing the time elapsed metric provides valuable insights into user interaction and efficiency. In the custom UI, the FXI users demonstrated task completion times similar to those of LIT compared to the initial UI, where the ratio indicated that FXI users took three times longer than LIT users.

Interestingly, the significant difference in completion time observed in FXI and LIT users in the initial UI was not mirrored in the custom UI. This absence of statistical significance does not necessarily indicate a clear positive shift; LIT users' performance time increased by 50% in the custom UI. This may be because the custom UI could have introduced usability improvements that positively impacted FXI users' completion time but did the opposite for LIT users in terms of time. For instance, the improvement that eliminates the form and provides a one-step interaction might be too slow and annoying for more LIT and tech-savvy users.

6.2.4.5 User Experience (UX)

The UX ratings highlighted the custom interface's exceptional performance across all six (6) UX metrics: novelty, excitement, predictability, efficiency, understandability, and enjoyability. As discussed earlier, the significance of critical UX factors varies depending on the nature of the artefact. In banking, understandability and efficiency are notably more crucial than other aspects.

Conversely, the initial interface mostly fell within the above-average to below-average zones. Notably, ratings for understandability and efficiency in the initial UI were below average, indicating areas requiring improvement. This shows the custom interface provided a considerable improvement for FXI in terms of UX.

6.2.5 Summary

This study underscores the importance of design that considers specific user groups' cognitive abilities and mental models. It further underscores the need to re-evaluate established design conventions and emphasises the value of tailoring design to suit the unique requirements of FXI users. The results showed that the enhancements implemented in the custom interface yielded significant improvements in users' performance in the digital skill related to money transfers on a mobile banking application. These enhancements are subject to further elaboration in the subsequent section of our main discussion. Here, we synthesise the findings to our research questions by assessing the outcomes of all three digital skills (see Chapter 9**Error! Reference source not found.**).

In the interim, the following section presents a similar investigation into the second digital skill: applying search filters in a shopping mobile application. Through this approach, I aim to provide a holistic perspective on challenging areas in mobile UI design for FXI users and solutions to improve usability and UX that consider these users.

7 Digital Skill 2: Applying Search Filters in Mobile Shopping

In Chapter 5, I identified the top three digital skills that presented the most challenges to FXI users. Among them, Chapter 7 focuses on one skill particularly: applying search filters on a mobile shopping application. I further explored this digital skill in this Chapter by presenting two interconnected studies (Study 2 and Study 3, as outlined in Chapter 4). Refer to Figure 28 for a thesis map that shows how this Chapter fits into the overall research structure.

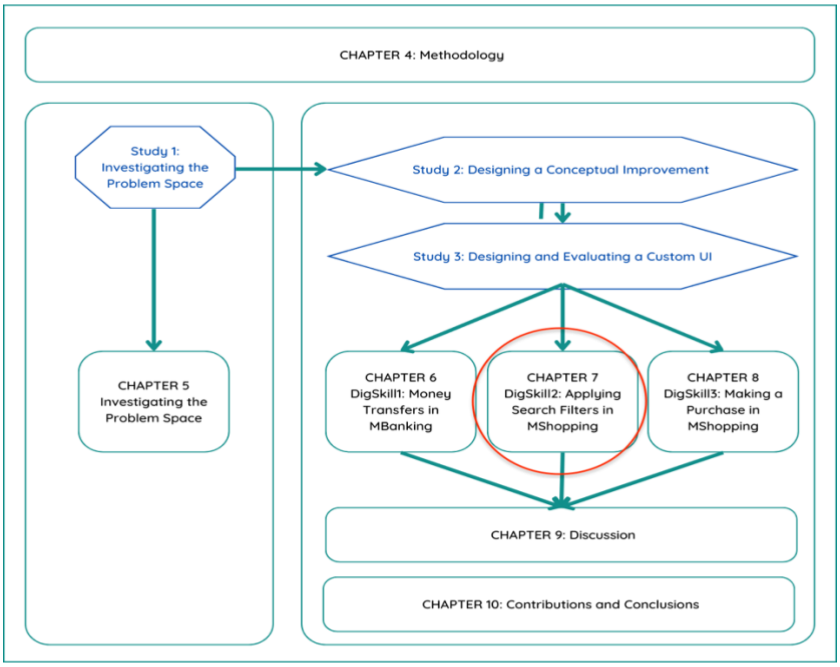


Figure 28: Thesis Flow Map – Chapter position in research structure.

These studies will provide insights into why this digital skill was found challenging and present a custom UI, which is developed and tested to assess its usability and user experience. Subsequently, I summarise the results to determine whether the evidence supports improvements in user performance, particularly focusing on error and task completion rates, tapping count, and the time FXI users take in the custom interface.

7.1 Designing a Conceptual Model for Improvement

Applying search filters is ubiquitous across applications, empowering users to personalise the information they access according to their preferences. This functionality assumes paramount importance in domains like online shopping, where an overwhelming array of products are on offer. Consequently, it is a vital digital skill geared towards efficiency and delivering a tailored experience to individual users. However, Nigerian FXI users find themselves excluded from reaping these benefits. As demonstrated in Chapter 5, FXI experienced a completion rate of 0%, with 95% encountering errors, compared to 0% and

20% for LIT users. FXI users also spent significantly more time and tapped more frequently. Moreover, FXI users rated the shopping application poorly compared to other mobile applications on the UEQ-S benchmark (Schrepp et al., 2017).

As such, this study focuses on the challenges faced by Nigerian FXI users when applying search filters in mobile shopping applications. In this study, I will address the first research question, which is as follows.

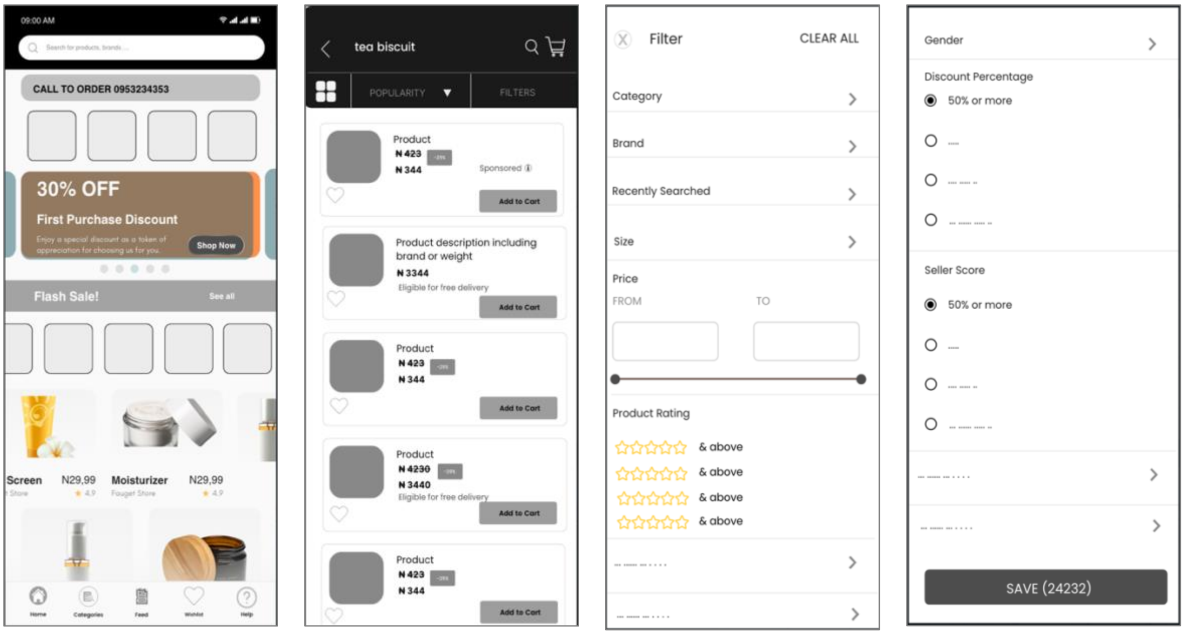
> RQ1: What design patterns of the user interface specifically cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

As discussed in the methodology section, this builds on the initial data collection conducted in Chapter 5, where the following data collection methods were employed: survey, think-aloud, and screen interaction recording. In the next section, I will present my findings based on the qualitative methods described in section 4.2.

7.1.1 Results

The task analysis of the mobile shopping application showed that the users needed to interact with the screens in Figure 29. As depicted in Figure 29, the interaction flow involves: (a) home screen, depicting the search icon where users can enter desired product name, (b) choosing the option for filters, (c1) filter screen showing filter categories, and (c2) continuation of the screen in c1 with further filter options when the user scrolls down. The UI patterns used in the design of the screens include.

a) Figure 29a: text/char input, fixed menu, icons.
b) Figure 29b: Fixed menu, icons and buttons.
c) Figure 29c1 and c2: Form, sort/filter, vertical list, text/char input, spinner, scroll and buttons. Note that Figure 29c1 and Figure 29c2 represent the same screen, with Figure 29c2 continuing from Figure 29c1 when the user scrolls down.



(a) (b) (c1) (c2)

Figure 29: Screens of the shopping interface depicting the search filter screens.

A review of the screen recordings and verbalisations showed that the common errors made by participants include the following.

a) Screen ID → <Figure 29b> Difficulty determining the correct icon for the filtering icon (10 participants)

b) Screen ID → <Figure 29b> Inability to see the correct filtering icon because it was not obvious (9 participants)

c) Screen ID → <Figure 29c1> Difficulty in inputting the price range (7 participants)

d) Screen ID → <Figure 29c1> Inputting the price range in the wrong field – within the search dialogue (7 participants)

e) Screen ID → <Figure 29c1> Difficulty understanding the concept of filtering (6 participants)

f) Screen ID → <Figure 29c1> Difficulty in seeing the price range function (4 participants)

g) Screen ID → <Figure 29c1> Choosing the wrong function for the price (2 participants)

h) Screen ID → <Figure 29c2> Forgetting to tap the save button after choosing filters (2 participants)

These difficulties were further analysed by comparing users' mental models with the interface's conceptual model on relevant screens following the task sequence. For example, the interface expected users to search for a product first and then choose the filter button, which was located at the top right of the screen with the word 'filter' displayed, see Figure 29b. However, in the mental model of FXI users, the option to select filters was not immediately apparent. Their mental model suggested combining the search for a product and the filter selection into one step, similar to a browser search, see Figure 30. This led to messages notifying users that the entered product was unavailable.

Figure 30: Sample participant entry depicting the browser search mental model applied to search filters.

Some users recognised the need to make a selection to access filters but were uncertain about what the selection should be. They often resorted to random interactions, hoping to stumble upon the correct choice. Participants frequently mentioned not noticing buttons/icons at the top of the screen because they focused on the middle and lower sections.

Additionally, some users saw the icons at the top, including the correct filter button, but were unaware it was clickable, see Figure 29b. Others thought the word 'filter' represented a function unrelated to filtering, such as changing colours.

> I saw the icons, but I thought the filter was an option to change the app's colours (P10)

While some users could not proceed without help, others successfully opened the filter dialogue where they could choose and apply filters. Despite the two options the interface offers for setting price filters - text/char input and horizontal sliders (a form of mechanical style control pattern) - as shown in Figure 29c1, participants encountered issues with both. None of the participants used the alternative scroll bar option.

A closer examination of the filter dialogue showed that the text/character input field for setting the price range filter did not update properly, causing problems for all users, including the LIT participants. Interestingly, all FXI users assumed they had made a mistake when encountering this issue and believed they were inputting data in the wrong field. In contrast, LIT participants recognised the input field's fault.

Meanwhile, some FXI users could not locate the price selection on the page, while others selected the wrong function. Additionally, some users who successfully found the correct functions for setting the ratings forgot to tap the save button after choosing filters. This was due to the vertical list presentation of information, which required scrolling to the bottom to access the save button, as noted by one participant.

> The save should be at the top of the screen because I did not think I had to scroll down to see save after choosing the filters (P11)

Furthermore, some participants did not understand the concept of filtering, opting to scroll through search results manually instead.

7.1.1.1 Post-Study Interview

In the open-ended section of the interview, participants highlighted several challenges, including the following.

User Interface Design: Four FXI participants mentioned certain UI patterns, particularly icons and buttons representing ordering, sorting, and filtering features in Figure 29b, were difficult to comprehend. Nine participants mentioned that the icons at the top of the screen were not visible to them. Additionally, two participants mentioned the horizontal scroll bar for setting price filters was not visible, causing them to rely solely on the faulty text input field. In a revealing explanation, one participant rationalised their thought process regarding Figure 31 as follows:

> I saw this 'filter', but I did not know that I [could] select it. Like this option here [*points to the sort feature*], it should have an arrow next to it, so I know that there are more options there. [However], the filter does not have an arrow - this is why I thought I could not select it. (P15)

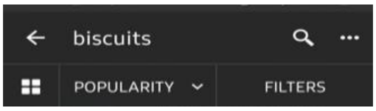


Figure 31: User explanation of icon difficulties on the home screen. .

In other cases, five users mentioned that the filter dialogue was complex because it presented much information.

Familiarisation and UI Vocabulary: Seven participants believed that with practice, they could improve their proficiency with the interface. They often attributed their difficulty in completing tasks to their shortcomings. Six participants observed that the process in the mobile shopping environment differed from their real-life experiences. Furthermore, twelve participants voiced concerns about the language used in the application, specifically highlighting words such as 'filters'.

Suggestions: Some participants offered suggestions for improvement. Specific recommendations included changing "filters" to more relatable terms like 'more' or 'other options,' and relocating the save button on the filter screen to enhance visibility.

7.1.2 Key Findings

The results shed light on specific UI patterns that posed significant challenges for FXI users, including issues with forms, icons, buttons, and scroll functionality. There was also the malfunctioning text input fields when attempting to set filters, which was a problem with the interface rather than the users. However, a deeper exploration of this digital skill revealed that several noteworthy challenges extended beyond UI design patterns. Notably, the mental models held by FXI users unveiled their unfamiliarity with the concept of filtering, leading to difficulties in task execution.

The conceptual model draws on the metaphor of shopping and categorising items and assumes users are familiar with shopping environments where products are arranged by category, including price levels, best sellers, et cetera. However, understanding how to select items based on filters can be difficult if users lack this familiarity. For example, several participants mentioned scrolling through multiple pages in the search results to locate products within the specified price range. Despite explanations on filtering as a concept, this underdeveloped mental model likely contributed to participants' inability to recognise the 'filter' option when presented. Instead, FXI users relied on mental models they were more familiar with, such as the browser search engine model. This absence of familiarity revealed a fundamental disconnect between users' expectations and the conceptual model of the mobile interface, which led to the users following the wrong task sequence to do the task. This highlights the need for more intuitive ways to convey the filtering feature.

Regarding the UI patterns specifically, the complexity of the form pattern, which presented numerous filtering options, likely contributed to FXI users' battles in locating the price selection within the interface. This suggests that presenting abundant information on a mobile interface can impact fundamental design principles like visibility.

Regarding buttons and icons, participants demonstrated familiarity with the search and more options icons. However, issues emerged when icons and buttons were positioned at the top of the screen, making them less visible to participants and thus leading to difficulties in recognition and interaction. The order icon was particularly problematic, as participants were unsure of its purpose. Concerning the filter button, its lack of distinguishing attributes left users unaware that it could be clicked. Similarly, the save button's placement at the bottom of the vertical list within the filter dialogue caused users to overlook it. These issues with icons and buttons can be linked to broader design principles such as affordance and visibility.

Specifically, regarding the scroll pattern, two notable problems emerged. In the first instance, users had challenges employing the scroll bar to set the desired price range. This could be because vertical scrolling is more familiar to users due to language patterns. In the second problem, users were unaware that scrolling vertically was necessary to access the save button. This means it is more likely that the oversight may have resulted from a lack of visual cues in the UI, as the design assumed users possessed prior knowledge of the need to scroll down in a vertical list presentation.

Furthermore, many FXI users expressed the belief that practising with the interface multiple times across various research points would enhance their task completion abilities. This suggests that users may rely on rote memorisation when interacting with interfaces.

In summary, this discussion underscores the critical relationship between users' mental models, UI patterns, and design principles, shedding light on FXI users' multifaceted challenges when applying search filters in mobile applications. In the next section, I propose a conceptual design to address these challenges for FXI users.

7.1.3 Proposed Conceptual Model for Improvement

The primary objective in shaping the conceptual model was to harmonise it with the users' mental model. Figure 32 provides a glimpse into the initial paper-based conceptual model, which underwent several refinements to effectively address the identified issues.

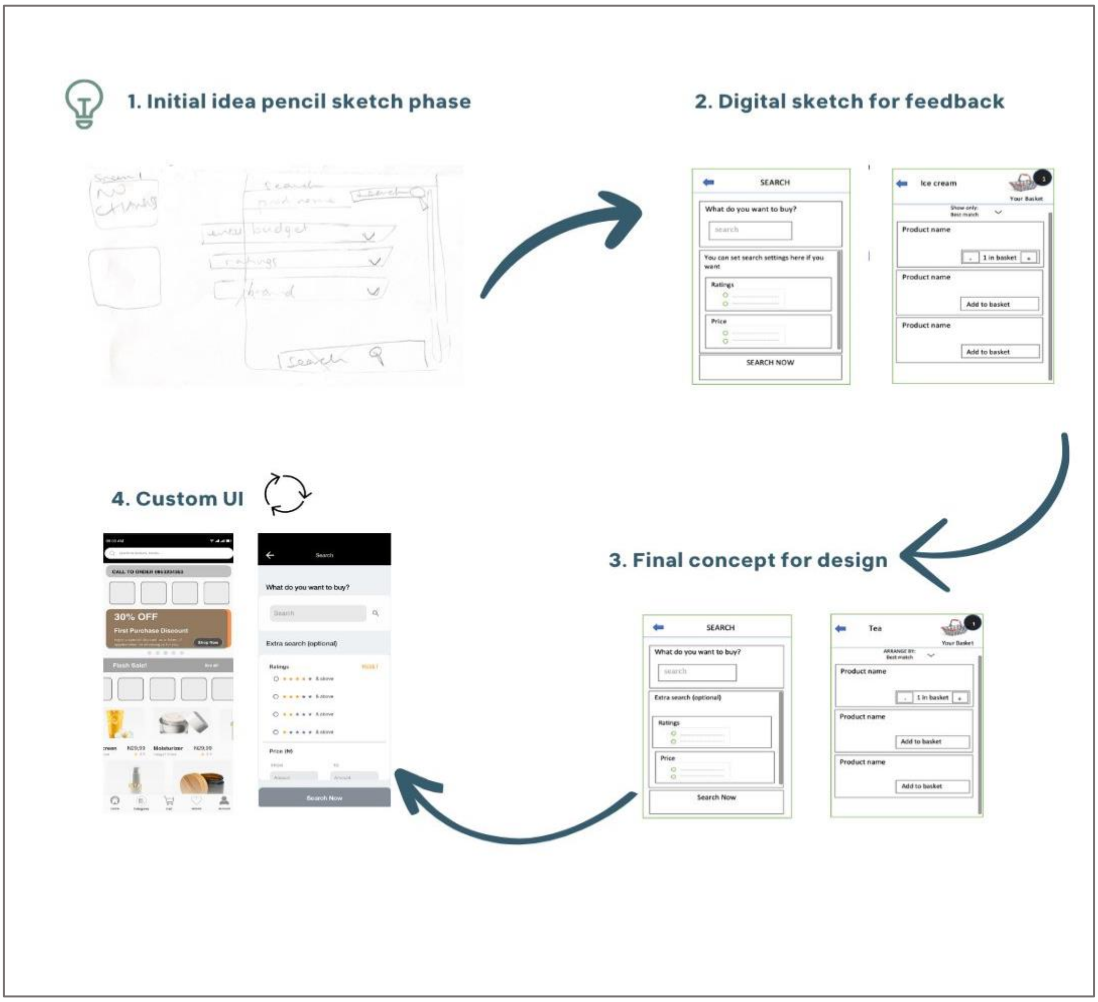
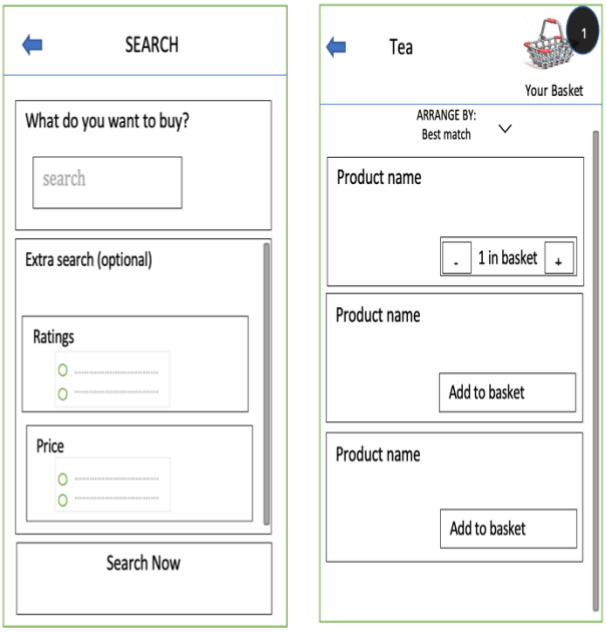


Figure 32: Design iterations for search filters from the paper-based conceptual sketch to the design of the custom UI.

The paper-based sketch evolved into a final conceptual model design, as depicted in Figure 33, as a visual representation of the new interface design. From L-R in Figure 33, the interaction flow includes (a) the search screen is opened after the user selects the search icon from the home screen, and (b) the search results screen is opened after the user applies the search filters to their search.



(a) (b)

Figure 33: Low fidelity prototype of the conceptual model for the shopping custom UI.

As depicted in Figure 33, I restructured the sequence of user interactions based on an analysis of their mental models, leading to the removal of problematic screens in pursuit of enhanced designs. To enable users to employ the search filters, the initial step was to select the search icon from the home screen, a task they had no difficulty accomplishing, thus requiring no redesign. However, improvements were deemed necessary for the subsequent steps.

Upon selecting the search icon, the search dialogue now opens; see Figure 33a. In the revised design, instead of initially viewing search results and then choosing the filter option, I integrated the filter within the search dialogue, condensing the process into a single step rather than two. This change was based on two key findings from the prior study: 1) users expected a browser search mental model, wherein they input the product name and filters within the same search field, indicating that their mental model did not distinguish between these steps, and 2) users did not have the concept of filtering searches in their model. By making the filter option visible within the search step, which they are familiar with, I aimed to prompt them to consider using filters as a possibility.

Furthermore, I replaced the term 'filter' with the phrase 'extra search (optional),' signifying that it was not a mandatory search parameter. Once the user inputs all the necessary information and selects the 'search now' button, the search results appear in a new dialogue (Figure 33b).

This version of the conceptual model served as the foundation for conveying specific design requirements to the third-party UI designer. In the upcoming study, this enhanced conceptual model will be transformed into a customised user interface (UI), which users in Nigeria will assess to determine if it improves user performance.

7.2 Designing and Evaluating a Custom UI

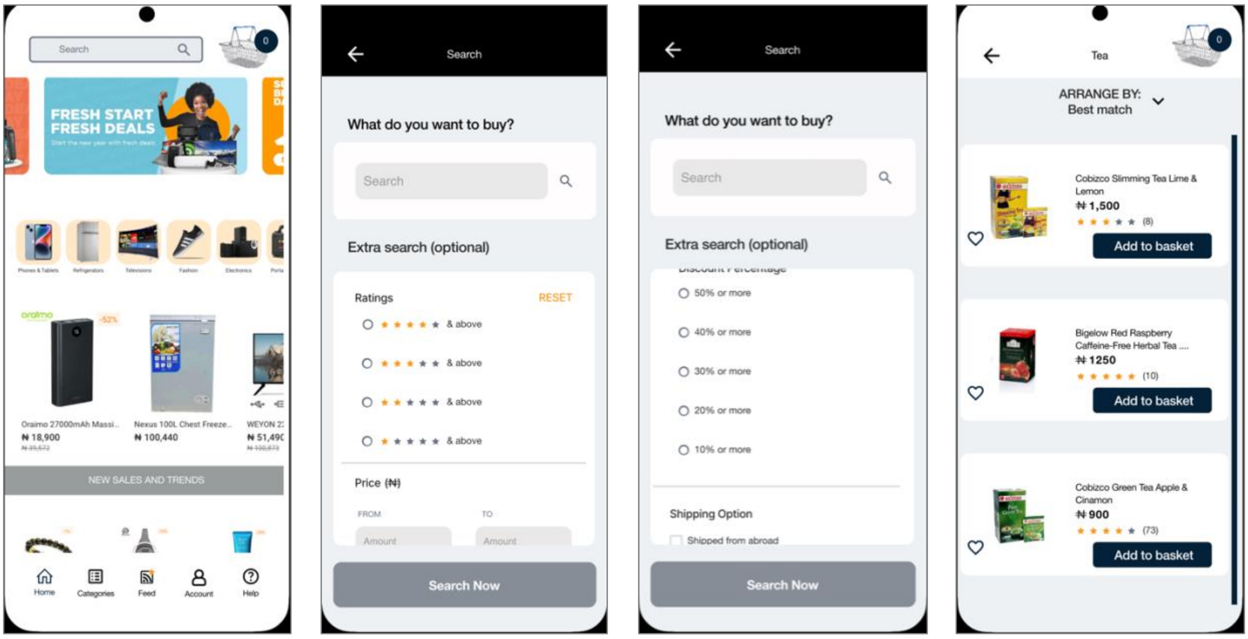
This section focused on an experimental study, where I designed and evaluated a novel mobile shopping interface, building on the findings from the previous section. The earlier study unveiled specific UI challenges faced by FXI users, including issues with forms, icons, buttons, and scroll features. It also revealed a notable concern regarding the unfamiliarity of filtering in most FXI users' mental models. Additionally, it raised considerations about other design principles, such as visibility and affordance. The previous study concluded with a proposed concept for improvement. In this study, my focus was to address research question 2:

> RQ2: What design techniques can improve interaction for FXI Nigerians while interacting with mobile banking and shopping applications on smartphones?

Consequently, I will describe the development of a custom user interface derived from the conceptual model. This will be followed by an experiment involving FXI and LIT users to assess the effectiveness of the implemented improvements based on user performance metrics.

7.2.1 Custom UI

The conceptual design transitioned into an interactive prototype (see Figure 34), embodying operational aspects. The interaction flow involves:(a) home screen. (b1) The filter screen displays filter categories, (b2) the continuation of the screen in (b1) with additional filter options accessible through scrolling, and (c) the search and filter results screen, which presents search results for tea. This involved critical design decisions in areas like screen layout, button placement, visual cues, and more. This section explores the design patterns and principles that shaped the development of the custom UI.



(a) (b1) (b2) (c)

Figure 34: Custom UI for search filters in mobile shopping.

As in the preceding Chapter, I maintained the colour theme design from the initial user interface to ensure thematic consistency. This choice stemmed from the absence of colour theme issues in the initial UI.

In addressing the form UI pattern, which previously posed challenges for users, I retained the form design while revising its content. The new form confined the search and filter categories to a content pane (see Figure 34b). This approach leveraged content panes as a categorisation technique, clearly demarcating different filter options and mitigating the risk of overwhelming users with excessive information.

Within the search bar itself, I introduced a prompt over the search pane to facilitate user interaction and provide clear guidance on where to input the search term (see Figure 34b). A search icon was also positioned to the right of the search entry field, offering users two options, including the 'search now' button. Placing this icon adjacent to the search option reinforced the idea of the optional use of filter options in a broader context.

Regarding the scroll feature, I incorporated a vertical scroll pattern within the relevant pane as a visual cue to prompt users to scroll down when necessary. Control patterns were also introduced to lock each entry field within its dedicated pane, ensuring that scrolling did not disrupt the position of elements. Consequently, as users scrolled through the list of filters, the search pane at the top remained unaffected and consistently visible, with only the filter pane responding to the scroll action. Moreover, the horizontal scroll feature initially used for price filters was replaced with a simple text entry field. This alteration was informed by users' familiarity with text entry and the recognition that a scroll filter for a price range on a small mobile screen did not offer an ideal user experience.

A similar control pattern was applied to the 'search now' button, which now resides permanently at the bottom of the screen, remaining unaffected by users' scrolling actions. This design ensured the continuous visibility of the button, addressing the issue of users forgetting to save after applying filters.

In the search and filter results screen (Figure 34c), I altered the colour scheme of the top pane from black to white. This choice addressed visibility issues previously encountered with the top icons in the initial UI. Furthermore, while the primary focus of this digital skill was not on sorting, I modified the term' popularity' to 'arrange by' to better represent the sorting functionality. In the initial interface, sorting was not explicitly labelled as 'sort' but rather assumed the name of the selected sorting option. By default, it was referred to as 'popularity.'

In the next section, my focus shifts towards evaluating the impact of these changes on enhancing user performance.

7.2.2 Experiment

This section discusses the experiment conducted with FXI and LIT users to assess the impact of design solutions in the custom UI on usability and user experience (UX) compared to the initial UI. It is important to note that the data for the initial UI is derived from Chapter 5 Investigating the Problem Space. Participants were assigned two tasks as outlined in Table 15.

Table 15: Participant search filters task description

1. Search for the product "tea" using the Mobile Shopping Application.
2. Apply the following filters:
    - Set a price range filter between ₦1000 to ₦3000.
    - Set filter to display only products with ratings above three stars.

7.2.3 Results

This section presents the experiment's results for both FXI and LIT users, organised according to the analysis of hypotheses and findings related to user experience. See section 4.3.2 for further discussion on the rationale for hypotheses and justification of analysis methods). The results are shown below.

7.2.3.1 Hypothesis 1

Twenty (20) FXI participants were recruited to interact with the custom UI designed to reduce errors experienced by FXI users. An exact McNemar's test was conducted to test the hypothesis:

> Ho: proportion of errors made by FXI in the initial UI = proportion of errors made by FXI in the custom UI.
>
> Ha: proportion of errors made by FXI in the initial UI ≠ proportion of errors made by FXI in the custom UI.

The findings revealed that the proportion of error-free instances decreased from a pre-intervention value of 15% to 5% post-intervention, showing a non-statistically significant difference, $p = 0.625$.

7.2.3.2 Hypothesis 2

Twenty (20) FXI participants interacted with the custom UI designed to improve the task completion rate for FXI users. An exact McNemar's test was conducted to test the hypothesis:

> Ho: proportion of task completion by FXI in the initial UI = proportion of task completion by FXI in the custom UI.
>
> Ha: proportion of task completion by FXI in the initial UI ≠ proportion of task completion by FXI in the custom UI.

The results indicated an increase in the proportion of task completion from 25% pre-intervention to 40% post-intervention, which was not statistically significant ($p = 0.508$).

7.2.3.3 Hypothesis 3

This hypothesis compares the performance of twenty (20) FXI and five (5) LIT users to determine whether the custom UI reduced disparities in error rate, task completion, and time taken. The hypothesis is as follows:

> Ho: The custom UI led to a reduction in performance disparities between FXI and LIT users in terms of error rate, task completion rate, and time taken.
>
> Ha: The custom UI did not result in a reduction of performance disparities between FXI and LIT users in terms of error rate, task completion rate, and time taken.

Note that a tapping count ratio greater than 1:2 (LIT: FXI) signifies a significant difference since no statistical analysis was conducted on this measure due to its count data nature. The results based on the four user performance measures are as follows:

Error Rate: Figure 35 illustrates the disparity in error rates between the two user groups within the initial UI, with a difference of 85% (85% for FXI vs 0% for LIT). However, in the custom UI, this difference decreased to 15% (95% for FXI vs. 80% for LIT). Fisher's exact test was employed to analyse the results, revealing that in the custom UI, there was no statistically significant association between the user group and error rate (p = 0.367). Conversely, a statistically significant association between the user group and error rate was observed in the initial UI (p = 0.001).

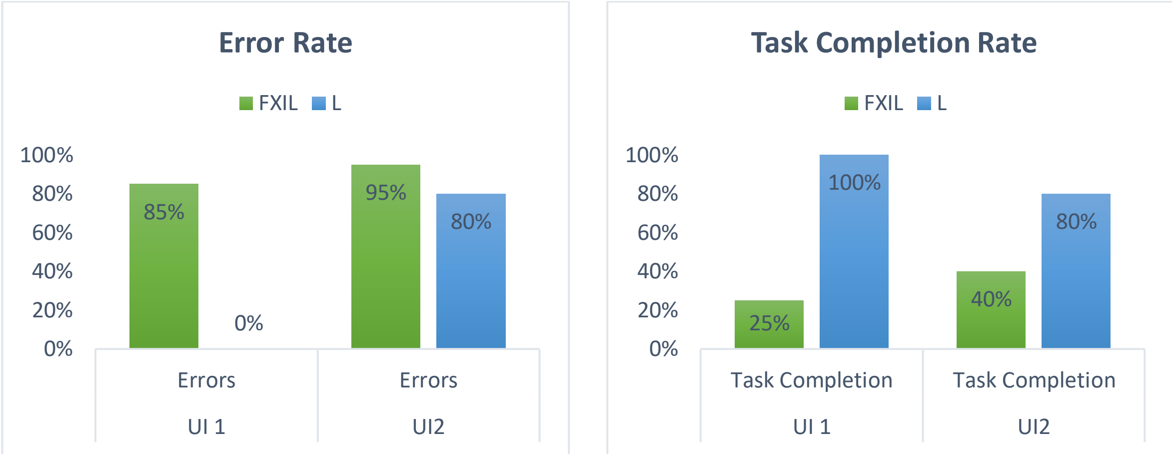


Figure 35: Filtering search results FXI v LIT (Initial UI v Custom UI).

Task Completion Rate: Figure 35 highlights the difference in task completion rates between the two user groups using the initial UI, with a notable gap of 75% (25% for FXI vs 100% for LIT). Conversely, in the custom UI, this difference decreased to 40% (40% for FXI and 80% for LIT). A Fisher's exact test for the initial UI showed a significant association between the user group and task completion rate (p= 0.005), whereas no statistically significant difference was found for the custom UI (p = 0.16).

Time Elapsed: As shown in Table 16, the ratio in the time taken to complete the assignment between FXI and LIT using the initial UI was 3:1 (FXI: LIT). Meanwhile, in the custom UI, the ratio was 1:1. Because the assumption of homogeneity of variances for the independent sample t-test was violated, the Welch t-test is interpreted. The Welch t-test revealed consistent findings across both the initial UI and custom UI. In the custom UI, a significant difference in the meantime was observed (p = 0.002), while a statistically significant association between the user group and the meantime was also detected in the initial UI (p = < 0.001)

Table 16: Comparing average time in seconds and ratios to apply search filters in the initial shopping UI vs custom UI

	Study 1: Investigating the Problem Space		**Study 3: Designing and Evaluating a Custom UI**	
Time*	**Number**	**Ratio**	**Number**	**Ratio**
FXI (n = 20)	69	5:1	119	2:1
LIT (n = 5)	15		52	

	Study 1: Investigating the Problem Space		Study 3: Designing and Evaluating a Custom UI	
Time*	**Number**	**Ratio**	**Number**	**Ratio**
*The time was measured in seconds and represented in the number column as such.				

Tapping Count: In the initial UI, the tapping count ratio between FXI and LIT was 3:1, with FXI tapping 18 times compared to LIT's 5 times. However, in the custom UI, this ratio decreased to 1:1, with FXI and LIT tapping 18 times, as depicted in Table 17.

Table 17: Comparing the average number of taps in numbers and ratios to apply search filters in the initial UI vs custom UI for shopping.

	Study 1: Investigating the Problem Space		Study 3: Designing and Evaluating a Custom UI	
Tapping Count	**Number**	**Ratio**	**Number**	**Ratio**
FXI (n = 20)	18	3:1	18	1:1
LIT (n = 5)	5		18	

7.2.3.4 UEQ-S

Similar to the method used in Chapter 5, FXI users rated their UX using the UEQ-S in the post-study interview. The mean values for the UEQ scales in the benchmark data set for UI2 are as follows:

i Novel: 1.37
ii Exciting: 1.79
iii Predictable: 1.53
iv Efficient: 1.89
v Understandable: 1.32
vi Enjoyable: 1.21

The results of these UX scales are depicted in Figure 36, which showcases the UEQ-S assessment for both the initial UI (UI1) and the custom UI (UI2) and includes a visual comparison with the benchmark set by the UEQ-S for mobile applications. The line represents the results for the shopping interface, showing the initial UI (UI1) and custom UI (UI2). Meanwhile, the coloured bars represent the ranges for the scales' mean values. **where the value '3' represents a positive experience, while '-3' represents a negative one.

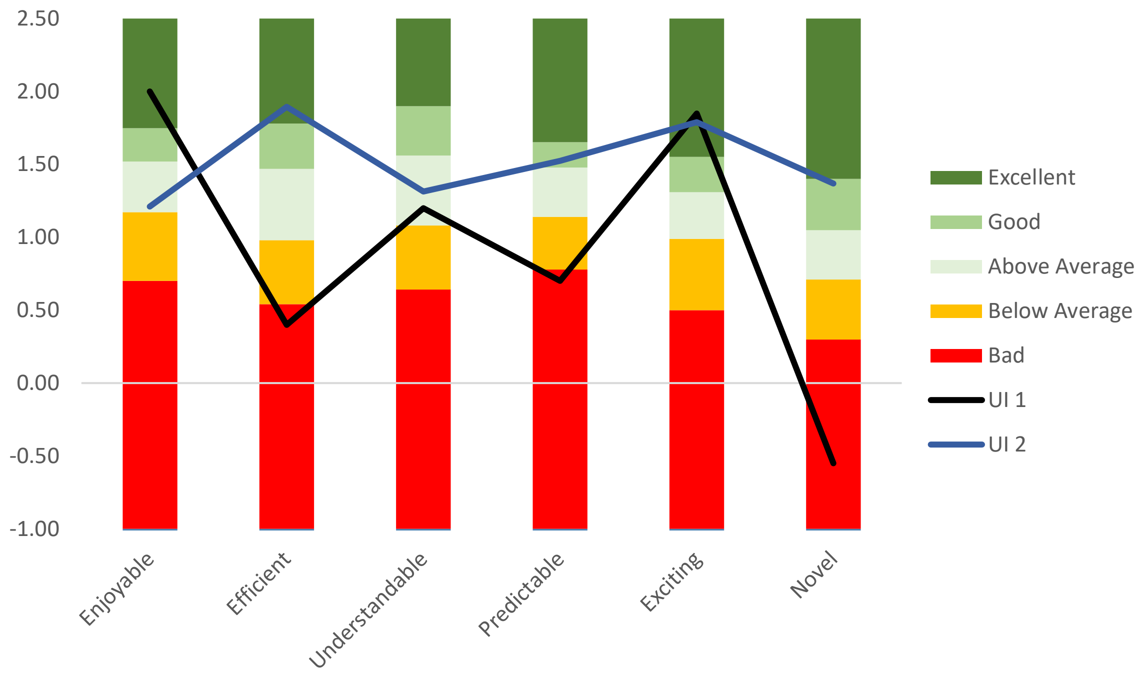


Figure 36: UEQ-S Benchmark – Shopping UI (Initial vs. Custom). .

7.2.4 User Performance Evidence: Custom UI vs. Initial UI

This research aimed to address challenges faced by FXI users when using search filters in mobile shopping environments. The findings underscored the importance of considering the browser search mental model for users. I will discuss the results in the context of user performance metrics in the following sections.

7.2.4.1 Error Rate

The initial disparity in error rates between FXI and LIT users, which stood at 85% in the initial UI, significantly decreased to 15% in the custom UI. However, this reduction was not entirely positive, as it coincided with a rise in error rates for LIT users, from 0% to 80%. For FXI users, although the error rates increased by 15%, this change was not statistically insignificant.

These errors emerged primarily from interactions with the search filter screen, see Figure 34b. Some issues persisted from the initial UI despite the changes made to improve the interaction of FXI. For example, despite redesigning the filters within the search dialogue, some users reported not seeing these options (frequency: 3). Consequently, they entered the product name and generated the results without considering the filters section that was below. This behaviour might be attributed to attentional bias driven by goal-oriented attention. FXI users were primarily focused on viewing the results and potentially reviewing product options before deciding on which filters to apply (frequency: 3), directing their attention solely to the search input field.

In other instances, FXI users entered the product name and desired filters within the search field, mirroring the browser search model that users employed in the initial interface (frequency: 5). Another recurring problem was the issue of users lacking familiarity with the concept of filtering in mobile applications (frequency: 6).

> No, I [do not] think there is a way to filter, and this is the best way [*referring to scrolling manually through the search results*] P16.

It was not unexpected to notice some errors in the custom UI as the concept of filtering was difficult to grasp for most users in the initial UI. However, the expectation was that the mental links would subconsciously teach or trigger concepts that are relevant to filtering, which in turn allows them to learn the concept of filtering and apply it in their interaction. Notably, some participants initially experienced errors but later recovered and completed the task (frequency: 6).

Also, participants specifically found the English used complicated (frequency: 6). For example, with filtering by price, understanding the "from and to" function was difficult for some, while comprehending the terminology and concept of rating (expecting numbers instead of star emojis) also posed challenges.

7.2.4.2 Task Completion Rate

The performance gap between FXI and LIT users decreased from a statistically significant 75% in the initial UI to a non-statistically significant 40% in the custom UI. For FXI users, the custom UI led to a task completion rate increase from 25% to 45%, although this improvement lacked statistical significance. This indicates a marginal enhancement in FXI performance compared to the initial UI. However, these improvements may not be substantial enough to conclude definitively that the custom UI effectively addressed the challenges posed by the initial UI.

7.2.4.3 Tapping Count

In the custom UI, both user groups exhibited a similar number of taps. In contrast, the initial UI revealed that FXI users tapped three times more frequently than LIT users. The custom UI offered a more streamlined and focused interaction flow. Incorporating the 'arrange by' sort feature and streamlining the search results screen by eliminating three additional options simplified the UX. Furthermore, the transition from a black colour scheme to a white one in the custom UI played a crucial role in improving visibility. With better contrast and legibility, users were likely able to locate and select options more efficiently, potentially reducing the number of taps required.

Overall, the tapping count results suggest that the custom UI simplified the interaction process.

7.2.4.4 Time Elapsed

The analysis of the time elapsed metric provided valuable insights into user interaction and efficiency. Interestingly, the significant difference in completion time observed between FXI and LIT users in the initial UI was mirrored in the custom UI. The performance gap between FXI and LIT users was smaller in the custom UI compared to the initial UI. In the initial UI, FXI took approximately five times longer than LIT users, while in the custom UI, FXI took about twice the time compared to LIT users. Despite the change in UI, the relative performance difference between FXI and LIT users persisted, with FXI taking more time than LIT users.

7.2.4.5 User Experience (UX)

Critical quality aspects of user experience depend on an application's nature and goals. (Sharp et al., 2019; Schrepp et al., 2017). Enjoyability, excitement, efficiency, and understandability are relatively more important than novelty for shopping applications. In the custom UI, improvements were observed in efficiency and predictability, with ratings shifting from below average to excellent in both aspects. The understandability and excitement aspects remained consistent and were rated above good. Novelty witnessed the most significant improvement, progressing from bad to excellent. However, there was a decline in the enjoyable aspect, shifting from excellent in the initial UI to good in the custom UI.

These findings indicate that while usability aspects did not significantly improve, FXI users reported enhanced user experience.

7.2.5 Summary

In summary, the custom UI design aimed to address specific challenges faced by FXI users. The critical design choices made in shaping the custom UI were based on findings from the prior study. The most significant transformation in the custom UI was the integration of search filters into the search dialogue, aligning with users' mental models rooted in search engine-style searches. Other design choices included categorising filter options within content panes, introducing prompts and icons for user guidance, implementing vertical scroll patterns with control features, and enhancing visibility through colour scheme adjustments.

The results showed a reduction in disparities between FXI and LIT users in error rates, but this decrease was accompanied by an overall increase in errors for both groups, primarily in interactions with the search filter screen. Task completion rates marginally improved for FXI users but lacked statistical significance, indicating the custom UI did not fully address initial UI challenges. Tapping counts implied limited exploratory actions in the custom UI, while time efficiency decreased for both groups, indicating a drawback. However, user experience, especially in terms of efficiency and predictability, improved, though enjoyability had a minor setback.

8 Digital Skill 3: Making a Purchase in Mobile Shopping

In Chapter 5, I identified the top three digital skills that presented the most challenges to FXI users. Chapter 8 narrows my focus to one of these skills: making a purchase in mobile shopping applications. See Figure 37 for a thesis map that shows how this chapter fits into the overall research structure.

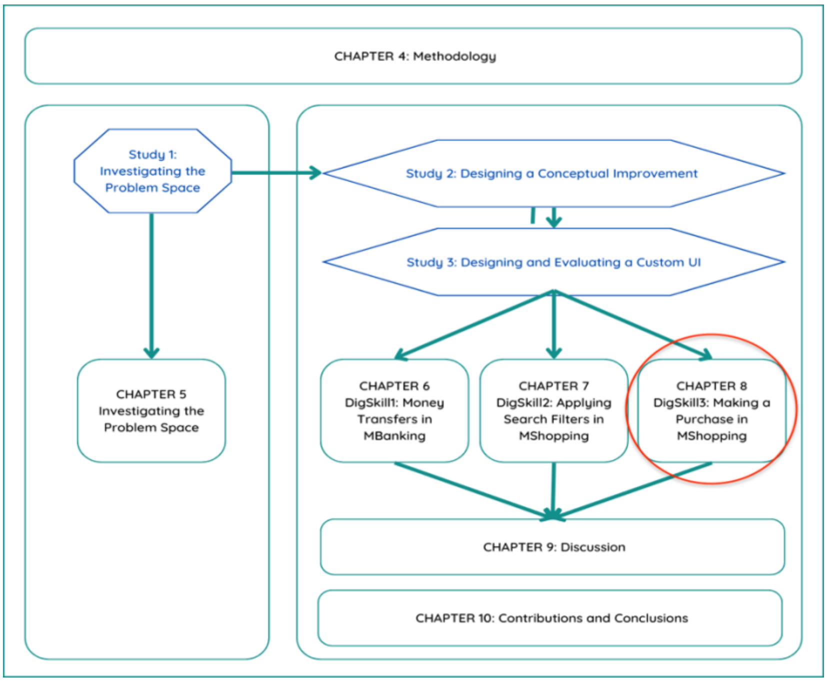


Figure 37: Thesis Flow Map – Chapter position in research structure.

Within this chapter, I present two interconnected studies (Study 2 and Study 3, as outlined in Chapter 4) that provide insights into the challenges faced by FXI users and introduce a custom UI developed and tested to enhance user performance in terms of usability and UX. Subsequently, I summarise the results to determine whether the evidence supports these performance improvements, emphasising error and task completion rates, tapping count, and the time taken by FXI users in the custom interface compared to the initial UI in Chapter 5.

8.1 Designing a Conceptual Model for Improvement

Purchasing items and services on smartphones has become a vital skill for everyday life, simplifying various tasks like online shopping, utility payments, in-app purchases, et cetera. However, the findings from Chapter 5 highlighted the challenges faced by Nigerian FXI users in mobile shopping. Notably, 90% of FXI users encountered errors, while none of the LIT users did. Only 25% of FXI users completed the task, unlike 100% of LIT users. Furthermore, FXI users had more than twice the number of taps and took three times longer than their LIT counterparts.

As a result, this study investigates a comprehensive analysis of the think-aloud and screen interaction data of FXI users to uncover the specific UI design patterns that made purchasing on the mobile shopping application challenging. The primary research question guiding this study is:

> RQ1: What design patterns of the user interface specifically cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

This section builds upon the data collected in Chapter 5, which included surveys, think-aloud protocols, and screen interaction recordings. In the following section, I will present findings based on the qualitative methods described in section 4.2.

8.1.1 Results

The task analysis of the mobile shopping application revealed that users must follow a sequence of steps, as depicted in Figure 38. The interaction flow involves: (a) home screen, showing the cart icon in the top right corner (b1) and (b2) product details page showing options and promotional items (c) shopping cart screen depicting the cart items (d) showing options for delivery when the user selects checkout in previous screen (e) payment options screen (f) summary page with an option to confirm an order. As shown in Figure 38, each screen is associated with specific UI design patterns, which are as follows.

a) Figure 38a: text/char input, fixed menu, icons.
b) Figure 38b: ordered display of information, fixed menus, buttons and icons.
c) Figure 38c: list display of information, fixed menus, buttons and icons
d) Figure 38d: lateral access (tabs and pagination), featuring buttons.
e) Figure 38e: lateral access (tabs and pagination), featuring text/char input and buttons.
f) Figure 38f: lateral access (tabs and pagination), featuring one button.

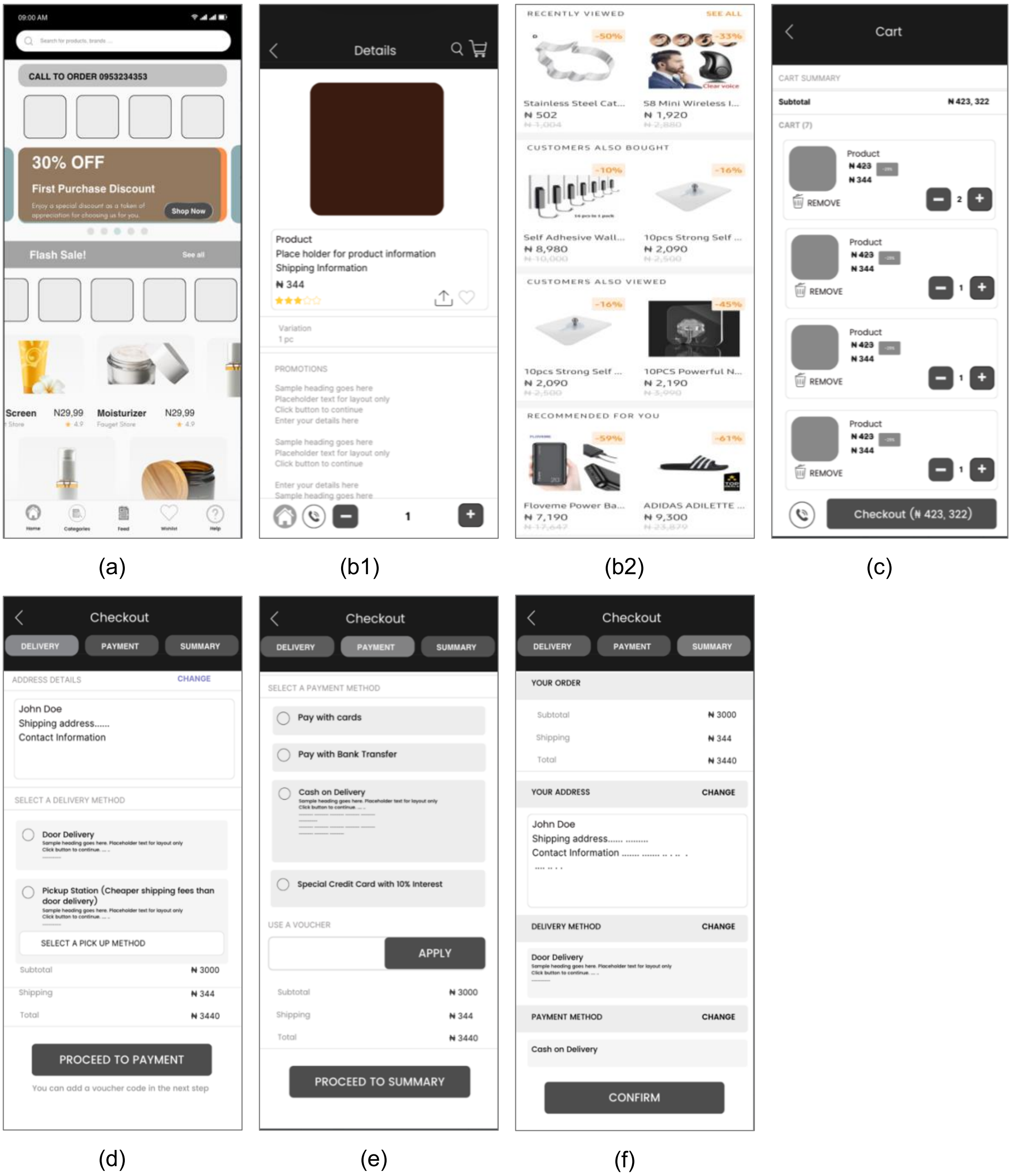


Figure 38: Screenshots of the shopping UI depicting the checkout screens as follows.

Analysis of the screen data and participant verbalisations showed that the most recurring errors made by FXI include the following.

a) Screen ID → <Figure 38a> Difficulty in seeing the cart icon (12 participants)
b) Screen ID → <Figure 38a> Difficulty in making the connection that the cart icon represented a cart (7 participants)
c) Screen ID → <Figure 38c> Difficulty in finding the checkout option (13 participants)
d) Screen ID → <Figure 38e> Difficulty with the voucher code (8 participants)
e) Screen ID → <Figure 38c> Selecting the wrong option for checkout (7 participants)

f) Screen ID → <Figure 38d> Selecting the wrong option for payment (6 participants)

These challenges were further examined by aligning users' mental models with the interface's conceptual model while considering the task sequence and individual screens. Fundamentally, for users to complete a purchase, they must go into the shopping cart. Consequently, the initial step involves users selecting the cart icon at the top right of the screen (see Figure 38a). However, this step heavily relies on users making the mental connection between the cart icon and its representation of taking the user to the payment feature, similar to a real shopping environment. The results showed a lot of variability in terms of users' mental models.

For instance, some participants did not notice the cart icon, primarily because it was positioned at the screen's top, making it less noticeable amidst other interface elements. One participant remarked:

> "I think the basket will be in home. I know it will be a button. I did not see it because it is too many and it [does not] look like a basket" (P16)

Several FXI users formulated alternative mental models regarding the cart's location. Some participants believed they could access the cart by returning to the product dialogue where they initially added items (Figure 38b). They anticipated discovering a 'buy now' option within the product dialogue that would lead them to the cart. Four users anticipated finding the cart at the bottom of the page, assuming that scrolling through the products on the search results dialogue would eventually reveal the cart. Two participants resorted to using the search bar during their quest for the cart. Interestingly, one participant even attempted to search for a basket as if it were a product, under the impression that they needed to locate a basket to place their selected items inside for delivery.

> "I think I will search for the basket. Or enter the app [referring to the main dialogue] and scroll to find it. The search is showing me waste bins. [I am] expecting to see a basket with my things inside so that if they want to deliver it to my house, my things will be inside. I think if I go back into the product page, there will be a basket option where my selected products are." (P6)

Additionally, some participants misunderstood the cart icon, assuming it represented something other than a shopping cart. A few others initially selected the cart icon but later decided it did not serve the correct function and proceeded to explore it elsewhere.

> "I saw the basket before but did not think that is where to click to start the buying process. I thought when I click add to cart that means I have bought it." (P10)

Once users selected the cart icon, they were directed to a dialogue displaying a cart summary with their chosen items and a checkout button at the screen's end (Figure 38c). Within this step, variations in users' mental models became apparent. Some participants, despite being on the correct dialogue and seeing the checkout button, could not proceed because they did not comprehend that "checkout" meant finalising the purchase. Other participants assumed that the checkout function would be found on the page displaying the details of their selected products (Figure 38b).

Furthermore, a few participants erroneously selected an icon that seemingly added additional units of the products to the cart, believing this would lead them to the point of completing the purchase. Another participant attempted to utilise the search option to discern "how to bring things to my house." These participants were unable to proceed without help.

In navigating the checkout screens, participants tapped on the text presented on the next tab, expecting this to navigate them to the next stage (Figure 38d). However, the tab design was intended solely as a page status indicator at the top of the screen and was not clickable. This dialogue was designed with the lateral access UI design pattern, featuring buttons, tabs, and pagination UI elements as the design structure. Consequently, participants faced an impasse in progressing to the payment stage without assistance because they had chosen pagination buttons to move to the next dialogue. This challenge might have been exacerbated by the absence of a visual cue indicating the possibility of scrolling vertically to access more information.

Furthermore, the checkout screen presented substantial information, including item summaries and promotional items. This complexity made it more challenging for users to locate the button that would take them to the next page.

In the next (payment) screen (Figure 38e), some participants encountered challenges when faced with the text/character input field for the voucher code. Others believed it was a mandatory field about confidential banking information required for the payment to be processed. Other participants did not understand that the button ('proceed to summary') at the bottom of the payments page was designed to navigate to the final payment confirmation dialogue (Figure 38f).

> 'I do not know what this voucher code is, so I cannot move forward. I expect to see 'transfer money' here, but it is not here, so I do not know where to go from here'.

These results collectively illuminate FXI users' challenges when navigating the mobile shopping application, with the interface design patterns, user mental models, and linguistic nuances contributing to their difficulties.

8.1.1.1 Post-Study Interview

The analysis of the post-study interview provided further insight into the challenges faced by FXI users while interacting with the mobile shopping application.

User Interface Vocabulary: Twelve participants mentioned that they did not understand some of the terms and phrases used on the interface, including "checkout," "cart," and "proceed to summary."
User Interface Design: Participants, specifically ten individuals, expressed concerns about the icons used in the interface, noting that they found them difficult to understand.
Analogy: Six participants stated that they found the task challenging because the processes involved were complex and differed from their usual shopping experiences in physical supermarkets.

8.1.2 Key Findings

The analysis of participants' verbalisations alongside screen data revealed a notable disparity between the mental models held by users and the conceptual model embedded within the interface. Effective shopping experiences are typically designed to align with analogies drawn from real-life scenarios. Users' ability to navigate an interface is greatly influenced by their prior experiences. In the case of FXI users, a gap emerged in their ability to connect the dots - specifically, understanding that completing a purchase necessitated them to "take" the shopping cart to the payment stage, involving selecting the cart and following instructions to enter payment details.

Regarding UI patterns, the icon representing the cart did not resemble the shopping carts commonly found in Nigerian supermarkets, further obstructing users from grasping its intended function. Additionally, the navigation UI pattern, designed to provide lateral access via tabs, confused users. The UI had intended these tabs to inform users of their current stage within the three-step checkout process. However, FXI users mistakenly believed navigation should occur laterally rather than by scrolling vertically and selecting buttons to advance to the subsequent screens. The absence of a scroll indicator to guide them to the buttons leading to the next screens exacerbated this issue.

Furthermore, visibility problems with icons at the top of the screen were also evident. This may have been due to the background colour choice, rendering the icons less discernible and causing users to overlook the cart icon.

Beyond UI patterns, content-related challenges emerged, particularly in terms of language. Using terms such as 'cart' and 'check out' proved problematic for FXI users, as these words differed from the more commonly used 'basket' and 'pay' or 'buy' in the Nigerian context. The term 'checkout' rarely finds its way into everyday communication. Additionally, users had difficulties with the field requesting a 'voucher code' due to their lack of familiarity with the term 'voucher.' Notably, users assumed this was a mandatory field, hindering their progress. This underscores the fact that users often experience difficulties in discerning which fields require compulsory information and which do not.

In evaluating the digital skill of making a purchase through a mobile shopping application, the results highlighted several difficulties arising from interface analogies that did not align with the Nigerian context. Furthermore, other UI design issues contributed to these challenges, including the use of lateral tabs for navigation, the order of information display, and icon design. In the subsequent section, I explore an approach to address these issues.

8.1.3 Proposed Conceptual Model for Improvement

The preceding section showed that the shopping metaphor did not effectively resonate with FXI users. To create a conceptual model for improvement, I explored alternative metaphors that would better align with the familiarity of these users. The goal was to discover a metaphor to make the interface more intuitive and relatable to FXI users. I also considered the UI patterns that would be suited to represent the metaphors.

In designing the conceptual model for improvement, the primary objective was to take into account the typical shopping experience in physical Nigerian supermarkets and suggest design improvements based on this account. This choice was guided by an in-person visit to stores in Nigeria. Moreover, considering the linguistic context of Nigeria, attention was given to everyday language usage. The observations and reflections on these issues culminated in an iterative design, as depicted in Figure 39.

Figure 39: Designing and developing a conceptual improvement for making a purchase in mobile shopping.

This iterative process led to the final conceptual model, as depicted in Figure 40.

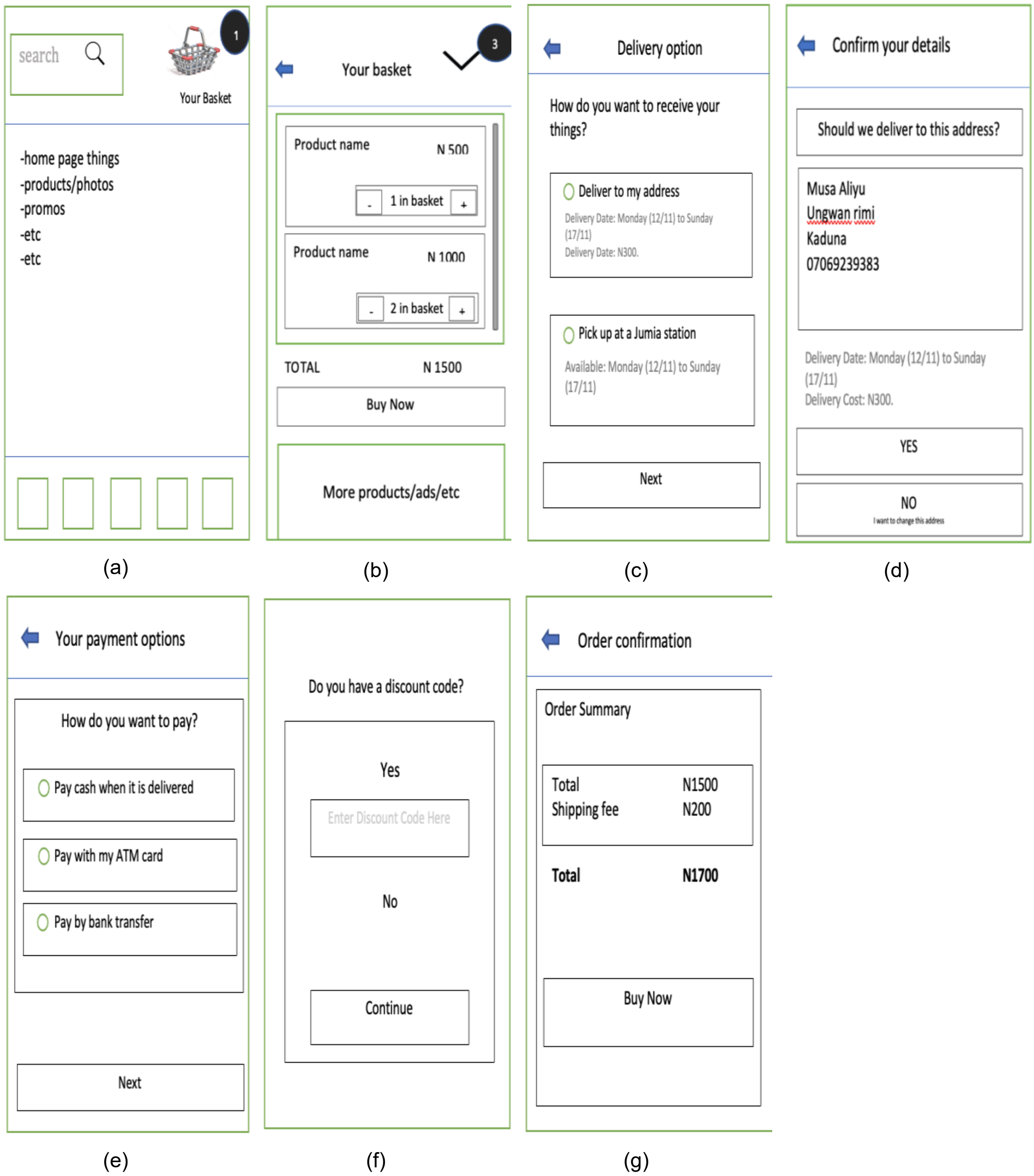


Figure 40: Low-fidelity prototype of the conceptual model for the shopping custom UI.

Upon examining the shopping process in Nigerian stores, I observed two aspects that shaped my design approach. These observations stemmed from the shopping experience in physical Nigerian supermarkets and the challenges faced by FXI participants with using the initial UI.

First, in physical stores in Nigeria, it is common practice for customers to select a shopping cart or basket before they begin shopping. I believe this practice is prevalent in various regions. It contrasts the online shopping experience, where users typically add products to a cart without interacting with it before making a selection. Even when a customer might not require a basket, the convention of using one remains prevalent in Nigerian stores.

Secondly, I noted that the term 'basket' is often used in Nigeria to refer to what might be called a 'cart' in other contexts. Lastly, the shopping process in local stores, distinct from larger supermarkets, is more conversational and less linear. In these settings, there are usually one or two attendants, limited space for movement, and a unique approach. Customers interact with attendants, articulating what they want to purchase, and attendants gather the items, placing them in a basket or on the payment counter after a store tour to collect the requested products. Totals are calculated, sometimes involving bargaining, and payment occurs afterwards. This process is notably different from the typical online shopping experience, though there is a subtle commonality when considering the metaphor of utilising a search feature.

With these insights in mind, I considered a design approach that takes inspiration from in-store shopping practices. Specifically, I contemplated a literal design approach that would involve presenting users with an empty 'basket' as soon as they launch the application, displaying the specific items they have added to the 'basket' in real time. However, it was essential to strike a balance. Being excessively literal could lead to confusion or unrealistic user expectations, contradicting the fundamental rationale for employing interface metaphors.

This prompted the recognition that the specific challenge faced by FXI users is the need to understand the importance of interacting with the virtual 'basket' to complete their purchase. I identified this as a significant bottleneck, alongside language-related issues and interaction style concerns, which were the core of the challenges. In light of these, my conceptual improvement efforts primarily focused on streamlining the existing sequence of steps.

To tackle these issues, I introduced a step indicating to users that entering the cart is the essential action for making a purchase. To address language-related difficulties, I made changes by incorporating plain language that was aligned with Nigerian colloquialisms. For example, I chose to use the term 'basket' instead of 'cart' and 'buy now' instead of 'checkout.' I also modified the language within the 'voucher code' field to 'discount code' in a separate step. Furthermore, I transformed the interaction style from instructive to conversational, creating a more user-friendly experience. Additionally, the interface underwent adjustments to present information more gradually and distinctly. This revised conceptual model formed the basis for communicating custom design requirements to the third-party UI designer.

8.2 Designing and Evaluating a Custom UI

In the examination of mobile shopping for Nigerian FXI users, I discovered several challenges. These stemmed from design patterns, including icons and lateral navigation, which often led to confusion due to FXI users' expectations of lateral movement contrasting with the vertical scrolling in the interface. Notably, issues arose in identifying the cart icon, primarily because of its discreet placement at the screen's top and the lack of a clear mental association with its role as a shopping cart representation. Language barriers, particularly regarding unfamiliar terms such as 'cart', 'checkout' and the voucher code input field, exacerbated these challenges. This section examines the design of a custom user interface aimed at addressing these challenges.

The preceding Study 1 concluded with a proposed concept for improvement. This section aims to address research question 2:

> RQ2: What design techniques can improve interaction for FXI Nigerians while interacting with mobile banking and shopping applications on smartphones?

To address this question, I will present the design of the custom user interface based on the conceptual model and an experiment involving both FXI and LIT users to assess the effectiveness of the improvements.

8.2.1 Custom UI

This section presents the design patterns and principles that guided the development of the custom UI, as depicted in Figure 41. The interaction flow involves: (a) search results screen (b) additional screen representing the physical analogy of adding an item to the basket (c) shopping basket screen (d) delivery options screen (e) confirmation of delivery details screen (f) payment options screen (g) a pop-up replacement screen for discount code (h) the order summary and confirmation screen.

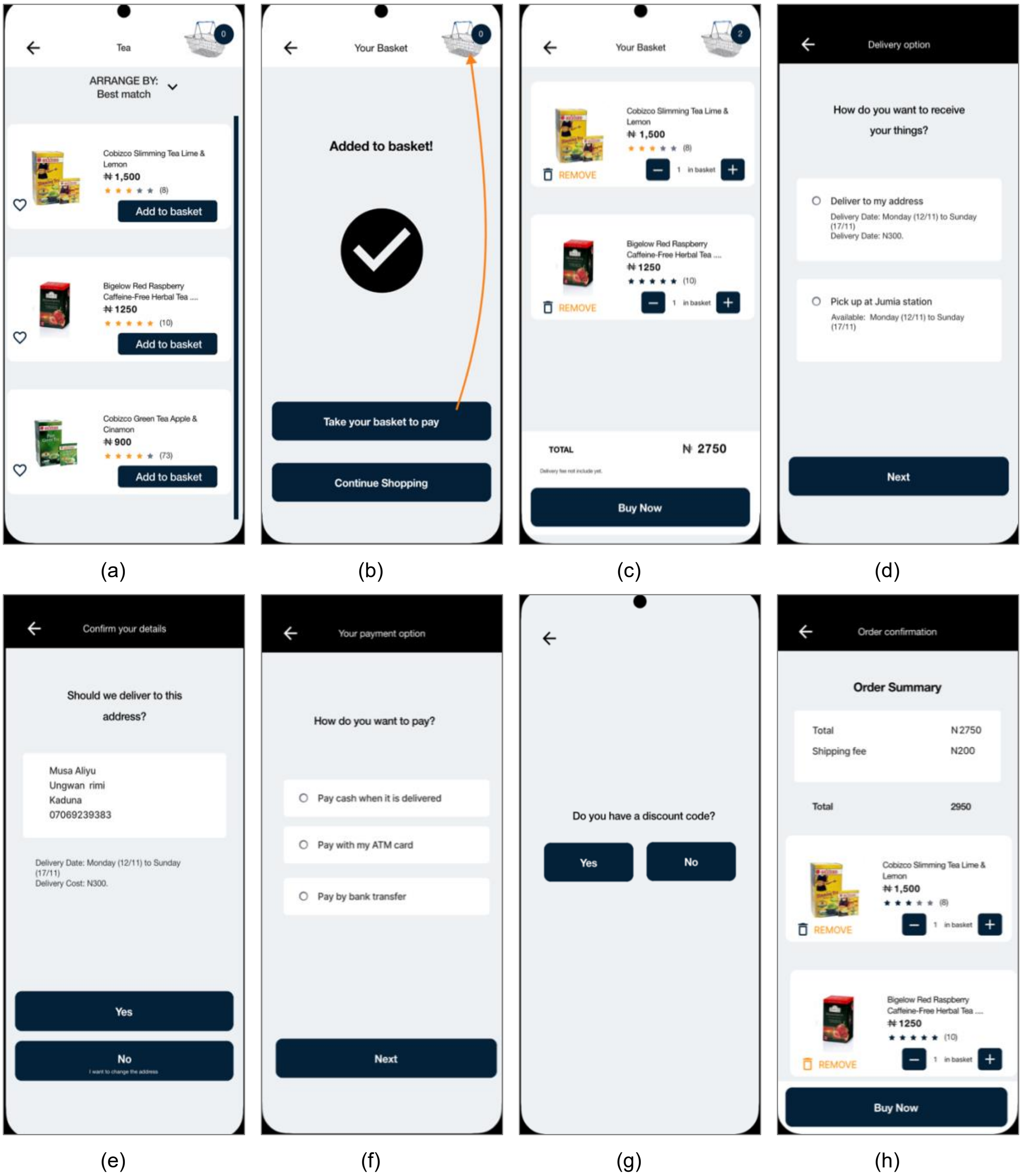


Figure 41: Custom UI for making a purchase in mobile shopping.

As highlighted in the previous section, one significant alteration was introduced when a user adds a product to the basket. An animation featuring an arrow connecting to an option, represented as a button with the text 'take the basket to pay,' was implemented, see Figure 41b. This analogy was modelled after the physical act of dropping an item in a cart in a physical supermarket. As such, it served to bridge the gap in users' mental models, addressing the issue of FXI users not immediately making the mental connection between the cart icon and its role as a representation of a shopping cart.

Furthermore, I replaced the initial basket icon with one that aligns with the Nigerian context, opting for a 3D representation of a basket, see Figure 42. This decision was informed by visits to Nigerian stores and consultations with local contacts who provided insights into the types of baskets commonly used. The choice in 3D was influenced by the consideration that lower literacy levels often correlate with difficulties in identifying 2D objects, as highlighted in the reviewed literature section (see 2.1.2).

Figure 42: Shopping basket icons - showing the icon used in the initial UI vs the new icon in the custom UI.

To enhance the interface's usability, I replaced the lateral access pagination with a step-by-step process for each screen while retaining the vertical scrolling design pattern. Recognising that FXI users had difficulties with distinguishing required text entry fields, I introduced prompts with a simple yes or no question instead. This design choice allowed users who selected 'no' to proceed, eliminating their perception that they could not continue without completing these fields. An example of this is shown in Figure 41g, where I introduced a pop-up screen that replaced the initial voucher text/chart input field in the initial UI, see Figure 38e. Additionally, I made slight adjustments to the colour theme, changing the top background from black to white to improve visibility for users.

The next section explores assessing how these alterations have affected user performance.

8.2.2 Experiment

This research section discusses the experiment conducted with FXI and LIT users. The aim of the experiment was to evaluate whether the design solutions in the custom UI enhanced usability and user experience (UX) for FXI users compared to the initial UI. As a reminder, participants were asked to do only two tasks, as shown in Table 18.

Table 18: Participant making a purchase task description.

1. Add any "tea" product to your shopping basket using the Mobile Shopping Application.
2. Go to the shopping basket and make the purchase so that the tea is delivered to you.

8.2.3 Results

This section provides the results of the experiment conducted with FXI and LIT users on the custom UI. It is essential to emphasise that the data referring to the initial UI in this section is drawn from Chapter 5 Investigating the Problem Space. The rest of this section is organised according to the analysis of the hypotheses and the results related to user experience. Refer to section 4.3.2 Design for a more detailed discussion regarding the reasoning behind the hypotheses and analysis presented in this section. The results of these tests are as follows.

8.2.3.1 Hypothesis 1

Twenty (20) FXI participants were recruited to take part in a custom UI redesign to reduce the number of errors experienced by FXI users. An exact McNemar's test was run with the following hypothesis.

> Ho: proportion of errors made by FXI in the initial UI = proportion of errors made by FXI in the custom UI.
>
> Ha: proportion of errors made by FXI in the initial UI ≠ proportion of errors made by FXI in the custom UI.

The findings revealed a notable increase in the proportion of error-free instances from a pre-intervention value of 10% to 55% post-intervention, demonstrating a statistically significant difference ($p = 0.012$).

8.2.3.2 Hypothesis 2

Twenty (20) FXI participants were recruited to participate in a custom UI redesign to improve the task completion rate for FXI users. An exact McNemar's test was conducted to assess the following hypothesis.

> Ho: proportion of task completion by FXI in the initial UI = proportion of task completion by FXI in the custom UI.
>
> Ha: proportion of task completion by FXI in the initial UI ≠ proportion of task completion by FXI in the custom UI.

The results showed a substantial increase in the proportion of task completion from a pre-intervention value of 25% to 90% post-intervention, indicating a statistically significant difference ($p = < .001$).

8.2.3.3 Hypothesis 3

In this section, the hypothesis focuses on comparing FXI and LIT users' performances to see if there has been an improvement. As such, the hypothesis is as follows.

Ho: The custom UI led to a reduction in performance disparities between FXI and LIT users in terms of error rate, task completion rate, and time taken.

Ha: The custom UI did not result in a reduction of performance disparities between FXI and LIT users in terms of error rate, task completion rate, and time taken.

I will present the results based on the four user performance measures: including error rate, task completion, taps and time taken. As a reminder, a tapping count ratio greater than 1:2 (LIT: FXI) is considered a significant difference since I did not run a statistical analysis on this measure because of its count data nature.

Error Rate: Figure 43 illustrates the disparity in error rates between the two user groups when using the initial UI, with a substantial difference of 90% (90% for FXI vs 0% for LIT). However, in the custom UI, this difference decreased to 45% (45% for FXI vs 0% for LIT). The results of Fisher's exact test indicated that in the custom UI, there was no statistically significant association between the user group and error rate (p = 0.123). In contrast, a statistically significant association between the user group and the error rate was observed in the initial UI (p = < .001).

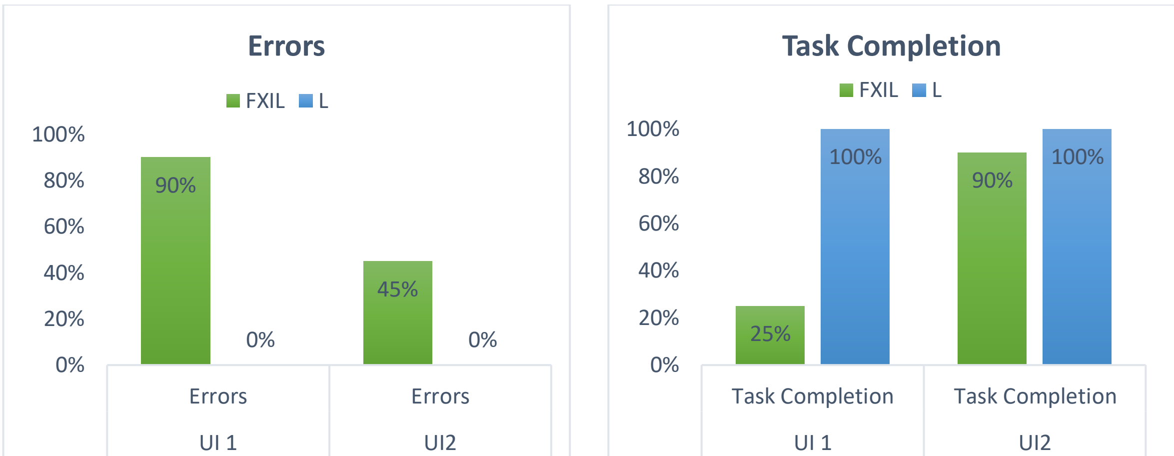


Figure 43: Locating the shopping cart and checking out FXI v LIT in Initial UI v Custom UI.

Task Completion Rate: Figure 43 illustrates a substantial difference in task completion rates between the two user groups when using the initial UI, with a significant margin of 75% (25% for FXI vs 100% for LIT). However, in the custom UI, this difference decreased to 10% (90% for FXI and 100% for LIT). The statistical analysis using Fisher's exact test indicated a significant association between the user group and task completion rate in the initial UI (p = 0.005). In contrast, no statistically significant difference was found in the custom UI (p = 0.633).

Tapping Count: The initial UI showed a tapping count ratio of 32:13 (FXI: LIT), whereas in the custom UI the ratio was 12:7; see Table 19.

Table 19: Comparing the average number of taps in numbers and ratios to complete purchases in the initial UI vs custom shopping UI.

	Study 1: Investigating the Problem Space		**Study 3: Designing and Evaluating a Custom UI**	
Tapping Count	**Number**	**Ratio**	**Number**	**Ratio**
FXI (n = 20)	32	32:13	12	12:7
LIT (n = 5)	13		7	

Time elapsed: Table 20 highlights the disparity in time taken by both user groups in the initial UI, with a ratio of 28:9 (FXI: 168 seconds vs LIT: 54 seconds). However, in the custom UI, the ratio was 73:35 (FXI: 73 seconds vs LIT: 35 seconds). A Welch t-test conducted revealed a significant difference in time (p = < .001) in the initial UI, while the custom UI also demonstrated a significant difference (p = 0.04).

Table 20: Comparing average time taken in seconds and ratios to make a purchase in shopping on the initial UI vs custom UI

	Study 1: Investigating the Problem Space		**Study 3: Designing and Evaluating a Custom UI**	
Time*	**Number**	**Ratio**	**Number**	**Ratio**
FXI (n = 20)	168	28:9	73	73:35
LIT (n = 5)	54		35	
*The time was measured in seconds and represented in the number column as such.				

8.2.3.4 UEQ-S

Similar to the method used in Chapter 5, FXI users were asked to rate their UX based on the UEQ-S in the post-study interview. However, I specifically collected UEQ-S data for each individual UI. As a result, despite the different digital skills examined in Chapters 7 and 8, the UEQ-S results remain consistent for both chapters, given that they relate to evaluations conducted on the same mobile application. I have already documented the detailed UEQ-S findings for the shopping UI in section 7.2.4.5 User Experience (UX).

8.2.4 User Performance Evidence: Custom UI vs. Initial UI

In this section, I discuss the results of the experiment conducted with FXI and LIT users on the custom UI designed to address usability and UX challenges compared to the initial UI. This discussion will be organised according to the analysis of the hypotheses and results related to user performance and experience.

8.2.4.1 Error Rate

The findings revealed a significant increase in error-free instances, rising from 10% pre-intervention to 55% post-intervention in the custom UI, signifying a marked reduction in errors for FXI. Moreover, while the initial UI showed a significant difference in performance gap (90%)

in error rates between FXI and LIT users, the custom UI notably narrowed this gap to 45% for FXI users with no statistically significant difference observed for user groups.

The errors experienced by FXI in checking out on the custom UI could be categorised into three broader groups. Navigation issues to the checkout page emerged as a recurrent problem, with some participants facing difficulty reaching the checkout page (Frequency: 2), indicating confusion surrounding the concept of the basket and its role in the checkout process. Awareness and noticeability issues of checkout elements became evident, as one participant experienced transition problems from search results to checkout (Frequency: 1) and overlooked crucial elements like the final "Buy Now" button on the checkout page (Frequency: 1). Additionally, a category involving confusion in payment and order sequencing surfaced, including difficulties in selecting the mode of payment, misunderstanding the transaction process (Frequency: 1), and expecting a different button function, such as "Continue" instead of "Buy Now" (Frequency: 1)..

These findings underscore the profound impact of the custom UI intervention on error reduction among FXI users. The significant increase in error-free instances post-intervention demonstrates the effectiveness of tailored UI designs in mitigating errors among users facing accessibility challenges. Additionally, while the initial UI highlighted substantial performance disparities between FXI and LIT users in terms of error rates, the custom UI notably narrowed this gap. The absence of a significant association between user groups and error rates in the custom UI suggests a more equitable error experience for both FXI and LIT users, signifying the potential of UI adaptations in fostering a more inclusive and error-resilient user experience.

8.2.4.2 Task Completion Rate

The study's hypotheses and subsequent tests yielded compelling insights. Firstly, the implementation of a custom UI demonstrated a remarkable enhancement in task completion rates for FXI users, soaring from 25% in the initial UI to a staggering 90% post-intervention, signifying a substantial and statistically significant improvement. Secondly, the investigation into performance disparities between FXI and LIT users revealed intriguing outcomes. In the initial UI, a notable discrepancy existed, with FXI users achieving a gap of 75% in task completion rates between FXI and LIT. However, upon introducing the custom UI, this gap narrowed significantly to only 10%.

Notably, statistical analysis showcased a substantial difference between FXI and LIT users in the initial UI but revealed no significant disparity in the custom UI. These results collectively indicate that the custom UI intervention substantially increased task completion rates for FXI users and notably mitigated the performance differences between FXI and LIT users observed in the initial UI setting. This finding showcases the potential of UI adaptations in facilitating a more inclusive and efficient user experience across diverse user groups.

8.2.4.3 Tapping Count

The tapping count comparison between FXI and LIT users in both the initial and custom UIs reflects the evolution of user interaction patterns following identified interface challenges and subsequent enhancements. In the initial UI, the tapping count ratio stood at 32:13 (FXI: LIT), indicating a notable disparity in interaction approaches. This divergence correlated with difficulties users faced in comprehending navigation, dealing with icon visibility, and encountering language-related barriers. However, with the introduction of the custom UI, a shift in the tapping count ratio was observed, depicting a ratio of 12:7 (FXI: LIT). This alteration suggests that the UI elements in the custom UI might be more noticeable and interpretable to FXI and LIT users. The revised ratio indicates an adaptation in user interaction behaviours, potentially influenced by the modifications integrated into the custom UI. These changes align with the iterative efforts aimed at bridging the gap between users' mental models and the discoverability of interface concepts.

8.2.4.4 Time Elapsed

The examination of checkout duration revealed distinct differences between FXI and LIT users in both the initial and custom UIs, shedding light on their interaction patterns and experience. In the initial UI, the time ratio displayed a significant disparity, indicating FXI users notably taking three times longer compared to LIT users, depicting challenges in user interaction for FXI users during checkout. These challenges stemmed from various interface-related difficulties encountered by FXI users, such as navigation complexities and language-related barriers, contributing to prolonged checkout times. Similarly, the custom UI showcased a differing time ratio difference of FXI taking twice longer than LIT, signifying an altered but still notable gap in checkout duration between the user groups.

The Welch tests conducted for both UI versions indicated significant time differences between FXI and LIT users, reinforcing the distinct experiences and challenges faced by FXI during the checkout process. The significant time difference in both UI iterations emphasises the persistent discrepancies in efficiency between FXI and LIT users in both UIs, regardless of the constraints of the custom UI's partial exploration possibilities for users.

The findings underscore the complexities FXI users encounter with information processing aligning with previous observations of interface challenges. The continued presence of significant time differences highlights the nuanced nature of addressing accessibility concerns and suggests the need for further enhancements to create a more inclusive solution.

8.2.5 Summary

The study highlights the importance of prioritising users' current skills and shaping custom solutions, particularly for users like FXI individuals with specific accessibility needs. Through implementing custom UI interventions, significant enhancements emerged across various performance metrics, notably reducing errors, improving task completion rates, and narrowing performance disparities between FXI and LIT users. These outcomes underscore the effectiveness of tailored UI designs in fostering more inclusive and resilient user experiences. However, persistent challenges in checkout duration signify the imperative for further exploration into information processing efficiency and literacy.

Nonetheless, the progress achieved through these enhancements will be expanded upon in the subsequent section of our primary discussion. In Chapter 9**Error! Reference source not found.**, I aim to consolidate these findings to address our research questions by evaluating the outcomes of all three digital skills (refer to Figure 37 for the thesis map). This comprehensive approach seeks to offer a holistic viewpoint on challenging aspects of mobile UI design for FXI users and proposes solutions to enhance usability and UX tailored to these users' needs.

9 Discussion

This research considered the effectiveness of current mobile banking and shopping applications for Nigerian FXI users. The findings prompted a redesign, which was subsequently assessed with users to address challenges in the initial applications. The goal was to identify more inclusive UI design patterns for FXI users. The research questions addressed in this study are as follows:

1. What UI design patterns cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?
2. What design techniques can improve interaction for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

Before directly addressing these research questions, I will discuss the overall challenges FXI users face in a thematic format. This discussion will link the challenges experienced by FXI users in the tested UIs with aspects of functional illiteracy that contributed to those difficulties. The discussion will integrate topics related to problematic UI design patterns and their proposed improvements, explanations for issues with UI design patterns and mental models used in the proposed improvements and understanding of the behaviours of FXI users in terms of cognitive styles, cultural influences, experiences, familiarities, and other contextual factors. These topics are organised into four main themes: language-related challenges, reasoning and problem-solving, visual attention, and visual perception. After exploring these themes, I will provide a summary discussion that specifically addresses research questions 1 and 2 and the contributions, limitations, and future work.

9.1.1 Language Challenge in Interfaces

The challenges encountered by FXI in using the initial mobile applications suggest that limited exposure to formal schooling, rather than an absence of reading skills, significantly influences their interaction. Evidently, confusion arose among FXI due to unfamiliar terms and a misunderstanding of error messages in both initial mobile applications. The UI content, featuring technical terminology familiar primarily to individuals with formal schooling, presents a significant obstacle for users lacking exposure to such specialised language. For instance, terms like "vouchers", "beneficiaries," or "debit accounts" within the initial UIs require a more extensive vocabulary bank typically acquired through prolonged formal education (refer to Figure 18b). FXI may not have advanced beyond basic education or acquired reading skills through formal education, so their exposure to such terminologies might be limited. Consequently, comprehending technical terms becomes challenging, resulting in deficiencies in reading comprehension.

Additionally, research underscores the diminishing relevance of individuals' proficiencies when those skills are not consistently applied to their daily responsibilities (Thatcher and Ndabeni, 2005). Consequently, even if FXI were exposed to terms like "debit account" during their schooling, this knowledge might have faded over time if their daily activities did not require the regular use of such vocabulary, given that these terms are not commonly used in everyday contexts. While technical language might be justified in sophisticated systems like Enterprise Resource Planning (ERP) applications for banking staff, it is redundant for typical banking customers using mobile services. Specifically, researchers have highlighted the challenges of FXI users due to unfamiliar banking terminology, emphasising the significance of simpler, basic language in designing inclusive technologies (Rayed et al., 2023; Medhi et al., 2009). Therefore, simplifying language in UI content to everyday language, devoid of unnecessary technical jargon, is crucial.

- Implication 1: Using plain language in designing inclusive technologies.

This finding is consistent with the recommendations from various studies advocating the use of simple, straightforward language that is easily understood FXI (Teran et al., 2024; Rayed et al., 2023; Vosloo, 2018; Medhi et al., 2011). These studies emphasise the avoidance of complex terms, recognising their challenge for individuals with lower literacy levels even if they are presented in the local language (Medhi et al., 2011) and offered in UIs that are not reliant on text only (Cuendet et al., 2013).

Another instance underscoring the potential influence of formal schooling on FXI's performance in language use within the initial UI is reflected in the search for destination bank details in the banking application (see Figure 18d). The inclusion of an abbreviation of the bank name in the initial UI, commonly used in the Nigerian context, posed a challenge for both user groups. However, distinct behaviours emerged. While LIT could identify the abbreviated bank name and navigate the list to find a match for the abbreviation, FXI had difficulties recognising the abbreviation usage and assumed the bank name was absent. To bridge this gap, aligning with prior recommendation (Chen et al., 2016), employing plain and locally recognised language is crucial. Providing the bank name in abbreviations and full meanings could aid FXI users.

- Implication 2: Ensuring consistency in UI content with locally recognised terms in the context of use.

This research also found that the use of conversational language in UI interaction is easier to comprehend for FXI, as evidenced by the improved interaction in the custom vs initial UI (see Figure 38 vs Figure 41). While prior recommendations align with this approach, such as Chen et al. (2016) who emphasised the use of simple language and direct-action steps (e.g., 'pay bill' instead of 'bill payments), my findings extend this by specifically suggesting conversational interaction styles for improved user understanding. This involves structuring the interface's language and communication to mimic a human conversation, ensuring that prompts, instructions, and interactions are conversational and easily understandable.

- Implication 3: Incorporating conversational interaction styles in the UI design to facilitate improved user understanding and interaction for FXI.

9.1.2 Reasoning and Problem Solving

The findings from the experiment with FXI users in mobile applications, particularly the shopping UI, highlight challenges in recognising and initiating purchases. This can be linked to the broader cognitive processes discussed in the literature (see section 2.1.2). As previously mentioned, human reasoning often relies on analogies, which are integral to problem-solving and other cognitive functions (Bechtel and Graham, 1999). An examination of the shopping process in the UI revealed that the design effectively mirrored a shopping process in a literal sense. While it is logical to assume that all FXI users have real-life shopping experiences, closer inspection of the analogies showed that shopping in the Nigerian context is not as straightforward and structurally organised as it is in the Western context (see section 8.1.3. for a fuller discussion). This disparity poses a notable challenge, as the absence of this organisational structure may have contributed to FXI's ability to relate to the mapped-out shopping process within the UI.

Additionally, as Luria's study indicated, problem-solving skills can be influenced by literacy and exposure to Western education and styles of reasoning rather than developmental issues (Huettig and Mishra, 2014). This could explain why FXI users, who may have less exposure to Western styles of reasoning, experienced difficulties with the UI's shopping process. Therefore, examining the contextual relevance of the analogies embedded in UI designs is crucial. These analogies must derive from context-specific knowledge to facilitate FXI's understanding of task sequences necessary for completing desired actions.

- Implication 4: Ensuring that analogies used in UI design are contextually sensitive and relevant, considering the specific cultural and behavioural patterns of FXI users.

Considering the challenges in aligning contextual analogies with mobile design, the critical question arises: how can these analogies be effectively represented in such cases? The answer might lie in adopting the mental model of *first principles*, which becomes imperative in redesigning processes within UIs. First principles thinking is characterised by separating underlying ideas from assumptions (Weinberg and McCann, 2019). This practical approach aims to minimise errors in thinking and often begins with the foundational elements of what is believed to be true (Weinberg and McCann, 2019). These elements serve as building blocks to construct well-founded and, at times, innovative conclusions.

Applying the concept of first principles thinking to the shopping context, all users, including FXI, navigate a process from recognising a need to completing a product exchange. The primary issue identified in this context was a lack of knowledge on how to initiate the checkout process. In the case of FXI users, a gap emerged in their ability to connect these dots. Specifically, the problem was understanding that completing a purchase necessitated them to *take* the shopping cart to the payment stage, involving selecting the cart icon and following instructions to enter payment details in the subsequent screens. Applying the first principles model helped pinpoint what FXI believed to be true and how that matches/differs from the underlying conceptual model in the UI design.

- Implication 5: Incorporating first principles thinking in UI redesign by breaking down complex processes into fundamental, easily understood elements.

To address this gap in understanding and enhancing user performance, the redesign strategy employed the creation of a bridge screen, aiming to persuade users to connect those dots because representing the model FXI had of shopping was not feasible due to its lack of structure, as discussed above (see Figure 41b). This screen features an animated arrow that appears upon selecting an item to add to the cart, directing the user's attention towards the cart icon. Accompanying this visual cue is a message prompting the user to 'take the basket to pay'. This change significantly improved user performance, as demonstrated by the outcomes observed with the custom UI. Therefore, this emphasises the importance of UIs accommodating analogies while providing intuitive connections to aid users in understanding unfamiliar concepts when necessary.

- Implication 6: Incorporating mental links in UI design to aid understanding of unfamiliar concepts.

This perspective aligns with the recommendation made by researchers in designing for FXI. Providing clear, visual messaging tailored to the specific step in a task sequence aimed at reassuring and encouraging users to progress to the subsequent stages confidently is widely recognised (Guimarães et al., 2022; Qureshi, 2016)).

The recommendation on contextually sensitive analogies is particularly relevant for all users, as research indicates a tendency to fail in retrieving potentially useful analogies. The best predictors to trigger memory access are surface similar stories (e.g., using similar objects and characteristics) rather than structurally similar (analogous, with similar higher-order causal structure) (Bechtel and Graham, 1999). FXI demonstrated difficulty in recognising metaphors like the shopping cart due to a lack of surface similarities with their immediate context. Notably, introducing the Nigerian version of a cart in physical stores improved the retrieval of this analogy within the custom UI, underscoring the crucial role of surface-similar objects in aiding memory retrieval (see Figure 42 for a comparison of the shopping cart icons). As such, UIs should consider the surface-similar objects to trigger memory retrieval of useful analogies.

- Implication 7: Incorporating surface-similar objects in icon representation to retrieve underlying analogies and metaphors.

This finding that visual cues that link to users' experiences are relatively better for users with limited literacy aligns with previous research (Teran et al., 2024). Specifically, West and Lehrer (2013) highlight individuals' challenges, especially FXI, when visual details fail to match their immediate context. West and Lehrer note how LITs rely on learned abstractions for communication, enabling them to understand symbols, icons and other abstractions that might not be self-explanatory but are comprehensible due to their education. The authors note that FXI might be confused if visual cues do not match their immediate context.

Similarly in a study with FXI in Brazil, participants experienced difficulties with abstract static signs. Adaptations in the second case study to reflect real-world characteristics facilitated FXI's understanding. However, signs related to educational contexts remained challenging to understand (Teran et al., 2024). This was further emphasised by a study on traditional visual communication practices in rural Bangladesh, where practitioners intentionally used concrete representations drawn from users' social and religious experiences instead of abstract forms (Sultana et al., 2021).

Building upon prior research, while previous research highlighted the significance of abstractions in understanding non-self-explanatory symbols, my discussion offers another perspective that explores analogies and metaphors. Moreover, my discussion recognises the discourse in cognitive research, suggesting that failure to retrieve certain analogies might extend to all users, not only FXI.

Additionally, relational reminding increases when the same relational terminology is used in the memory item and the probe item, suggesting that uniform encoding of the item is important in supporting the recognition of analogies (Bechtel and Graham, 1999). This emphasises the importance of using contextually relevant terminology while leveraging cognitive bias models such as *Maslow's hammer* and *availability bias*, both involving an over-reliance on a familiar tool (Weinberg and McCann, 2019). Abraham Maslow aptly noted in 1966, "If the only tool you have is a hammer, it is tempting to treat everything as if it were a nail." These cognitive biases explain the reason why, when tasked with applying filters to search results in the initial mobile shopping UI, FXI used their familiar knowledge to conduct searches on search engines like Google by including the product name and their desired filters within the search field (see Figure 30). Interestingly, even when the filters were brought into the same search dialogue as the case of the custom shopping UI (see Figure 34b), many FXI still utilised this same technique of using the search engine mental model. This shows how powerful such cognitive bias models can be in shaping our thinking and actions.

As such, leveraging these cognitive bias models in using contextually relevant terminology in the custom UI can be effective because users could relate to those terminologies due to their over-reliance on familiar knowledge (refer to the discussion on replacing money transfer and checkout terminologies in 6.1.3 and 8.1.3 respectively). This is evidenced by FXI users performing better in a custom UI with terminology relevant to day-to-day interaction in such contexts. Therefore, the exact relational terminology in UI content design should be used to trigger relational reminding of the analogies. It is important to note that this might be contextually different, as the terminology used in one region might be less common in another region because there are many synonyms for common words in language.

- Implication 8: using exact relational terminology in UI content design to trigger relational reminding of the analogies.

However, the use of mental links and relational terminology might not always convey analogies to users who are completely unaware of an analogy that is very abstract. One of the difficulties across both UIs (initial and custom) was the user's lack of familiarity with the possibility of applying search filters in the shopping application. To illustrate this idea to users in the custom UI, I incorporated the search filters at the stage where users input the search term, assuming that if it is in this screen, then the users must see it because their mental model indicated that setting the filters is done within the same stage as inputting the search term. As such, the design rationale was that if the filter options are provided as optional options within the search dialogue, then this will create a mental link for them. However, this design choice failed to trigger that analogy. This suggests that those design recommendations might only apply in cases where users have a practical and less abstract idea of the underlying concept to be conveyed.

The challenge faced by FXI in comprehending the analogy related to filtering might stem from varying approaches to categorisation and ordering, specifically as applied within FXI or Nigerian user contexts. This observation aligns with existing research on cognitive differences in categorisation based on societal structures and cultural contexts (see the subsection on 'display of information' in section 3.1.4.2 for a fuller discussion). For instance, studies indicate that Westerners typically progress from childhood categorisation by colour to adult categorisation by shape and function, whereas African adults often continue to prioritise categorisation by colour (Bechtel and Graham, 1999). Similarly, individualistic societies, like many Western cultures, emphasise taxonomic classifications, while collectivist societies, such as East Asian cultures, favour relational groupings (Ji et al., 2004). Furthermore, the linguistic structure of a culture shapes perception and categorisation, with Western languages emphasising nouns and objects, contrasting with East Asian languages that focus on verbs and relationships (Reinecke and Gajos, 2011).

Similarly, a study that explored the mental models of FXI and illiterate Nigerian women to design a mobile maternal care application found that these users tended to arrange clustered categories in chronological order, regardless of the application's physical layout (e.g., top-to-bottom or left-to-right). This contrasts with Western users, who often prefer information to be organised topically (Asipade et al., 2021).

Although some of these studies primarily focus on Western and East Asian cultures, they suggest that categorisation might be influenced not just by literacy but also by broader socio-cultural factors. This indicates a promising direction for future research exploration. These findings emphasise the need for a deeper investigation into categorisation and ordering patterns specific to Nigerian FXI. Another potential factor contributing to the challenges observed in filtering within the shopping custom UI might relate to issues with visual attention (refer to section 2.1.2.3 Visual Attention). This raises the critical question: How can we effectively communicate and convey new analogies to FXI users to improve their interaction with UIs?

Researchers have endeavoured to pinpoint the most effective method of illustrating an idea for those with limited literacy (Saleh and Sturm, 2018; West and Lehrer, 2013; Brown et al., 2011; Lobo et al., 2010). An example of this is a study aiming to assess how different presentations of a concept were comprehended. Each participant was provided with a randomly selected representation showcasing health symptoms (Medhi et al., 2008). These representations encompass text, static drawings, photographs, videos, and animations. The findings indicated that static drawings were better comprehended than lifelike photographs. However, the authors noted a potential for misunderstanding when representing actions through static drawings. For instance, in their job-seeking mobile application, users misunderstood the representation of an icon depicting the action of cleaning dishes as a kitchen (Medhi et al., 2008). Another example is the research by Coetzer (2019), where the HCI principles of affective design and anthropomorphism were explored as design solutions for FXI users in a mHealth application design.

Building on the observation of how FXI users naturally combine product and filter information in search queries (like Google's search), future work could explore a system that adapts to these persistent mental models rather than trying to change them. For example, Chahal and Gopalan (2022) demonstrated an approach for FXI users where their system parsed natural search inputs to extract key information while inferring unspecified values automatically. A similar approach could be applied to filtering interfaces, where instead of requiring users to learn new filter concepts, the system could intelligently parse combined product and filter information (like price ranges) from search inputs - a pattern that aligns with FXI users' observed tendency to enter all information into search fields based on their familiar Google search mental model.

Notably, another interesting observation from the filtering task is the difference in the reasoning/behaviours of FXI vs LIT users. A closer examination of the filter dialogue showed that the text/character input field for setting the price range filter did not update properly, causing problems for all users, including the LIT participants. Interestingly, most FXI users who encountered this issue persisted in their attempts to input data, repeatedly trying the same approach despite its lack of success. They continued to believe they were at fault rather than considering the possibility of a system error. In contrast, LIT participants, after a few attempts, recognised the input field's fault and explored alternative explanations or solutions. While Norman (1983) and Moray (1987) described the tendency for users to persist with ineffective mental models - 'cognitive lock-up' as a general phenomenon, our observations suggest that this behaviour may be more pronounced in FXI users than LIT users. This difference extends the general concept of 'cognitive lock-up' by indicating that it might vary in intensity or frequency across varying literacy levels in users.

Other instances from this research supporting this view include:

- When tasked with finding bank details, FXI users consistently resorted to scrolling through long lists rather than utilising the available search function (discussed in Section 6.1.2).
- Some FXI users' difficulties in understanding and applying the concept of filtering, even after receiving explanations (discussed in section 7.1.2).
- Some FXI users typically attribute the issue of search filters not working when inputted into the search input field as network problems rather than considering other possibilities (noted in the observation notes in Appendices K and O).

These observations collectively suggest that FXI users may experience a more intense form of cognitive lock-up compared to users with higher literacy levels. They demonstrate a stronger tendency to adhere to familiar but potentially inefficient strategies, resist the incorporation of new concepts or functionalities into their existing mental models, and attribute unexpected behaviours to familiar issues rather than exploring new possibilities. This potentially increased cognitive lock-up presents a challenge in UI design, especially when introducing new concepts or analogies to FXI users.

The continued challenge of conveying new analogies to FXI leaves a significant issue unresolved: how to effectively communicate analogies, such as filtering concepts, to FXI users. While strategies like incorporating mental links and relational terminology have proven effective in specific cases, they might not adequately convey highly abstract analogies.

Difficulties persist in conveying entirely abstract concepts, evident in users' unfamiliarity with applying search/filters. Bridging this gap in conveying abstract concepts to users unfamiliar with them urges the exploration of novel solutions in future work.

9.1.3 Visual Processing and Perception

Research has underscored the profound impact of literacy on visual information processing, highlighting how literacy enhances the rapid identification of similar items, visual integration capabilities, the ability to discern details in visual stimuli, influencing not only reading but also cognitive processes related to visual integration and spatial understanding (Huettig and Mishra, 2014; Dehaene et al., 2015; Szwed et al., 2012; Van Linden and Cremers, 2008), (see section 2.1.2.1 for more on this discussion).

Through our observations, it became evident that FXI users tend to focus their visual processing predominantly at the screen's centre, leading to a significant oversight of features presented elsewhere. For instance, FXI users exhibited difficulties in recognising icons like filters, sorting options, and the cart in the initial shopping UI (see Figure 29a and b). Similarly, they did not use the search function at the top of the screen to locate destination bank names in the initial banking UI but rather scrolled through the long list of bank names (see Figure 18d). Interestingly, this was also noticed in the custom mobile banking UI, where FXI did not see the option to enter new payee details because it was the first option but rather focused on the middle portions where there were lists of past payees (Figure 23c). This aligns with Dehaene's assertion that individuals with limited reading skills tend to adopt a holistic rather than an analytical approach when looking at visual stimuli (Dehaene et al., 2015).

The dichotomy between analytical and holistic thinking styles guides individuals' navigation of UIs. Analytical thinkers, prevalent in Western cultures, tend to navigate UIs by sequentially traversing sections, whereas holistic thinkers, more common in Eastern cultures, adopt a circular scanning approach (Dong and Lee, 2008). This perspective relates analytic vs holistic approaches to linguistic organisation, highlighting a complex dynamic between literacy and culture in varied cognitive styles that shape visual processing.

Additionally, the view that literacy influences visual integration capabilities resonates with the challenges faced by FXI in interacting with form design patterns in the initial UIs. FXI had issues with the overall structure of complex forms, following a sequence, and spatial organisation of form fields. This is similar to the observations in prior research on the different visual search strategies between FXI and LIT users, where the former often adopt a one-step-at-a-time strategy while the latter employ an integrated approach (Olivers et al., 2014). This distinction underscores the challenges faced by FXI users in navigating interfaces with multiple elements evident in the form patterns in the initial banking UI (Figure 18b). This led to the redesign choice that considered involved using individual screens targeting each input requirement, influenced by the mental model of Hick's law (see Figure 23).

Hick's law focuses on limiting choices and reducing decision time (Weinberg and McCann, 2019). Applying this model to the UX design for FXI aligns with the idea of reducing choices to combat analysis paralysis. In a form pattern, users may encounter numerous fields simultaneously, leading to cognitive overload and extended decision times. Hick's law allowed us to provide users with a multi-step decision with fewer choices at each step. This design choice significantly improved FXI's performance in the custom UI, as evidenced by the user's performance in money transfers on the custom banking UI.

Consequently, designers should use individual screens, each targeting one input requirement, rather than form patterns to address FXI's preference in attending to each aspect individually. This streamlines decision-making by presenting fewer choices at each step.

- Implication 9: replacing form patterns with individual screens targeting each input requirement.

The transition to individual screens aligns with prior suggestions advocating for input limitations per screen (Melo et al., 2024b; Shah and Sengupta, 2018; Qureshi, 2016). Notably, this design choice adds more steps and might have different implications for users with different characteristics. Researchers have suggested smaller path lengths of 5 units in depth and 5 to 10 units in length for FXI (Islam et al., 2023; Chaudry et al., 2012), while paths longer than five steps were argued to complicate tasks inherently (Kodagoda et al., 2009). Our observations revealed that an increased number of steps did not obstruct FXI's performance but affected LIT individuals' performance time.

This finding underlines a critical aspect: optimising usability for specific user groups requires a balance between task complexity and user comprehension rather than solely aiming for shorter sequences. It introduces an inherent trade-off in design across multiple dimensions when catering to all users. While certain enhancements, like language simplification on the interface, benefit all users, others, like the introduction of additional screens, might not. Considering the diverse literacy levels among users, achieving an optimal UX necessitates balancing all users' needs.

Building on the challenges encountered in navigating complex form structures among FXI users, another significant observation relates to the distinction between required and optional input fields. The difficulty in differentiating between these field types often induced risk-averse responses, prompting users to abandon task assignments.

Polarity, derived from physics, embodies a concept with only two possible values (Weinberg and McCann, 2019). Utilising this concept in framing input requirements presents a distinct advantage by offering users two explicit options or states. Instead of designating an input field as optional or required, a simplified approach could involve posing a straightforward question such as 'Do you have a discount code?' with clear responses of 'Yes' or 'No'.

By presenting inputs as binary choices, users can navigate the UI regardless of their full comprehension of the meaning behind the input field. For example, FXI users unfamiliar with the term' discount code' were still able to proceed by selecting 'No,' effectively bypassing the input field and advancing to the subsequent steps in the custom shopping UI (compare formerly 'voucher' code field in Figure 38e vs now 'discount' field in Figure 41g). Consequently, implementing a polarity-based design for input fields simplifies decision-making and breaks through potential barriers created by users' uncertainties about input field meanings, which is important.

- Implication 10: implementing a polarity approach in design for input requirements.

Furthermore, the deliberate use of black-and-white design elements at the top of the shopping UI might have inadvertently contributed to FXI users overlooking crucial functions placed in those areas (see Figure 29a and b). This design choice may have inadvertently coincided with FXI users' tendency to concentrate their attention on the middle portion of screens, leading them to miss vital functions located at the edges. Similar behaviour has been noted in previous research among FXI users interacting with smartphones (Islam et al., 2016).

As discussed in the literature, literacy influences object processing, including the recognition of 2D visual elements and colour differentiation, particularly in recognising black and white objects (refer to section 2.1.2.1 for more discussion in the literature). This aspect is crucial in understanding the challenges faced by FXI users in recognising the 2D black and white design of the cart icon in the mobile application. This observation is similar to findings in Guimarães et al. (2022**).** Designers should thus take into account these challenges arising from users' visual focal points, considering the potential advantages that coloured 3D items could offer to improve visibility and usability within the interface.

- Implication 11: incorporating 3D-coloured icons to enhance visual processing during mobile interactions.

9.1.4 Visual Attention

An individual's interpretation of visual information substantially shapes their attentional focus when engaging with a UI. In our findings, FXI users encountered difficulty attending to the sequence of tasks when transferring money between accounts (Figure 18b), resulting in unmet expectations and erroneous actions. Conversely, LIT individuals proficiently handle form-based tasks, comprehensively evaluating and organising information across relevant fields. This aligns with prior discussions in the literature, where studies illustrate how literacy influences users' processing of visual information, particularly in discerning target objects amidst competing visual data (Van Linden and Cremers, 2008; Olivers et al., 2014).

Furthermore, FXI encounter challenges in managing abundant screen information due to slower visual search strategies and a preference for reading over scanning (Srivastava et al., 2021; Colter and Summers, 2014). This behaviour complicates attending to relevant aspects amidst screen clutter, as observed in FXI's interaction with screens containing substantial information in the initial UIs. Additionally, this behaviour might have contributed to the longer interaction times we observed with the UIs compared to LIT users across most of the skills we tested. This observation aligns with findings that FXI took more than twice as long as LIT users in task completion rates for similar tasks (Guimarães et al., 2023). These findings emphasise the necessity for streamlined UI content to reduce cognitive effort, ease visual search, and capture user attention effectively on UIs.

- Implication 12: streamlining UI information and eliminating redundant elements improves user interaction.

This implication aligns with previous research emphasising the adverse impact of unnecessary visual elements (Ahmed et al., 2015). Prior research has consistently advocated for a minimalist, uncluttered interface design that optimises whitespace, thereby mitigating interface complexity and feature overload (Anam and Abid, 2020; Saleh and Sturm, 2018; Idrees et al., 2017).

While striving for a minimalist and clutter-free interface remains an essential goal, we must acknowledge instances where incorporating abundant information on the UI becomes inevitable. In such scenarios, adopting a deterrent mental model becomes crucial. The deterrent model aims to dissuade or prevent certain actions or behaviours by imposing barriers, thereby discouraging individuals from engaging in unfavourable activities (Weinberg and McCann, 2019). When applied to UI design, this model becomes a guiding principle, structuring UI elements to facilitate clearer navigation, minimise errors, and uphold user focus on essential tasks within the interface.

In the context of designing interfaces for FXI users, the deterrent model addresses the challenge of presenting abundant information by strategically refraining from certain actions. This refraining process can effectively streamline information organisation, mitigate visual overload, and ensure sustained visibility of pivotal elements, such as aspects tied to users' objectives, e.g., selecting 'save' buttons.

For instance, in our observations with FXI, instances arose where users needed a button to progress within the UI yet faced issues due to button invisibility caused by the need to scroll (Figure 29c). These challenges stemmed from the presence of abundant information on the screen, making it imperative to scroll to access crucial elements like progress buttons.

Similar challenges with scroll patterns have been reported in previous studies (Rayed et al., 2023; Anam and Abid, 2020; Hill and Simha, 2016; Medhi et al., 2011). Consequently, HCI recommendations regarding scroll patterns for FXI have been proposed. However, these recommendations differ, with some researchers suggesting avoiding scrolling altogether (Agrawal et al., 2013; Medhi et al., 2011), while others suggest that while less intuitive, it can be learned and utilised effectively by such users (Hill and Simha, 2016; Chaudry et al., 2012).

In response to these challenges, the custom UI underwent a redesign of its scroll patterns, incorporating visual cues and control mechanisms that confined screen sections within control panes (see Figure 34b). This adjustment limited the impact of scrolling to specific panes rather than affecting the entire page. Furthermore, these control patterns were instrumental in redesigning buttons as fixed menus, ensuring their visibility despite abundant on-screen information or scrolling actions (e.g., Figure 34b). Notably, these changes significantly improved FXI users' interaction with the custom UI, challenging the assumption that scrolling inherently confounds them. Based on these positive outcomes, we advocate for the integration of embedded visual cues (similar to Rayed et al., 2023) and control panes within scroll patterns to guide users effectively.

- Implication 13: Incorporating content control UI patterns such as content panes and fixed menus to guide users.

Further observations with FXI showed that they often encountered challenges in visually locating buttons, especially in distinguishing between actionable elements and plain text within the UI. These issues are crucial concerning visual attention. For instance, users faced difficulties in selecting the debit account in the initial banking UI, where the visibility of buttons did not distinctly signify their interactive nature amidst the text on the screen (refer to Figure 18c). To mitigate this, the custom UI incorporated unfilled radio UI elements within buttons, with the aim of providing a visual cue to prompt user selection (e.g., Figure 25). This approach aligns with prior research emphasising the importance of larger interactive elements, like radio buttons, to enhance user interaction (Chaudry et al., 2012). Additionally, studies advocate for detailed illustrations, particularly for buttons, aiding users in easily discerning and interacting with actionable elements (Anam and Abid, 2020; Qureshi, 2016). These challenges in differentiating interactive components significantly relate to the broader theme of visual attention, underscoring the pivotal role of clear visual cues in user interface design.

- Implication 14: designing radio elements within button UI patterns to clearly signal the need for user input.

Furthermore, the effectiveness of employing the deterrent model within UI design is exemplified by specific changes made within the checkout process in the shopping UI. Initially, the shopping UI included lateral access tabs meant to indicate various stages within the checkout (see Figure 38d, e and f). However, FXI users misunderstood these tabs as cues for navigating to subsequent screens, consequently missing vital buttons positioned below. To address this misinterpretation, the custom shopping UI removed the lateral tabs entirely and retained only the navigation buttons. This deliberate adjustment significantly reduced potential misinterpretations of UI patterns and aimed to guide users more effectively through the checkout process by associating clear actions with distinct UI patterns.

- Implication 15: narrowing the potential interpretations of UI patterns to aid users in associating each pattern with a single action and minimising confusion.

This implication aligns with prior research emphasising minimalist UI strategies to mitigate confusion among users with limited literacy (Guimarães et al. (2022). Notably, our study diverged from previous findings where FXI users encountered difficulties in discovering and comprehending tabbed menus (Qureshi, 2016). In contrast, our FXI participants easily discovered the tabbed menu patterns, although their intended function as progress indicators was misunderstood on the UI.

Moreover, FXI users frequently faced challenges in navigating the interface, leading to persistent confusion regarding their position within the UI. This navigational complexity significantly influenced their visual attention, often resulting in distraction and hindering their ability to maintain focus. Notably, interactions that required transitioning between screens to input data on forms and then returning to the initial screen exacerbated these challenges, adversely affecting users' visual attention and complicating their overall interaction experience. For further reference, see the discussion in section 6.1.1 in reference to Figure 18c and d.

These findings underscore the vital relationship between navigation difficulties and their profound impact on visual attention within the interface. Numerous studies have emphasised the importance of simple navigation structures. For instance, researchers have suggested that listing items on a single page, rather than using multi-level hierarchies, simplifies interactions and aids in maintaining user focus (Melo et al., 2024b; Ahmad et al., 2017; Kodagoda et al., 2010). Further evidence supports the preference for simplified and linear navigation structures to reduce complexity (Islam et al., 2023; Medhi et al., 2011). Additionally, the concept of hybrid navigation, combining elements of linear and hierarchical structures, has been proposed to offer navigational flexibility without compromising usability (Chaudry et al., 2012).

However, some prior studies expressed dissatisfaction with the implementation of hierarchical menus in UIs for FXI (Chen et al., 2016; Medhi et al., 2011). Specifically, Chen et al., advocated against hierarchical menus, a prevalent feature in USSD systems, in favour of advocating for "shallow" or direct navigation methods (Chen et al., 2016). Notably, more recent research suggests these concerns may need re-examination. FXI users achieved high success rates (98.6%) in navigating both hierarchical and list menus, though participants received 20-30 minutes of training before testing (Padhi et al., 2018).

The design of the custom UI took a different approach, drawing insights from the USSD system but yielding different outcomes. While initial difficulties were observed in the initial UI with hierarchical structures, the custom UI retained this structure with modifications. We introduced a forward-pass navigation style, guiding users through a predefined sequence of steps, minimising backward movement within the immediate sequence. Back buttons were included, allowing users to backtrack at their discretion and avoiding redirection to previous screens initiated by the UI. We avoided multi-level hierarchies, opting to list items on a single page to enhance user interaction, aligning with suggestions from prior work (Melo et al., 2024b; Lalji and Good, 2008). One instance where this solution was implemented in the custom UI in the banking UI was when we replaced the subsequent screen for selecting or searching for the destination account with an on-screen option designed as a fixed drop-down menu within a content pane. This adjustment ensured a forward-only flow in user interactions (see Figure 23).

Contrary to recommendations by Chen et al. (2016), our findings did not support the inefficiency of hierarchical menus in the custom UI designed for FXI users but rather aligned with Padhi et al.'s (2018) findings. Despite not having the advantage of prior training like in the latter study, the deliberate use of hierarchical structures in our custom UI significantly improved user performance. This approach streamlined the navigation process, reducing the risk of user confusion and instances of users getting lost within the interface.

- Implication 16: emphasising forward-pass navigation in hierarchical navigation while creatively presenting information within a single screen can enhance user interactions.
- Implication 17: utilising control patterns such as drop-down UI elements to reinforce forward-pass navigation within hierarchical structures.

Further evidence highlighting the challenge of maintaining users' attention arises from the consequences associated with utilising pop-up notifications for error messages, which significantly influenced users' grasp of their position within the UI. To address this issue, the custom UI eliminated pop-up notifications entirely, replacing them with on-screen messages (compare Figure 19 in initial vs Figure 24 in custom banking UIs). This strategic adjustment aimed to maintain a seamless flow within the interface, eliminating disruptions caused by pop-ups and aligning with the deterrent model to ensure a more straightforward interaction. Notably, this redesign extends prior practices that often rely on separate error screens.

- Implication 18: integrating on-screen options for user feedback within a control pane instead of employing disruptive pop-up error notifications.

Building upon this redesign strategy, the focus shifted to another critical aspect of interface interaction: effectively communicating feedback to users, a challenge observed in the initial UI. This difficulty in providing clear feedback, compounded by issues related to language complexity (as discussed in section 9.1.1), underscored the need for further enhancements in guiding users through the interface. Users encountered obstacles in discerning where to input changes, shedding light on a crucial visual attention issue. Addressing these challenges necessitated a visual feedback approach guided by the containment mental model.

The containment principle within UI design acknowledges potential issues and endeavours to prevent their escalation, much like 'stopping the bleeding' (Weinberg and McCann, 2019). The UI redesign primarily focused on limiting undesired actions by intercepting inaccurate inputs and redirecting visual attention. This involved using matching colour hues as visual cues to redirect attention and highlight error messages within the affected field (see Figure 24). Such an approach is consistent with established research highlighting colour's efficacy in emphasising and encoding information (Anam and Abid, 2020; Tiwari and Sorathia, 2014), underscoring its pivotal role in guiding attention and spotlighting critical information within the custom UI.

- Implication 19: using matching colour hues as visual cues to indicate error messages precisely where they occur.

The integration of the containment principle signifies an extension in UI design strategies. By delivering real-time visual feedback precisely where an error occurs, this method contributes to conventional colour highlighting practices. The provision of clear, jargon-free error resolutions holds immense potential to alleviate user frustration and bolster their confidence in using applications Srivastava et al., 2021).

The above discussion highlighted several design implications following empirical findings from this research and considerations with literature. These design implications have been pulled together as follows.

Table 21: Mobile UI Design Implications for Nigerian FXI Users

Theme	**Design Implications**
Language	• Implication 1: Using plain language in designing inclusive technologies. • Implication 2: Ensuring consistency in UI content with locally recognised terms in the context of use. • Implication 3: Incorporating conversational interaction styles in the UI design to facilitate improved user understanding and interaction for FXI.

Theme	Design Implications
Reasoning and Problem Solving	• Implication 4: Ensuring that analogies used in UI design are contextually sensitive and relevant, considering the specific cultural and behavioural patterns of FXI users. • Implication 5: Incorporating first principles thinking in UI redesign by breaking down complex processes into fundamental, easily understood elements. • Implication 6: Incorporating mental links in UI design to aid understanding of unfamiliar concepts. • Implication 7: Incorporating surface similar objects in icon representation to retrieve underlying analogies and metaphors. • Implication 8: Using exact relational terminology in UI content design to trigger relational reminding of the analogies.
Visual Processing and Perception	• Implication 9: Replacing form patterns with individual screens targeting each input requirement. • Implication 10: Implementing a polarity approach in design for input requirements. • Implication 11: Incorporating 3D-coloured icons to enhance visual processing during mobile interactions.
Visual Attention	• Implication 12: Streamlining UI information and eliminating redundant elements. • Implication 13: Incorporating content control UI patterns such as content panes and fixed menus to guide users. • Implication 14: Designing radio elements within button UI patterns to clearly signal the need for user input. • Implication 15: Narrowing the potential interpretations of UI patterns to aid users in associating each pattern with a single action and minimising confusion. • Implication 16: Emphasising forward-pass navigation in hierarchical navigation while creatively presenting information within a single screen. • Implication 17: Utilising control patterns such as drop-down UI elements to reinforce forward-pass navigation within hierarchical structures. • Implication 18: Integrating on-screen options for user feedback within a control pane instead of employing disruptive pop-up error notifications. • Implication 19: Using matching colour hues as visual cues to indicate error messages precisely where they occur.

9.1.5 Discussion Summary

The previous discussion provided insights into the findings of this research in terms of linking FXI users' challenges in the UIs tested with aspects of functional illiteracy that contributed to those challenges. This subsection now summarises this discussion by directly addressing the research questions posed in this thesis. To address both research questions and present a coherent summary, I will structure the findings using the following guiding lens:

UI pattern **A** is ineffective due to reason ***x*** (related to Research Question 1). Conversely, UI pattern/design consideration **B** is effective because it resolves reason **x** through reason **y** (related to Research Question 2).

Following this lens, the findings are presented in the tables below.

Table 22: Input/Output - Text/Char Input

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
(i) Language	(i)			
	Technical language: typically developed through formal schooling	Plain language	FXI are skilled in basic, everyday language	(Chaudhry et al., 2021)Click or tap here to enter text. Figure 23
	Use of abbreviations: this skill is typically developed through formal schooling	Full meaning in addition to abbreviation	Providing both abbreviation and full meanings ensures that terms are easily findable	
	Instructive interaction style: formal nature of this style may not communicate the need for input	Conversational interaction style	Informal approach that resembles day-to-day interaction and allows for question-based input requirements.	Figure 41
	Unfamiliar terminology not contextually relevant, e.g., ‘cart’ and ‘checkout’.	Use exact relational reminding, consistent with local context	- Implementing Maslow’s hammer and availability bias mental models. - Exact relational terminology triggers relational reminding	Figure 41
(ii) Input method indicator				
	- Challenges in recognising required input fields - FXI exhibit risk-averse behaviour tending not to	Utilise yes/no button pattern	Implementing a polarity-based mental model	Figure 41g

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
	explore functionalities independently			

Table 23: Widgets - Drilldown

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
(i) Icon				
	Mismatched analogies that are not context specific, failing to consider the specific cultural and behavioural patterns of FXI	Utilise additional screen(s) with directional visual cues	- Creation of mental links to facilitate understanding of unfamiliar concepts. - Implementing the first principles mental model to identify gaps in task sequence (user mental model vs conceptual model)	Figure 41b
	Lack of surface similarity in analogy represented, stemming from limited exposure to Western concepts or abstraction skills	Implement contextually relevant graphics	Using surface-similar objects aid in memory retrieval of metaphorical representations	(Cheema et al., 2022) Figure 42
	Limited processing of black and white, 2D graphics compared to coloured 3D	Use 3D coloured graphics	3D graphics are more recognisable and require less abstraction skills, while colours improve visibility.	(Guimarães et al., 2022), (Castro-Caldas, 2005) (Reis et al., 2006) Figure 42
(ii) Button				
	- FXI unable to progress when buttons are hidden at the bottom of pages, often influenced by unfamiliarity	Implement buttons as a fixed menu	- A constant button locked in position ensures visibility at all times.	Figure 34b

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
	with UI interaction elements (e.g., the need to scroll). - Visual search for target objects like buttons amidst competing visual data can also be slow and challenging for them		- Constant button display creates a mental link to suggest the next required input	
	Actionable elements are indistinguishable from plain text causing difficulty in identifying interactive elements	Radio button	Affordance: the unfilled radio button provides a visual cue indicating a need for selection	(Chaudry et al., 2012)
(iii) Multiple widgets				
	FXI encounter a less integrated approach when managing multiple aspects simultaneously	Eliminate redundant widgets	Reduced complexity (cognitive load) and increased user focus	(Saleh and Sturm, 2018) (Melo et al., 2024b)
	Tendency to engage with the first visible option without considering alternatives for their intended task	- Match each action with only one corresponding widget - Ensure each widget cannot be mistakenly interpreted to perform more than one action	- Establishes clear link between user expectations and possible UI actions. - Minimises the risk of errors	

Table 24: Widgets - Information Control

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
(i) Sort and Filter				

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
	FXI's approach to categorisation and ordering may differ due to varying skills influenced by culture, societal structure and linguistic organisation.	Task sequencing based on FXI's mental model failed to establish a clear indication of the availability and use of the sort and filter pattern.		(Reinecke and Gajos, 2011) (Bechtel and Graham, 1999).
	FXI users lacked experience with the concept of sorting and filtering, as it is not part of their mental models. This is evident in their compensatory behaviour, such as using the search engine experience to input sorting/filtering criteria into the search function.	Introducing entirely new abstract analogies to FXI users remains a challenge in this research and prior HCI4D work.		
(ii) Search Within	FXI are disoriented when they are returned to a previous screen after selecting an item in returned lists	Implement a drop-down pattern.	Reduces cognitive load, maintains task goal and clarifies user position within the screen	Figure 23d

Table 25: Input/Output – Input Selection

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
(i) Form				
	- Limited experience with the spatial organisation of forms.	Implement individual screens per input requirement	- Hick's law limits choices and reduces decision time	(Olivers et al., 2014) Van (Linden and Cremers, 2008)

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
	- Challenges in maintaining sustained attention with multiple form fields - Holistic viewing approach to visual stimuli: focus on middle of screen - Difficulty recognising input areas when errors arise in form submission.	following the mental model of Hick's law and containment.	- Redirects visual attention - Supports sustained attention by reducing cognitive load through task segmentation - Implementing one input per screen helps intercept inaccurate inputs by limiting confusion about which specific form field requires fixing, following the containment mental model.	Figure 23

Table 26: Components – Display of Information

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
(i) General information presentation				
	Slower visual search strategy, relying on reading instead of scanning	Streamlining UI content	Enhances interaction efficiency by reducing cognitive demand for visual attention and competing stimuli	
(ii) Lists				
Hierarchical model	- Confusion regarding their current position within the model	Implement a hybrid model that combines a simple hierarchy with a linear model	Provides a clearer structure with linear progression and flexibility to navigate between different categories	(Chen et al., 2016) Figure 23

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
	- Challenges in maintaining sustained attention			
	Disorientation when returned to a previous screen after selecting an item in returned lists.	Implement forward-pass navigation only	Ensuring the UI does not automatically return users to a previous screen enhances orientation, as users retain control with the back key at their discretion.	
	Unfamiliarity with sustaining/retaining visual attention	Avoid multi-level hierarchy	Reduced cognitive burden	(Melo et al., 2024b)

Table 27: Components – Revealing more Information

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
(i) Pop-up				
	- Disrupts sustained attention and hinders linear progression. - Confusion regarding the current position due to a combination of forward and backward navigation	Implement an on-screen indicator	-Maintains uninterrupted engagement and ensures continued focus on the primary content/task - Minimises the cognitive effort required for users to remember their position	Figure 24
	Difficulty recognising input areas for error messages	Implement an input method indicator with matching colours with the on-screen indicator	Redirects visual attention and establishes the relationship between on-screen indicator and input area	Figure 24

Table 28: Page Composition – Scroll

Ineffective Pattern	Reason for Ineffective Pattern	Alt Pattern/ Design Consideration	Reason for Effective Pattern	Reference
1. Scroll				
	- Lack of familiarity with vertical scrolling. - Scroll not discoverable.	- Implement a fixed scroll bar indicator. - Use a contrasting colour for the scroll bar indicator	- Affordance: constant scrollbar locked in position signifies the availability of a function - Colours aid in visibility.	Figure 34b
	Fear of losing position within screen content.	Implement fixed content panes within scrollable screen content	Fixed content panes secure scrolling to ensure scrolling does not affect the entire page, thereby preserving user position within the screen	Figure 34b

10 Conclusions and Future Work

10.1 Contributions

In Nigeria, where approximately one-third of the population is either illiterate or FXI, the increasing reliance on smartphones for daily activities presents significant challenges (The World Bank, 2020). Despite the growing penetration of mobile technology, with 64% of the Nigerian population having access to mobile phones and 61.4% to the Internet primarily through mobile devices (Federal Ministry of Communications and Digital Economy, 2019), a substantial digital divide persists, particularly for FXI users.

This thesis addressed the critical need to understand how FXI user interaction can be improved through thoughtful design. Specifically, it focuses on investigating more inclusive UI design patterns tailored to the unique challenges faced by Nigerian FXI users when using on smartphones, particularly in the context of mobile banking and shopping applications. These applications are crucial for financial inclusion and economic participation, with electronic payment transactions in Nigeria surging to N600 trillion in 2023, a 55% increase from the previous year (NIBBS, 2023). This study was guided by two primary research questions:

1. What UI design patterns cause difficulties for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?
2. What design techniques can improve interaction for FXI Nigerian users while interacting with mobile banking and shopping applications on smartphones?

Previous studies, as highlighted throughout section 3.1.4, have examined challenges faced by FXI users in mobile application usage. However, studies on Nigeria in this regard are especially lacking. Given the lack of Nigeria-specific studies in this area, we conducted a preliminary investigation to determine if these difficulties are present in the Nigerian context before addressing our main research questions. Through a comprehensive evaluation of 17 digital skills across two mobile applications, our research revealed pervasive challenges FXI users face. While time and resource constraints limited an in-depth focus to three specific digital skills (namely, money transfer in mobile banking, applying search filters, and making purchases in mobile shopping), the findings suggest widespread difficulties among FXI users, highlighting the severity of their exclusion from the benefits of the digital world.

Subsequently, to address RQ1, the study conducted an empirical evaluation of common design patterns across two existing mobile applications on the three (3) digital skills, analysing user performance and behaviour. For RQ2, the research developed and tested custom interface versions designed based on the insights from RQ1 and compared the outcomes to those from RQ1. This allowed a direct assessment of which design techniques mitigated previously identified barriers.

The approach taken was underpinned by the mental model of 'framing' to guide understanding of users' interactions, their challenges, and to explore a design shift approach that aligns with FXI users' mental models (see section 1.1.2 for a fuller discussion on framing). This perspective aimed to capitalise on users' existing skills and abilities rather than attributing difficulties to user characteristics, with the overarching goal of simplifying interaction for FXI users.

This work fills a significant gap in the HCI4D field by adopting a mental model approach to understanding UI design patterns and their relevance to FXI users in Nigeria. It aligns with the broader goals of HCI4D to create technologies that serve underrepresented populations in developing contexts, as highlighted in section 1.2.4. This contribution extends beyond identifying challenges to provide a broader view of the underlying reasons for these difficulties and recommendations for these challenges.

The **core contribution of this thesis, therefore, is the provision of a context-sensitive lens on mobile application design for FXI users in Nigeria**, which addresses a significant and previously underexplored gap in HCI and HCI4D research. Table 29 summarises the novel contributions of this research and explicitly links each one to the research question(s) it addresses.

Table 29: Summary of key contributions and alignment to research questions.

Contribution Area	Specific Contribution	RQ	How it Contributes to RQ
Theoretical	Context-specific analysis of FXI users' mental models	RQ1, RQ2	Offers original empirical insights into how Nigerian FXI users conceptualise and engage with mobile UIs, contributing to both identifying root usability problems (RQ1) and informing the development of contextually relevant designs (RQ2).
Theoretical	Reframing "simplicity" in HCI for FXI users	RQ1	Contributes to RQ1 by showing that conventional UI design patterns can fail for FXI users, helping to explain why some patterns can be difficult.
Practical	Empirically derived, FXI-informed design guidelines (Tables 21–28)	RQ2	Direct contribution to RQ2 by translating observed usability issues into design techniques specifically tailored for FXI user needs in mobile banking and shopping contexts.
Practical	Custom prototypes designed specifically for FXI Nigerian users, empirically	RQ2	Demonstrates design techniques that work for 3 key digital skills (money transfers, applying filters, and checking out), filling a gap in design practice and HCI4D literature (RQ2).

	evaluated to reflect their mental models		
Methodological	Novel integration of DLGF into usability evaluation in HCI	RQ1	Contributes to RQ1 by enabling structured analysis of which digital competence areas (e.g., problem-solving or communication/collaboration) posed the most challenges for FXI users. These insights would likely be missed in traditional usability testing.
Methodological	Standardised definition and measurement for FXI using DIBELS8	RQ1, RQ2	Contributes to RQ1 by ensuring accurate participant classification for analysing interaction difficulties. Supports RQ2 by validating that the design techniques were tested on appropriately defined FXI users, enhancing reliability of findings.

The following section now elaborates the key contributions of this research across the three dimensions: theoretical, practical and methodological approach.

10.1.1 Theoretical Contributions

FXI Mental Models: Building on Normans' (1983) conceptualisation of mental models as "what people really have in their heads and guide their use of things", this research contributes insights on how Nigerian FXI users' mental models are heavily influenced by a complex interplay of factors when interacting with mobile interfaces. These include cognitive aspects (e.g., processing abstract 2D and black-and-white icons), cultural relevance (e.g., the contextually relevant analogies and culturally appropriate design elements), language and textual literacy (e.g., issues with complex technical language and too much textual information), experiences that may be formed through literacy training (e.g., recognising the use of abbreviations), and technological familiarity especially in abstract terms (e.g., lack of recognition of common UI conventions of scrolling or button affordances). These are presented in more detail in section 9.

This contribution contributes to the discourse on the structure and content of mental models. It reveals how these structures manifest in FXI users' interactions with mobile interfaces. This extends the applicability of mental models to a previously understudied population and provides evidence on how mental models manifest in a non-Western FXI context. Specifically, the discussion on analogies and metaphors builds on the longstanding interest in how users construct mental models as discussed by Gentner (1983) and Carroll and Mack (1985) - in this case FXI, Nigerian users (see section 3.1.3.1 for theoretical perspectives on mental models). This finding builds on both works by highlighting the importance of cultural context in analogy effectiveness for FXI, specifically in the representation of task sequences, exact relational terminology, and surface similar metaphors (see section 9). The implication for HCI is a more nuanced understanding of how diverse user groups conceptualise and interact with UIs, necessitating a shift from designer-centric assumptions to user-centric realities in UI design.

Challenging HCI Norms: This research challenges traditional HCI assumptions about what constitutes a "simple" or "intuitive" interface, particularly for FXI users. The findings demonstrate that interfaces aligning with FXI users' existing mental models, even if more complex by traditional standards, can be more usable for this group. For instance, in redesigning form patterns following Hick's law, we found that FXI users performed better with a series of individual screens for each input requirement rather than a single, seemingly simpler form with multiple fields. (see section 9.1.3). This research suggests that for FXI users, interface familiarity and alignment with existing mental models may be more important factors in task performance than the apparent complexity of the interface. This insight contributes to our understanding of how mental models influence task performance for this specific user group**.** This suggests that Norman's (1983) emphasis on matching system design to users' mental models applies to FXI users in Nigeria, reframing simplicity in usability research not as minimal design but as alignment with users' mental models and cognitive processes. The implication for HCI is a shift from universal design principles to context-specific, human-centred definitions of usability, emphasising the importance of cognitive and cultural factors in determining what is truly 'simple' or 'intuitive' for diverse user groups.

10.1.2 Practical Contributions

Design Guidelines and Implications: This research provides empirically derived design guidelines and identifies specific links between UI design patterns and FXI user experiences in mobile banking and shopping applications in Nigeria. This expands on Norman's (1986) emphasis on transparent design models by providing specific design implications for creating interfaces that support the formation of effective mental models for FXI users. The developed design guidelines (presented in Table 21) were organised into themes where FXI users differed: language, reasoning and problem-solving, visual attention, and visual perception. Additionally, we identified links between UI design patterns and FXI user difficulties, as well as effective patterns more suited to FXI users (presented in Table 22 to Table 28). This contribution addresses a gap in research by comprehensively linking UI design patterns with factors related to FXI users. While previous researchers (e.g., Teran et al., 2024; Medhi et al., 2009), see section 3.1.4.5) have made significant strides in inclusive design, they have not specifically linked ineffective UI patterns, reasons for difficulties, and effective patterns for FXI users in a holistic manner, as we present in Table 22 to Table 28. It challenges the "plug-and-play" approach in mobile HCI, emphasising the need for context-specific design considerations (Javahery et al., 2011), as discussed in section 3.1.4.6. These insights lay the groundwork for refined hypotheses and controlled studies. This contribution aligns with core HCI4D principles by addressing the critical theme of literacy barriers in technology use, focusing on underserved populations, and advancing HCI4D's goals of creating inclusive technological solutions for developing communities.

The implications of this contribution are: it provides designers and developers with actionable guidelines for creating more accessible mobile applications; offers a framework for evaluating existing UIs; enhances understanding of FXI users' specific needs and challenges; bridges the gap between theoretical understanding and practical application; enables more informed decision-making in UI design; and contributes to the development of more targeted and effective inclusive design strategies in HCI4D.

HCI Design Prototypes: This research produced new artefacts, including conceptual models and custom UI prototypes, for three (3) critical digital skills in mobile banking (see sections 6.1.3 and 6.2.1) and shopping (see sections 7.1.3, 7.2.1, 8.1.3 and 8.2.1), accompanied by empirical usability and UX data from Nigerian FXI and LIT users. Notably, these skills were selected as representative of broader challenges. The significance of this contribution lies in its evidence-based approach to improving mobile applications for FXI users, addressing critical gaps in Nigeria's digital landscape. Despite rapid growth in mobile banking and e-commerce, adoption remains low due to factors including system complexity and limited digital literacy (Daniyan-Bagudu et al., 2017; Omotosho, 2021; Siano et al., 2020). Previous research has focused primarily on adoption factors (Omotosho, 2021), with limited attention to usability and FXI users. The only prior usability experimental study in banking showed existing Nigerian applications were ineffective for FXI users but did not provide artefacts (Adama et al., 2017). In online shopping, while UX is crucial for adoption, many platforms still face design challenges (Esho and Verhoef, 2021; Olagunju et al., 2020). This research directly addresses these gaps by providing tested solutions demonstrating improved usability for FXI users, who are widely neglected (see 1.1.3 for a fuller discussion of these gaps). It offers evidence of effective inclusive design implementation in the Nigerian context, potentially influencing future designs and contributing to greater digital inclusion, which could potentially further boost financial inclusion and economic participation in Nigeria. By translating theoretical guidelines into practical, tested solutions, this work advances the HCI4D field, contributing to creating inclusive digital interfaces for FXI users in developing contexts.

10.1.3 Methodological Approach Contributions

Digital Literacy Global Framework: This research introduced a contribution by integrating the Digital Literacy Global Framework (DLGF) with traditional usability and UX methods to investigate user interaction, specifically for FXI (published in Mohammed et al., 2023). Our literature search confirmed this as a novel approach in HCI and usability studies. This approach contributes to addressing the historical limitations in theoretical focus in HCI4D research noted by Van Biljon and Renaud (2021) and Dell and Kumar (2016). It aligns with Toyama's (2010) emphasis on interdisciplinarity in HCI4D and responds to the growing importance of digital literacy in societal participation (van Deursen and van Dijk, 2014; Helsper and Eynon, 2013); see section 3.1.5.5 for a fuller discussion. The application of the framework can be seen in section 4.1.5.1 while the rationale for the framework in HCI4D is discussed in 3.2.2. For instance, when we applied the DLGF to analyse tasks in mobile banking and shopping applications, we discovered that the Communication and Collaboration digital competence area was the only one where tasks were not difficult for FXI users, likely due to their familiarity with social networking. This insight suggests that leveraging familiar communication patterns in UI design could improve usability for FXI users across other digital competence areas. Without the DLGF framework, this understanding of FXI users' varying competencies across different digital skills might have been overlooked in traditional usability testing. Further details on the results following this application are in section 5.4.3.

The implication of this contribution is that it provides a comprehensive view of inclusive design research, offering structured themes for investigating specific digital competence areas. It enhances understanding of user capacities in HCI4D contexts, enabling more targeted design solutions. Furthermore, it facilitates potential collaboration among policymakers, designers, and researchers, fostering a holistic approach to digital literacy challenges. Importantly, it advances the interdisciplinarity of HCI4D research by combining digital literacy and usability perspectives.

Measuring Functional Illiteracy in HCI4D: This research introduced a standardised method for measuring functional illiteracy (FXI) in HCI4D contexts, a contribution published in (Mohammed et al., 2023). The significance of this contribution is underscored by the lack of clear literacy definitions and measurement techniques in HCI4D (Mohammed et al., 2023; Srivastava et al., 2021). This gap has hindered effective research and design in HCI4D for this user group because it obstructs clear conceptualisation of users' needs and appropriate design solutions, making this contribution relevant, as highlighted in section 2.1. The measurement introduces a standardised measurement approach using the DIBELS8 Maze test that builds on the definition, which improves upon previous approaches by incorporating multiple factors often overlooked or treated separately in earlier studies, including digital skills, language proficiency, reading comprehension, and adult focus. It also addresses the need for a quick, culturally adaptable measurement technique, filling a gap identified in the reviewed literature (see Srivastava et al., 2021; Mohammed et al., 2023 for more details).

This contribution has important implications because it promotes standardised criteria for user needs assessment and solution design in HCI4D, enhancing research replicability by providing a clear measurement technique. Furthermore, it encourages more precise terminology use in HCI4D studies and supports more inclusive technology design by improving understanding of FXI users' characteristics.

10.1.4 Contributions Summary

Through these contributions, we aim to advance the theoretical understanding of inclusive design in HCI by providing new insights into the mental models and challenges of FXI users in developing contexts. The practical contributions offer actionable guidelines for designers to create more accessible and usable interfaces for diverse user groups. Moreover, previous research shows that interfaces designed for less skilled users are more accessible to users who do not have special needs (Schmutz et al., 2017)

The implications of this work extend beyond interface design, potentially influencing policy-making and digital literacy initiatives in Nigeria and similar developing contexts. Specifically, this research aligns with initiatives like Nigeria's National Digital Economy Policy and Strategy (NDEPS), which aims to achieve 95% digital literacy in Nigeria by 2030. However, our work emphasises that improving digital literacy is not just about education but also about creating more inclusive and usable digital interfaces.

These findings not only contribute to bridging the digital divide but also point to promising directions for future work, which are discussed in detail in the following sections of this chapter.

10.2 Limitations and Future Work

10.2.1 Limitations

While this study contributes significantly to the HCI4D field, it also has some limitations that must be acknowledged. It was conducted in a single location in Nigeria, which limits its generalisability to other cultural contexts. Additionally, it involved a relatively small sample size of the comparison group of LIT users. It is essential to clarify that the primary focus of our study was not a direct comparison between FXI and LIT. Instead, our aim in assessing LIT users' performance was to conduct an unbiased usability check, ensuring that the user interface is not unnecessarily complex or problematic for all user groups. While we could have performed a usability walkthrough, we opted to involve other Nigerian users to provide a more comprehensive perspective. However, we recognise that a larger LIT sample could have provided more robust comparative insights.

Time constraints posed another limitation to our study. These restrictions prevented us from conducting longitudinal observations, which could have provided valuable insights into learning patterns and long-term usability. Furthermore, we were unable to introduce a second task test, either after a break or on the following day, which could have evaluated the participants' improvement and minimised the novelty effect and terminology-related biases.

In terms of methodology, while the mixed methods approach provided a comprehensive perspective, we acknowledge that a method involving eye-tracking technology could have provided more objective, quantifiable data, including heatmaps, to help us better visualise the interaction patterns of users, especially in aspects related to visual processing and attention. However, several factors limited its applicability in this research. Eye-tracking technology often requires controlled, laboratory-like settings, conflicting with the aim of studying the users in a less pressured environment. Importantly, at the project's inception, mobile eye-tracking setups had limitations regarding calibration accuracy, which was particularly concerning for our target group. These technical constraints, combined with concerns about participant comfort and natural behaviour, influenced our decision. Eye-tracking setups can feel intrusive, particularly for functionally illiterate users who may already feel self-conscious or anxious in research settings. There was a risk that including such a setup could alter participants' natural behaviour, potentially skewing our results. Additionally, the cost and technical expertise required for implementing eye-tracking were another limitation. As the technology evolves and potentially becomes more accessible, eye-tracking could be included in future investigations.

Additionally, the terminology, definition, and recruitment inconsistencies for FXI challenge meaningful comparisons and understanding of FXI characteristics. This inconsistency raises concerns about research outcomes' consistency and comparability, which I acknowledge as a limitation as it complicates finding relevant work. Nonetheless, the section that addresses this within this thesis has provided a clear discussion and rationale for each of the variables used to assess FXI in this work, making it a novel contribution that is comparable to future work. This consideration, among others, opens several promising research directions emerging from this work, which are further presented as follows.

10.2.2 Future Work

Cognitive Aspects: A critical area for future research is a more detailed study of the cognitive aspects relevant to FXI users. While there are studies on how literacy and formal schooling train cognitive aspects for various tasks, gaps exist in specifically examining how these factors influence the comprehension of UI design elements. Understanding which cognitive skills are necessary for comprehending UI patterns is crucial. This work could build on the findings presented in Table 22 to Table 28, where key areas for future investigation were identified, such as isolating specific factors influencing FXI user interaction and exploring the skills required for understanding UI design patterns.

Another area for potential investigation is adapting search filters to recognise natural language inputs, which could improve usability and user experience for FXI users. For example, recent research demonstrated a system that parses natural language entries and infers missing information for FXI users (Chahal and Gopalan, 2022). Although their paper did not include evaluation results with FXI users, it offers a promising approach to improving search functionality. Future research could explore similar methods, enabling systems to extract product and filter information directly from natural search entries to create a more intuitive experience for FXI users. While the current prototype lacked the complexity required for natural language processing, this remains an area worth exploring to align search features more closely with FXI users' mental models.

Additionally, there is a significant gap in understanding what skills FXI users possess, as they do not lack the intelligence or problem-solving skills necessary to use technology effectively. For example, categorisation is a skill relevant to day-to-day tasks and several aspects of UI design (e.g., forms, navigation, information presentation). Understanding how people categorise things in real life within their context can inform UI design for a more familiar interaction.

Expanding the Scope: A gendered analysis of the results could yield more insights, as men and women tend to process information differently and perceive aesthetics differently. For example, exploring the comparisons in the following groups can show how both literacy status (FXI vs. LIT) and gender (men vs. women) impact the results and would add depth to the analysis.

- FXI vs. LIT women: Compare functionally illiterate women to literate women.
- FXI vs. LIT men: Compare functionally illiterate men to literate men.
- Men vs women: Compare men and women in general, without regard to literacy status.

Additionally, there is potential in exploring how our findings might apply to other contexts beyond Nigeria.

Adaptive Interfaces for Designing UIs: Investigating how adaptive interfaces could leverage our understanding of FXI mental models presents another exciting avenue for future research. Adaptive interfaces adjust themselves based on a user's skills and abilities. By leveraging machine learning algorithms and data analytics, interfaces could recognise and adapt their presentation and functionality to users' existing capabilities and preferred ways of engaging with technology (Khamaj and Ali, 2024).

Adaptive interfaces for FXI users have often focused on interface evolution as a teaching mechanism. For example, EvolveUI is a mobile design that gradually introduces new interface elements, assuming users should progress toward learning increasingly complex functionality (Saif et al., 2024). While recognising the value of educational approaches in many contexts, this perspective on interface design contradicts the *framing* established in section 1.1.2: that FXI users' different ways of thinking and interacting with technology reflect diverse cognitive styles rather than deficits to be corrected. Moreover, as noted in Hasan et al.'s study, many FXI users often have limited interest in learning complex sequences or interacting with sophisticated tools, even if these tools are intended to improve their quality of life or provide significant benefits (Hasan et al., 2021). As such, technology should adapt to users' diverse ways of thinking and interacting rather than expecting users to adapt to interfaces.

Moving away from this teaching-focused paradigm, we propose investigating adaptive interfaces that support users' existing interaction patterns while maintaining crucial interface stability. Research highlights how changing interfaces can frustrate users who rely on consistent, predictable elements (Greenberg and Witten, 1985). This insight suggests that adaptation should enhance and support, rather than modify or replace, users' natural interaction patterns.

A fundamental challenge lies in developing systems that recognise and support users' existing capabilities without disrupting their established patterns. This requires interfaces that adapt to user preferences while respecting all interaction patterns as equally valid rather than viewing some as more "advanced" than others.

Affordances could be crucial in this new approach by informing how interfaces adapt while preserving familiarity. By maintaining visual and functional similarities across different interface configurations, FXI users' existing knowledge remains relevant and valuable. This approach builds upon users' existing mental models instead of attempting to reshape them.

The goal is to respect users' natural ways of interaction while maintaining the consistency and predictability that FXI users need for successful interaction.

Interdisciplinary Collaboration: Given the multidisciplinary nature of this research area, future work would benefit from collaboration between professionals from multiple backgrounds. Bringing together experts in linguistics, cognitive psychology, and HCI is important. Ideally, this collaboration would involve researchers, designers, and policymakers, fostering a comprehensive approach to addressing the challenges and opportunities in designing for FXI users.

By addressing these limitations and pursuing these future research directions, we can continue to advance our understanding of designing inclusive digital interfaces for diverse user groups, particularly FXI users, in developing contexts.

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Appendices

Appendix A: Survey aimed to gather participants' background information

Background Info

Demographic data about participants & smartphone use

1. Name

2. **Gender**

- ○ Man
- ○ Woman

3. **Age group**

- ☐ 19-29
- ☐ 30-39
- ☐ 40-49
- ☐ 50+
- ☐

4. **Why did you come to the adult literacy center?**

- ○ Job purposes
- ○ Self learning needs
- ○ Just a hobby
- ○

5. **Are you currently employed?**

- ○ Yes
- ○ No

6. **If yes, what is your occupation?**

- ◯ Employed for wages
- ◯ Self employed
- ◯ Out of work looking for work
- ◯ Out of work but not looking for work
- ◯ Home maker
- ◯ Student
- ◯ Military
- ◯ Retired
- ◯ Unable to work

7. **What is the highest level of education you have ever successfully completed?**

- ◯ Primary
- ◯ Junior Secondary
- ◯ Senior Secondary
- ◯ Higher National Diploma (HND)
- ◯ Trade/vocational/technical training

8. **When you completed this qualification, how old were you?**

- ☐ Under 19
- ☐ 19-29
- ☐ 30-39
- ☐ 40-49
- ☐ 50+
- ☐

9. **Do you use a smartphone?**

- ◯ Yes
- ◯ No

10. **How long have you been using a smartphone?**

- ◯ Less than 1 year
- ◯ 1 - 3 years
- ◯ 4 - 6 years
- ◯ 7+ years

11. **How much time on average do you spend using a smartphone per day?**

- ◯ 1-2 hours
- ◯ 3-5 hours
- ◯ 6-9 hours
- ◯ 10+ hours

12. **What are the most frequent things you do on your smartphone?**

- ☐ Social networking
- ☐ Watching videos/news
- ☐ Seeking information through the browser
- ☐ Phone calls and messages
- ☐ Studying or learning
- ☐ Shopping
- ☐ Games
- ☐ Banking
- ☐ All the above
- ☐

13. **Do you use mobile banking apps on your smartphone?**

- ◯ Yes
- ◯ No

14. **If yes above, how would you rank your frequency in using mobile banking applications for your financial transactions?**

	Never	Rarely	Sometimes	Often	Always
Frequency	○	○	○	○	○

15. **How do you currently make financial transactions?**

- ☐ ATM
- ☐ Bank
- ☐ Agents (POS)
- ☐ USSD on mobile device
- ☐ Asking family/friends
- ☐ Mobile banking applications
- ☐ Web banking portals
- ☐ Cash
- ☐

16. **Do you use mobile shopping apps on your smartphone?**

- ○ Yes
- ○ No

17. **If yes above, how would you rank your frequency in using online shopping applications on your smartphone?**

	Never	Rarely	Sometimes	Often	Always
Frequency	○	○	○	○	○

18. **Have you ever been unable to achieve a task on a smartphone?**

- ○ Yes
- ○ No

19. **How do you resolve issues you face while using your phone?**

- [ ] Asking family/friends
- [ ] Google search
- [ ] Asking random person around
- [ ] Checking the manual
- [ ] Other...

20. **Have you ever taken lessons (whether formal or informal) on use of smartphones?**

- ○ Yes
- ○ No

Appendix B: Post-study questions

Please let us know how you feel about the app you used today

21. Annoying ------------------------- Enjoyable

1	2	3	4	5	6	7

22. Not understandable------------------ Understandable

1	2	3	4	5	6	7

23. Slow-------------------- Fast

1	2	3	4	5	6	7

24. Does not meet expectations-----Meet expectations

1	2	3	4	5	6	7

25. Boring ----------------------------------Exciting

1	2	3	4	5	6	7

26. Normal ----------------------------------Abnormal

1	2	3	4	5	6	7

27. Unsuccessful --------------------------------Successful

1	2	3	4	5	6	7

28. Thoughts about the design of the application

29. As a student of the literacy centre, do you think there is anything about the design of the application that might be what people need?

30. Any recommendations or suggestions about the design of the application

Appendix C: Alternatives to UX aspects

UX Aspects	**Word Choice for Nigerian Context**
Attractiveness	Enjoyable/annoying
Perspicuity	Understandable/not understandable
Efficiency	Fast/slow
Dependability	Meets expectation/does not meet expectations
Stimulation	Exciting/boring
Novelty	Abnormal/normal**
** The replacement of 'novelty' with 'abnormal' is my own adaptation based on Nigerian parlance, while the other alternatives are drawn from the UEQ-S word bank (Schrepp et al., 2017)	

Appendix D: Call for participation

Would you help a researcher find better ways to design mobile apps?

If your answer to all the questions is YES, please contact the headteacher to register your interest and further information.

1. Are you confident in speaking English language?
2. Is your age above 18 years?
3. Can you explain to someone else what you are thinking while using a phone?
4. Would you need help with using an app on the phone? E.g. WhatsApp?

If you agree, we will pay you a fee for your travel and meal costs during the research.

Appendix E: Participant Information Sheet

Improving Smartphone Interaction in Nigerian Users
Participant Information Sheet

We would like to invite you to take part in a research study which is done by a PhD student at Aston University.

Before you decide if you want to take part in the study, please listen to the following information carefully and ask the researcher if you have any questions before you decide whether you want to do the study or not. If you agree to do the study, we will ask to record you verbally saying that you agree to take part in our study. You will still be able to leave the study at any time you like.

The reason for doing the study is to find out how to design applications (for example, WhatsApp) on mobile phones so that it is easier to understand how to use them for people who find it hard to use.

We are inviting you to take part in this study is because you attend an adult literacy centre and because of this, we assume that you currently have difficulties in your reading skills.

If you agree to take part in this research, we will ask you to do a short reading test and ask you about how you use phones currently. Then, give you a list of things to do on a mobile phone (for example, search WhatsApp for the name of a contact) while you tell us what you are thinking throughout the process. At the end of this, we will ask you more questions about the things you were asked to do. We expect this to take a total of about 30 minutes.

We will ask for your permission to take a video recording of the phone screen and an audio recording of what you tell us. Anything you tell us will be private, including your identity.

We will share the results of the study with your literacy centre if you are interested in finding out what we learned from the study.

If you agree to do the study, we will give you 3000 naira in cash to cover your transport and any meals you may need during the study. We will pay this to you whether you complete the study or not.

Thank you for your time.

Appendix F: DIBELS8 Maze Form

DIBELS 8TH EDITION
UNIVERSITY OF OREGON | College of Education

Benchmark Maze 7.End

Name: ____________________ Date: __________________

Practice Passage

Tom goes to a school far from his house. Every morning, he takes a school (art / bus / work) to go to school. In the (afternoon / library / morning), he also takes a bus home.

STOP

Correct: ____________

Incorrect: ____________

Adjusted Score: ________

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DIBELS 8th Edition
Benchmark Maze 7.End

The Day the Sky Turned Black

My parents told me in July that the solar eclipse that was going to happen in August was a very rare event. A solar eclipse is when the ink/moon/spot appears to completely blot out the dark/night/sun. For this eclipse, in some parts and/of/on the United States the sun would be/tell/want completely covered by the moon, although he/it/now would only be a partial eclipse how/place/where we live. After my parents mentioned him/it/sun, it seemed like everyone was talking about/little/within it and I wanted to know more/over/some, so I did some reading.

I called/read/said that in ancient times people were calmly/near/often terrified of full solar eclipses. Since him/they/what did not understand what was happening all/for/to the sun, people in many cultures created/forced/heard elaborate myths and stories to explain computers/eclipses/rockets. Usually in these myths and stories absent/much/some animal, dragon or demon would try go/to/we eat the sun. People

Keep going ▶

Appendix G: Study Day Orientation Script

Welcome back and thank you for agreeing to participate in our research study on improving mobile apps for Nigerian users. Before we begin today's session, I'd like to tell you more about what the study is about and what we want from you. You'll have the opportunity to ask any questions at any time before deciding whether you want to continue to participate.

1. Purpose of the Study: We're looking at ways to make mobile applications easier to use for Nigerian users. Remember, if you find anything difficult, it's likely due to the app's design, not your abilities. We're testing the apps, not you. Also, we are not the designers for these applications, so kindly tell us honest opinions to ensure that apps are designed to be easy to use for Nigerians. Please remember that:

- Your participation is not compulsory; you can withdraw from the study at any time if you feel uncomfortable.
- We will not be recording your face during the study.
- All information collected will be kept privately and not shared with the public.

2. [Process Involved] Our session today will involve:

- A brief interview about your background and current phone usage
- A series of tasks on two mobile applications: (mobile banking app name) and (mobile shopping app name). The mobile banking application is an app that allows you to do things like money transfers, buying credit, see your account balance etc, while the shopping app allows you to buy things online like food items or clothes for example, and they will deliver it to your choice of location. So, we will be asking you to do some of these things on these two apps.
- After these tasks, we will ask you questions about your experience after completing the tasks

3. [Think Aloud] While you're doing the tasks, we'd like you to speak your thoughts out loud. This means saying whatever comes to mind as you use the apps.

5. [Recording/Observation]: We'll be recording audio of your voice and a video of the phone screen during the session. This helps us understand your experience better. We'll also be available here so that you can ask for clarification on anything.

6. [Privacy]: Everything you tell us, including your identity, will be kept private.

7. [Time and Compensation]: The whole process should take about 30 minutes. You'll receive 3000 naira for your participation.

8. [Right to Withdraw]: Remember, you can stop participating at any time if you feel uncomfortable.

9. [Demonstration]: Now, I'll show you a short video showing someone else doing something like what we are asking you to do. You will see that her face is not recorded in the video,

only her voice and you will hear us tell her that we want her to do something on the same mobile shopping app.

[Play pre-recorded demonstration video]

10. [Practice Task]: Let's do a practice task with the message app to practice the thinking aloud aspect. Please open the Messaging application, type a message to "John Doe" using the "Message edit box."

11. [Main Tasks]: Now let's move on to the main tasks. You'll have about 6 tasks to complete on the banking app and 13 tasks on the shopping app. Here is a list of them all on this sheet of paper that you can refer to at any point. For each task, I'll provide an explanation to help you understand what we would like you to do.

12. [User Experience Questionnaire]: After completing all the tasks, we'll ask you some questions about your experience using the apps.

13. [Questions]: If you have any questions or need clarification at any point, please ask us.

14. [Take Your Time]: There's no rush. Take as much time as you need for each task.

15. [Break Option]: If you feel tired at any point, you're welcome to take a break. Just let me know.

16. [Results Sharing]: If you're interested, we'll share the results of this study with your literacy centre once it's complete.

Do you have any questions before we begin today's session?

Appendix H: Supplementary material on UX questions analysis (Schrepp et al., 2016)

(i) **User Experience Question (UEQ-S) Benchmark Interval Scale**

	Enjoyable	Efficient	Understandable	Expectations	Exciting	Leading-edge
*Excellent	≥1.75	≥ 1.78	≥ 1.9	≥ 1.65	≥ 1.55	≥ 1.4
*Good	≥ 1.52 < 1.75	≥ 1.47 < 1.78	≥ 1.56 < 1.9	≥ 1.48 < 1.65	≥ 1.31 < 1.55	≥ 1.05 < 1.4
*Above Average	≥ 1.17 < 1.52	≥ 0.98 < 1.47	≥ 1.08 < 1.56	≥ 1.14 < 1.48	≥ 0.99 < 1.31	≥ 0.71 < 1.05
*Below Average	≥ 0.7 < 1.17	≥ 0.54 < 0.98	≥ 0.64 < 1.08	≥ 0.78 < 1.14	≥ 0.5 < 0.99	≥ 0.3 < 0.71
*Bad	< 0.7	< 0.54	< 0.64	< 0.78	<0.5	< 0.3

(ii) **Feedback per Benchmark Interval Scale**

**Excellent*: The evaluated product is among the best 10% of results.

**Good*: 10% of the results in the benchmark are better than the evaluated product, and 75% of the results are worse.

**Above average:* 25% of the results in the benchmark are better than the evaluated product, and 50% of the results are worse.

**Below average*: 50% of the results in the benchmark are better than the evaluated product, and 25% of the results are worse.

**Bad*: The evaluated product is among the worst 25% results.

Appendix I: Averages and sums for each task per user performance metric

i) Difficulty Tables for Mobile Banking Application

Table 30: Total Error Rate - Study 1, Mobile Banking

Total (Sum) Error Rate [count data]				
Tasks	**FXI [Sample – 20]**	**LIT [Sample – 5]**	**FXI**	**LIT**
T1	19	2	95%	40%
T2	12	1	60%	20%
T3	20	2	100%	40%
T4	19	2	95%	40%

Table 31: Total Task Completion Rate - Study 1, Mobile Banking

Total (Sum) Task Completion [count data]				
Tasks	**FXI [Sample – 20]**	**LIT [Sample – 5]**	**FXI**	**LIT**
T1	5	5	25%	100%
T2	12	5	60%	100%
T3	4	4	20%	80%
T4	1	4	5%	80%

Table 32: Average Tapping Count - Study 1, Mobile Banking

Average No of Taps [count data]					
Tasks	**Minimum No of Taps**	**Average No of Taps (FXI)**	**Average No of Taps (LIT)**	**Difference (FXI)**	**Difference (LIT)**
T1	13	36	19	23	6
T2	12	17	16	5	4
T3	9	15	13	6	4
T4	4	14	11	10	7

Table 33: Average Time Elapsed - Study 1, Mobile Banking

Average Time Elapsed [time data - seconds]			
Tasks	**Average Time Elapsed (FXI)**	**Average Time Elapsed (LIT)**	**Difference (Ratio)**
T1	187	60	3:1
T2	112	44	3:1
T3	110	41	3:1

T4	83	28	3:1

ii) Difficulty Tables for Mobile Shopping Application

Table 34: Total Error Rate - Study 1, Mobile Shopping

Total (Sum) Error Rate [count data]				
Tasks	**FXI [Sample – 20]**	**LIT [Sample – 5]**	**FXI**	**LIT**
T1a	16	0	80%	0%
T1b	17	0	85%	0%
T2a	9	0	45%	0%
T2b	9	1	95%	20%
T2c	17	0	85%	0%
T2d	7	0	35%	0%
T3a	2	0	10%	0%
T3b	17	2	85%	40%
T3c	20	2	100%	40%
T4a	19	2	95%	40%
T4b	13	0	65%	0%
T5a	12	0	60%	0%
T5b	18	0	90%	0%

Table 35: Task Completion Rate - Study 1, Mobile Shopping

Total (Sum) Task Completion [count data]				
Tasks	**FXI [Sample – 20]**	**LIT [Sample – 5]**	**FXI**	**LIT**
T1a	8	5	40%	100%
T1b	13	5	65%	100%
T2a	16	5	80%	100%
T2b	0	0	0%	0%
T2c	5	5	25%	100%
T2d	17	5	85%	100%
T3a	18	5	90%	100%
T3b	4	4	20%	80%
T3c	3	3	15%	60%
T4a	2	3	10%	60%
T4b	9	5	45%	100%
T5a	11	5	55%	100%

Total (Sum) Task Completion [count data]				
Tasks	**FXI [Sample – 20]**	**LIT [Sample – 5]**	**FXI**	**LIT**
T5b	5	5	25%	100%

Table 36: Average Tapping Count - Study 1, Mobile Shopping

Average No of Taps [count data]					
Tasks	**Minimum No of Taps**	**Average No of Taps (FXI)**	**Average No of Taps (LIT)**	**Difference (FXI)**	**Difference (LIT)**
T1a	7	19	8	12	1
T1b	14	32	18	18	4
T2a	3	10	3	7	0
T2b	8	21	21	13	13
T2c	3	18	5	15	2
T2d	2	9	3	7	1
T3a	3	6	5	3	2
T3b	2	16	12	14	10
T3c	6	9	8	3	2
T4a	3	12	11	9	8
T4b	7	16	7	9	0
T5a	1	15	2	14	1
T5b	10	32	13	22	3

Table 37: Average Time Elapsed - Study 1, Mobile Shopping

Average Time Elapsed [time data - seconds]			
Tasks	**Average Time Elapsed (FXI)**	**Average Time Elapsed (LIT)**	**Difference (Ratio)**
T1a	111	26	4:1
T1b	176	71	2:1
T2a	70	8	9:1
T2b	117	58	2:1
T2c	69	15	5:1
T2d	42	6	7:1
T3a	42	7	6:1
T3b	82	35	2:1

Average Time Elapsed [time data - seconds]			
Tasks	**Average Time Elapsed (FXI)**	**Average Time Elapsed (LIT)**	**Difference (Ratio)**
T3c	40	19	2:1
T4a	63	39	2:1
T4b	85	19	2:1
T5a	65	2	33:1
T5b	167	53	3:1

Appendix J: Statistical analysis results for time taken to complete tasks- Independent Samples T-Test Results - SPSS Output

Table 38: Independent Samples T-test - Study 1, Mobile Banking

Independent Samples Test - Mobile Banking Application											
Task IDs		**Levene's Test for Equality of Variances**		**t-test for Equality of Means**							
		F	**Sig.**	**t**	**df**	**Significance**		**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
						One-Sided p	**Two-Sided p**			**Lower**	**Upper**
T1	Equal variances assumed	3.354	.080	3.678	23	<.001	.001	127.050	34.546	55.586	198.514
	Equal variances not assumed			7.286	20.857	<.001	<.001	127.050	17.437	90.773	163.327
T2	Equal variances assumed	2.053	.165	1.932	23	.033	.066	66.050	34.195	-4.689	136.789
	Equal variances not assumed			3.827	20.851	<.001	<.001	66.050	17.258	30.144	101.956
T3	Equal variances assumed	3.759	.065	2.357	23	.014	.027	63.600	26.981	7.786	119.414
	Equal variances not assumed			4.275	22.730	<.001	<.001	63.600	14.879	32.801	94.399
T4	Equal variances assumed	3.838	.062	2.904	23	.004	.008	53.350	18.371	15.347	91.353
	Equal variances not assumed			5.699	21.433	<.001	<.001	53.350	9.362	33.906	72.794

Table 39: Independent Samples T-test - Study 1, Mobile Shopping

Independent Samples T-test											
Task IDs		**Levene's Test for Equality of Variances**		**t-test for Equality of Means**							
		F	**Sig.**	**t**	**df**	**Significance**		**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
						One-Sided p	**Two-Sided p**			**Lower**	**Upper**
T1a	Equal variances assumed	2.709	.113	3.453	23	.001	.002	84.900	24.585	34.042	135.758
	Equal variances not assumed			6.908	20.202	<.001	<.001	84.900	12.290	59.281	110.519
T1b	Equal variances assumed	2.629	.119	4.614	23	<.001	<.001	104.700	22.693	57.756	151.644
	Equal variances not assumed			6.341	10.913	<.001	<.001	104.700	16.511	68.324	141.076
T2a	Equal variances assumed	7.756	.011	2.302	23	.015	.031	62.150	27.000	6.297	118.003
	Equal variances not assumed			4.635	19.717	<.001	<.001	62.150	13.408	34.156	90.144
T2b	Equal variances assumed	4.303	.049	2.146	23	.021	.043	59.500	27.723	2.150	116.850
	Equal variances not assumed			3.393	16.302	.002	.004	59.500	17.537	22.380	96.620
T2c	Equal variances assumed	4.838	.038	2.986	23	.003	.007	54.200	18.150	16.655	91.745
	Equal variances not assumed			5.777	22.142	<.001	<.001	54.200	9.383	34.749	73.651

Independent Samples T-test											
Task IDs		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig.	t	df	Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						One-Sided p	Two-Sided p			Lower	Upper
T2d	Equal variances assumed	8.821	.007	1.910	23	.034	.069	35.650	18.669	-2.970	74.270
	Equal variances not assumed			3.876	19.108	<.001	.001	35.650	9.198	16.405	54.895
T3a	Equal variances assumed	6.620	.017	1.919	23	.034	.067	35.350	18.418	-2.751	73.451
	Equal variances not assumed			3.890	19.229	<.001	<.001	35.350	9.089	16.343	54.357
T3b	Equal variances assumed	3.035	.095	2.308	23	.015	.030	46.400	20.100	4.819	87.981
	Equal variances not assumed			3.183	11.005	.004	.009	46.400	14.577	14.318	78.482
T3c	Equal variances assumed	5.294	.031	1.790	23	.043	.087	21.800	12.182	-3.401	47.001
	Equal variances not assumed			2.913	17.812	.005	.009	21.800	7.484	6.064	37.536
T4a	Equal variances assumed	11.097	.003	1.364	23	.093	.186	24.150	17.704	-12.473	60.773
	Equal variances not assumed			2.607	22.575	.008	.016	24.150	9.262	4.970	43.330

Independent Samples T-test											
Task IDs		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig.	t	df	Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						One-Sided p	Two-Sided p			Lower	Upper
T4b	Equal variances assumed	4.693	.041	3.679	23	<.001	.001	65.550	17.817	28.692	102.408
	Equal variances not assumed			7.159	21.871	<.001	<.001	65.550	9.156	46.555	84.545
T5a	Equal variances assumed	7.441	.012	1.927	23	.033	.066	63.250	32.827	-4.658	131.158
	Equal variances not assumed			3.915	19.015	<.001	<.001	63.250	16.155	29.438	97.062
T5b	Equal variances assumed	7.426	.012	2.914	23	.004	.008	114.050	39.142	33.078	195.022
	Equal variances not assumed			5.599	22.398	<.001	<.001	114.050	20.368	71.853	156.247

Appendix K

Table 40: FXI users verbalisations during mobile money transfers – Study 1

Participant ID	Screen a	Screen b	Screen c	Screen d	Error pop-up screens
1				I am scrolling, but can't see the name of the bank to transfer to	I don't know what "select account to debit" means
2		I didn’t see this 'select account to debit' initially, that's why I did not do it first <input indicator>.			
3		I can't find where to put the account number you gave <form>	Hm I will just go back	I can't find the bank here	
4	I am not sure what this is asking me, so I will just choose the first option and see				I don’t know what they want again, I entered everything - maybe it's network
5		I am trying to enter the account number you gave me to send the money to, but it is giving me an error message showing that I have to select the account to debit, but I do not understand <control pattern, required input>		[Mobile banking app name] is not in this list	
6		I can't see that the GT account number has been added to the correct field, even after selecting it, so I think I should go back to re- search for it <input indicator>		It is like this bank is not here	I have clicked on "OK" but it is not taking me anywhere
7		There are errors on the page <form> I do not	I have chosen this	I am still searching but it's like it is not here.	I don’t know what they mean by this, let me go

Participant ID	Screen a	Screen b	Screen c	Screen d	Error pop-up screens
		know the purpose of this transfer narration, so I will just stop here			and check - I may have made a mistake
8		I can't enter the account number to send money to when I click on the place <control pattern, required field>		I think the bank is not listed here	I thought choosing "OK" will take me somewhere else
9			There is nothing here		
10		I am trying to find "select account to debit", but I don't know where to find it here <input indicator>			
11					
12		I am thinking where can I put in the account details	What do they want		
13		I can't enter the account number you gave me; I am clicking but nothing is happening <control pattern, required field>			Maybe it's network problem, they said I should 'switch on account'.
14	I am not sure what to choose from this <reference: options>		I think I have done this		
15	I don't know what they mean here. I will just choose the first one since it is [mobile banking application name]	I know that I have to put the account number I am transferring to, but I am not sure where I can put that here. Maybe if I click continue, it will then take me somewhere so that I can enter it <input indicator, required field>. I am not sure the meaning of "destination account'			

Participant ID	Screen a	Screen b	Screen c	Screen d	Error pop-up screens
16		I think it is meant to be here <reference: input field for destination account>, but it is not allowing me <input field, required>			It means I forgot to put something maybe, but I don't know where it is
17		I don't know what this means <reference to: 'destination account'>			
18		When I try to enter the account to send the money to, nothing happens <control pattern, required field>	This my own account [right]		I don't know what to change again, it is not obvious what they mean
19		Please what does "destination account" mean, I don't know what they want here.			Maybe I made a mistake in the way I entered the details
20		I am not sure the meaning of the things they want here, like what is 'destination account'. What is the purpose of "narration"	I think there is nothing here	I can't find [mobile banking app name] here	
Supporting notes Blank rows indicate the absence of verbalisations that fit the two recorded categories. Screen alphabets in the column headers correspond to the figures in their respective chapters. These tables represent FXI verbalisations exclusively. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.					

Table 41: FXI users post-study verbalisations in mobile money transfers – Study 1

Participant ID	Screen a	Screen b	Screen d	Other
1				The app was hard to navigate, I think USSD is easier, I expected

Participant ID	Screen a	Screen b	Screen d	Other
				it to be like that. The icons are understandable
2			I don't know why I didn't see that to choose from	There are a lot of steps, like I did not expect an additional step after the icon for transfer and after filling in the transfer details. Once the transfer details are filled, a 'send button' should be present like other apps
3				I use USSD, but this is not the same
4				
5		I did not see the first 'select account to debit' place when I opened the page, so that was why I had problems. Even the 'select destination account' should be [clearer] because I did not see it.		
6		'Select account to debit' should be easier to see		There should be different colours for the app like pink and ash. The English should be layman English, and the navigation should be bolder
7				
8				There are too many pages and navigation to get results. That is why I got confused and got many errors to do the transfer. It should be shortened. The English was complex too.
9				The icons are not clear, there should be better design
10		It is hard to view the details of the bank to transfer to		In USSD, it shows you all the details there when you enter the account

Participant ID	Screen a	Screen b	Screen d	Other
11				
12		The navigation icons in the bottom are not obvious	I did not know I had to choose the account	
13				It was complex, everything should be easier to understand. USSD is easier than that.
14		The 'select destination account' was confusing		
15	I thought the first option, 'first bank transfers', would mean where I am transferring from, so that was why I chose that option, but I think that was why when I entered the transfer details on the form, the application showed me many errors that the account details are wrong.	I think the application was easy for me, but the English made it hard for me to understand where to put the information you gave me about the transfer. Like this, 'select account to debit' now should be changed to something simpler to understand	I did not know I had to click something	
16				The English should be easier
17				
18				
19				The app was unfamiliar to me and there are too many things, I thought it will be like USSD
20				Transferring money was very hard. I thought it would be like USSD -like the application will be asking me questions
Supporting notes Blank rows indicate the absence of verbalisations that fit the two recorded categories. Screen alphabets in the column headers correspond to the figures in their respective chapters. The 'Other' category includes important verbalisations that may not be specific to a single screen. These tables represent FXI verbalisations exclusively. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.				

Table 42: Researcher notes on mobile money transfers – Study 1

- Screen ID <a> Seeming confused about what option is the correct one and/or wrong option selected [P4, P12, P14, P16]
- Screen ID <b> The required, first input field seems not obvious as participants skipped this field on the form [Form/input indicator. P1, P3, P4, P5, P7]
- Screen ID <b> Seeming confused about whether the bank name selection in screen d was successful [System initiated response. P6]
- Screen ID <b> Unable to enter some form fields because previous fields are blank or incorrect [Form/ control pattern, input field. P3, P4, P5, P6, P7]
- Screen ID <b> Seeming confused about the correct entry field for the transferee account details and or/not knowing the meaning of ‘destination account’ [Language. P3, P6, P7, P8, P10, P12, P15]
- Screen ID <b> The meaning of ‘narration’ is unclear, but the participants assume it is a required field [Language. P15, P16]
- Screen ID <b> The participants did not follow a top-bottom approach in filling out the bank details [Form/control pattern, input field. P1, P2, P3, P4, P11, P18]
- Screen ID <c> The button seems not clickable, so participants might think it is only plain text that does not require manipulation [Button. P5, P6, P7, P8, P13, P14, P15, P20]
- Screen ID <d> The participants did not attempt to use the search function to find the bank details, but rather resulted to scrolling. Potentially not visible to them or participants are not comfortable with the search function [Search. P1, P15, P17, P18]
- Screen ID <b> Confusion caused by the discrepancy between the abbreviated bank name and the full name [P3, P5, P6, P7, P8, P20]
- Screen ID <error pop-ups> Participants do not understand error messages [Language. P3, P4, P5, P6, P18]
- Expects a different screen after selecting ‘OK’ on error messages [System initiated response, P10, P18]
- Some participants think network problems are the cause of some errors they made [P2, P3]

Supporting notes

Screen alphabets in the “< >” correspond to the figures in their respective chapters.

For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.

Appendix L

Table 43: FXI users verbalisations during search filters in mobile shopping – Study 1

Participant ID	Screen a	Screen b	Screen c1	Screen c2
1		Okay, let’s say the highest price, these are the highest <reference: search results>		
2		I’m thinking if I type Ginger tea here <reference: search field>, will show me the process to get it. That’s what’s on my mind. Four stars and above, okay so this one has been added. I think it is this one <reference: 4 boxed icon on the top>		
3				
4		I will go to search then I will find the price		
5				
6		I will check the search space. Okay, let me be checking down and maybe I will see the one that is lesser		
7		I will use this <reference: search function> then I will see the price		
8				
9				
10		I saw the icons, but I thought the filter was an option to change the app's colours. Like I thought it would be colour of biscuits or something. I didn’t see the icons on the top earlier		
11				The save should be at the top of the screen because I did not

Participant ID	Screen a	Screen b	Screen c1	Screen c2
				think I had to scroll down to see save after choosing the filters
12				
13		I think I should use search to research this	I think it this would be discount but before choosing, I think I have to select the product I want the discount for <reference: price option>	
14		I think maybe if I go to the search, then I can put the price		
15		The down arrow key means that it can be clicked in the left one; but the right one does not have arrow, so I did not know that I should click it	This price should be inside the box, but I think I made a mistake	
16			The price is not entering, I think maybe I am supposed to put it somewhere different	
17				
18		I don't know whether it would be this one <reference: 4 boxed icon on the top>		
19				
20				
Supporting notes Blank rows indicate the absence of verbalisations that fit the two recorded categories. Screen alphabets in the column headers correspond to the figures in their respective chapters. These tables represent FXI verbalisations exclusively. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.				

Table 44: FXI users post-study verbalisations search filters in mobile shopping – Study 1

Participant ID	Screen a	Screen b	Screen c1	Screen c2	Other
1		I couldn't see the 'filter' because I expected it to be like how to search on Facebook. This is new and different because if I enter my profile and messages on Facebook, I can search for name			I think it was hard for me because I have never used it before, this is my first time. The process is very different from shopping in real life because there is no searching in supermarkets.
2					A learned person without experience will find it not understandable, but a learned person that has experience will find it understandable. The icons and naming are different and new from other apps. I feel with time people will learn how to use it
3					I think it will be easy if I try every day to learn and use the app. It is also because I don't have much experience using apps. -It was not same as how I buy things in the shop. I don't understand the icons and naming. Like this, <points at the icons below> I am not sure the meaning – I think 'help' is 'you provide',

Participant ID	Screen a	Screen b	Screen c1	Screen c2	Other
					feed is 'food', 'categories' – 'I have no idea'
4					I think like I will go home and learn it after many uses like, maybe 5 times
5	I did not really see the 'search' at first. The 'search' will be easier to see on the left side of the app	The things like filter were hard to get			
6					Nice design but it was too complicated or maybe it is because it is my first time. The process is too long, not like the supermarket. The English should be less hard because it was not easy to understand
7					This is hard and different because there is no human communication.
8	There is no button to press for search				This is easier than going to the store since they will bring it to my house. I did not know this before. The app should be easier than it is now with time.
9		The 'popularity' option is not understandable for lowest to highest to be under. I thought it would show different products or other items. The lowest-highest should be where the search is. Example, 'lowest to		The 'save' button should be at the top because it not easy to see it [at] the bottom	

Participant ID	Screen a	Screen b	Screen c1	Screen c2	Other
		highest Samsung'. I saw the 'filter' but I did not choose it because I thought the 'filter' was for changing colours or the design of the app			
10					The app is too complex
11			I did not see the option to use that for the filter of price <reference: vertical slider for price>		I expected it to be easier. In real life there are no icons, so it is hard to know.
12					I did not understand some things, like 'categories', <reference: icons on the bottom of the screen> but something like this, 'feed' was clear for me. Filtering was hard for me to do, at first I did not see the option
13		I did not see the things on the top of the screen, the 'popularity' and 'filters', at all.	I thought the price setting will be inside search		I did not understand 'feed' <reference: icons on the screen's bottom>
14		I understood the 'popularity' option because it is readable, and the arrow means that I can click it and there are more options there. I know that from WhatsApp, when I get messages there, they come with arrow that means 'more options'. But the 'filter', I was just			

Participant ID	Screen a	Screen b	Screen c1	Screen c2	Other
		[exploring] the app that's why, but it was not understandable			
15		I saw this 'filter', but I did not know that I [could] select it. Like this option here <*points to the sort feature*>, it should have an arrow next to it, so I know that there are more options there. [However], the filter does not have an arrow - this is why I thought I could not select it.			
16		The filter was very hard to find			If I practice this, I will learn to use it after time.
17		The filter was hard because I have never used the app. That's why I have no idea about 'popularity and filters'			I don't know about the meaning of any of this. No idea <reference: icons on the bottom>
18		It will be better if you change 'filter' to another thing because the word is hard; something like 'more'			
19					There are too many steps to do the tasks and the meaning of some things there <meaning the app> [are] not easy

Participant ID	Screen a	Screen b	Screen c1	Screen c2	Other
20		I can’t see anything here to do what you said <reference: filter>			It was hard, there are too many things everywhere and I guess you have to learn it to reap its benefits

Supporting notes
Blank rows indicate the absence of verbalisations that fit the two recorded categories.
Screen alphabets in the column headers correspond to the figures in their respective chapters.
The 'Other' category includes important verbalisations that may not be specific to a single screen.
These tables represent FXI verbalisations exclusively.
For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.

Table 45: Researcher notes on search filters in mobile shopping – Study 1

- Screen ID <b> Difficulty determining the correct icon for the filtering icon – some participants misinterpreted the option ‘sort’ option as the correct one to use for applying filters, others used the search function [P2, P4, P6, P7, P10, P13, P14, P15, P18, P20]
- Screen ID <c1> Inputting the price range presents challenges because the vertical scroll pattern is not obvious, or the problematic price input field is faulty and doesn’t update the entered data accordingly. Interesting that some participants believe this to be due to a mistake they made, rather than considering the possibility of a faulty UI design [Input field. P2, P3, P6, P9, P13, P15, P16]
- Screen ID <c1> Participants use search input field to enter the prices that are meant for the filters. The search function seems to be what participants are comfortable with using [P2, P4,P6, P7, P10, P14, P15]
- It seems like the concept of filtering is hard to grasp for the users, even after explanation. Unfamiliarity or explanation in abstract terms seems difficult to grasp. [P1, P3, P16, P17, P19, P20]
- Screen ID <c1> The price range option seems invisible amidst other filter options on the screen [Form/Spinner. P5, P9, P11, P13]
- Screen ID <c> Selecting another filter option in place of price, e.g., using star ratings instead [P13, P16]
- Screen ID <c2> Completed the price filter options but did not scroll down to select save before exiting the screen; rather the back button was used to leave the filters screen [Form/Button. P12, P16]

Supporting notes
Screen alphabets in the “< >” correspond to the figures in their respective chapters.
For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.

Appendix M

Table 46: FXI users verbalisations during checkout in mobile shopping – Study 1

Participant ID	Screen a	Screen b	Screen c1 and c2	Screen d	Screen e
1	I don't know where to see the write-up to buy <language>		There is a way to do it, but I don't think it is here, maybe somewhere there is payment option	I think maybe this <lateral access-tab>	I will stop here because I don't know the meaning of this voucher <language>
2	Can't find the shopping basket, though I saw it somewhere. The name I'm expecting to see is not what I am seeing for the basket. <icon>	Maybe it was down here or something on this page <vertical list>		It's not clicking, maybe network problem <lateral access-tab>	
3	I'm thinking how can I see the basket. <icon>		I will <search> for how they can bring it to my house using the search option		
4	I think the option will be in the home page so I will go there and find it. It will look like a basket drawing, I think. I couldn't see it at first because it is at the top corner, and I didn't expect it to be there -my mind wasn't up there <icon>		I think if I <search>, I will find it		It's not clicking because we don't have voucher code. I think voucher code is to do with the bank. <language>
5	I'm wondering how I can see the basket. <icon>				
6	I think I will search for the basket. Or enter the app <reference: home page) and scroll to find it. The <search> is showing me waste bins, I'm				

Participant ID	Screen a	Screen b	Screen c1 and c2	Screen d	Screen e
	expecting to see a basket with my things inside so that if they want to deliver it to my house, my things will be inside. Think if I go back into the product page, there will be a basket option where my selected products are. <icon>				
7	I think it will be under this page (ref prod details) and 'deliver' will be written <icon>		Where should I go to make them bring it. Here I see the things I chose but where should I go after <vertical list>		
8					
9			I think it will be in the product details page		I need the voucher code because it's needed to transfer money for the checkout <language>
10	I saw the basket before but did not think that is where to click to start the buying process. I thought when I click 'add to cart' that means I have bought it <icon>				I did not see how to continue
11	I am trying to <search> for it but I think maybe it is not here. It is in another place. <icon>	I will just scroll here, maybe it is in the end <vertical list>	I clicked on the cart at the top page twice because I thought it will show me where I can pay	I don't know why when I click on payment, it doesn't work <lateral access-tab>	I don't know what this voucher code is so I can't move forward. I want to pay but I have no idea where to go from here. I'm expecting to see 'transfer money here' <language>
12			I think the + means buy now		

Participant ID	Screen a	Screen b	Screen c1 and c2	Screen d	Screen e
13			I'm wondering where I can make the payment	Maybe there is another option	
14	I am expecting to see an option that says buy now on the prod details page so it will take me to checkout. Okay now I can see 2 units of prod, and 2 on the cart so that means maybe its there	It might be here. This is where I added the tea to the basket <vertical list>			What am I goanna do at this voucher code? Is it my transfer code or secret pin
15	There should be an icon somewhere	I will scroll to the end; it is there I think <vertical list>	I think I should check for a place that says buy		I think the voucher code will be a code for the payment.
16	I think the basket will be in home. I know it will be a button. I didn't see it because it is too many and it doesn't look like a basket		I didn't see this <button> at first	Why is the payment not working <lateral access-tab>	
17			I think the + means buy now. Oh no, it means add. I don't know how I will buy it. I am expecting to see 'buy now'		I don't know what this voucher code is but I need to put it before I can pay
18	I can't see it yet <icon>		But there is nothing here about payment at all	the payment is not working <lateral access-tab>	
19					
20	There are too many things here. It is hard to see it <icon>				

Supporting notes
Blank rows indicate the absence of verbalisations that fit the two recorded categories.
Screen alphabets in the column headers correspond to the figures in their respective chapters.
These tables represent FXI verbalisations exclusively.
For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.

Table 47: FXI users post-study verbalisations checkout in mobile shopping – Study 1

Participant ID	Screen a	Screen c1 and c2	Other
1			
2	The namings and drawings are not clear. The 'cart' should be renamed to 'basket' and look like a basket maybe. <language, icon>		Maybe with time, people will learn it but the things like the steps and <language> can be easier.
3	The checkout was hard. I did not understand the icons and meanings and it is very different from real life <language, icon>		
4		The English needs to be better, what is 'checkout' <language>	
5	I didn't know that drawing was the basket, and I saw it		
6	The processes are very long compared to real life but it was okay. I saw the drawing but did not know it meant basket or that it was they place to pay <icon>		The English should be less complex because it was not easy to understand for me at all. <language>
7	It did not look like a basket. <icon>	The navigation and icons are not clear. I found it hard to know where to go especially when I wanted to pay	The wordings are not understandable like the word 'variation', what does that mean <language>
8			Where to buy should be easier because even some things like 'cart' I did not know it at first. <icon>
9	The basket can be made easier to understand, you get?		
10		How to buy was hard for me, I have never done it before.	The process is not the same as real life, it is harder on the app
11	That is not what the basket looks like <icon>		There are many steps that are not explained and there is no help, so it is hard to do but it will be easier if someone goes home to do it more
12			Something like 'checkout' should be clearer and maybe 'pay' <language>

Participant ID	Screen a	Screen c1 and c2	Other
13		The checkout was not as clear, and I didn't think I can click it <lateral access-tab>	
14	The basket icon was different and hard to even see, so tiny <icon>		
15			The things like checkout and voucher were hard to get but if you know how to read, it'll be easy for you. <language.
16	I thought it was a wheelbarrow, It did not look like a basket to me at all, like what is that? <icon>		The process is long, and it is hard to find things, there are many things in the screen
17			
18	The basket was not clear, and I did not see it for very long	The payment was hard to understand, even 'checkout'. <language>	
19			There are too many steps to do the task
20			The processes are too hard, it needs to get simper even the English <language>
Supporting notes Blank rows indicate the absence of verbalisations that fit the two recorded categories. Screen alphabets in the column headers correspond to the figures in their respective chapters. The 'Other' category includes important verbalisations that may not be specific to a single screen. These tables represent FXI verbalisations exclusively. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.			

Table 48: Researcher notes on checkout in mobile shopping – Study 1

- Screen ID <a> There is a misunderstanding on the compulsory requirement to check the cart to proceed to payment [Icon, P5, P6]
- Screen ID <a> Participants are expecting that the buying option would be in the product details page (this seems to be possibly because there is some information on delivery details (e.g., estimated delivery date, delivery options on the product details page) [P2, P11, P14, P15, P20]
- Screen ID <a> Some of the participants do not see the basket icon and spend some time navigating through other pages searching for it. This might be related to visibility- affordance or metaphor or design choice -e.g., colours [Icon. P14, P18 P7, P6]
- Screen ID <a> Some participants go into the basket, but don't realise that this is the basket [P5, P10, P15]
- Screen ID <a> Using the search function to find the shopping cart. This might be based on the thinking that search functions should provide help, e.g., Google or perhaps based on thinking a basket is needed to take to the checkout, like in real shopping experiences [Search. P6, P11]
- Screen ID <a> Expecting the cart to be in the home page when they scroll down [Icon. P4, P8, P14]

- Screen ID <c> Expecting the cart to be written in the product details page, not drawn (and to say 'deliver') or 'buy' [P8, P10, P14, P15, P17]
- Screen ID <c> Mistaking other functions in the checkout page to mean ‘checkout’, e.g., + in prod unit for buy button [P12, P14]
- Screen ID <c> Seeing the checkout button but not knowing the meaning [Language. P1, P12, P13, P18]
- Screen ID <c> Expecting checkout to be in the product details page [P8, P10, P14, P17]

Supporting notes

Screen alphabets in the “< >” correspond to the figures in their respective chapters.

For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.

Appendix N

Table 49: FXI users verbalisations during mobile money transfers – Study 2

Participant ID	Screen b	Screen c
1	i think this the account number I am supposed to transfer to they gave me an option of yes or no	
2		
3		
4		
5		
6		
7		
8	I'll just choose the first one	
9		
10		
11	Is it this one I am supposed to select	
12		I cannot see where to select new account
13		
14		
15		I can't find the place to enter the account here
16	Which account do you want to pay from	Now I want to send money to Aisha and there is no Aisha
17		What is this am I supposed to press this
18	I think I'll just choose next	
19		
20		I didn't see the person I am sending the money to
Supporting notes Blank rows indicate the absence of verbalisations that fit the two recorded categories. Screen alphabets in the column headers correspond to the figures in their respective chapters. These tables represent FXI verbalisations exclusively. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.		

Table 50: FXI users post-study verbalisations in mobile money transfers – Study 2

Participant ID	Screen b	Screen c	Other
1			
2			You should be able to choose the colour of the application
3			
4			
5			
6			The writing and the colour of the app can be different
7			
8			
9			The writing should be bigger
10			People that can't read might find it difficult because the font is small
11			
12			People that cannot read might need some guidance on how to use the application. You should make the font bigger
13			
14	I found the two accounts to choose from hard	I did not notice the pay someone new button at first because it was new and I have never seen it before	
15		It was not obvious where to enter the information about the new account.	The colours make it hard to understand what the app is asking for. Maybe use black and white so that it is easier to read
16			People with low literacies will find it hard to read and do the steps because there are many steps. The app should present all the requirements for input in one form
17			The number of the steps are long, and they have to be able to know how to read
18			There should be shorter steps
19	It was my first time -that's why I didn't see this <reference: pay someone new option>		

Participant ID	Screen b	Screen c	Other
20			Optional button should blink or have a different colour. It requires a person to calm down and really read for word so important information should have a different colour
Supporting notes Blank rows indicate the absence of verbalisations that fit the two recorded categories. Screen alphabets in the column headers correspond to the figures in their respective chapters. The 'Other' category includes important verbalisations that may not be specific to a single screen. These tables represent FXI verbalisations exclusively. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.			

Table 51: Research notes on mobile money transfers – Study 2

- Screen ID <b> Participants had some issue with the account to transfer from – some may have selected the first option they saw, just to see if it moves them along not necessarily because they understood the required information. Possibly, they forgot their roles as the owners of the account/app [Language, P1, P8, P14, P17, P19]
- Screen ID <c> Participant found it difficult selecting a new beneficiary he didn't notice the pay someone new but later realized it on their own – one participant expected the payee account should be among the beneficiaries [Likely a visibility issue, P12, P15, P18]

Appendix O

Table 52: FXI users verbalisations during search filters in mobile shopping – Study 2

Participant ID	Screen a	Screen b
1	I am requesting to have a tea <reference: filter typed in search bar>	
2	I saw tea below 1500 naira when I searched <reference: search results returned tea that fits his filter criteria)	
3		
4	I don't see the types of tea <reference: without searching>	
5	I am thinking I will get the answer <reference: after typing filter in search bar>	
6		
7	I'm searching for it <reference: after typing filter in search bar>	
8		
9		Where can I see this 3-star rating? I can't see it it's supposed to be somewhere it's not here. Maybe I should reset (so that the star rating filter will appear)
10		I think I made a mistake maybe because it is 500 and 1500 and I put 1000. I don't understand how I am going to put my budget
11		
12	Do you think I should just put the price there <reference: seeking affirmation for using filter in search bar>	The problem is I am putting the same price I am putting in the 'form and to' <form/input field>
13		
14		
15		
16		No, I don't think there is a way to filter and this is the best way, to just search and see every type of tea
17		
18		
19		I am thinking it's confusing I am looking for where I can search the price
20		
Supporting notes Blank rows indicate the absence of verbalisations that fit the two recorded categories. Screen alphabets in the column headers correspond to the figures in their respective chapters.		

Participant ID	Screen a	Screen b
These tables represent FXI verbalisations exclusively. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.		

Table 53: FXI users post-study verbalisations in search filters in mobile shopping – Study 2

Participant ID	Screen a	Screen b	Other
1		I thought I should just search the filters, and I didn't see the other options below	
2		I didn't know you could filter I am used to doing it manually	
3			
4			
5		I think you should be able to type and search the filters	
6			
7		The ratings should be at the top of search menu	
8			
9			
10			
11		The issue of price filtering was not bold, and I was unable to see it	
12	I was concentrating on all the filter options that's why I didn't notice the search bar		
13		They should show you what do you want to buy in the beginning whether tea or it's shopping you want to do	
14			I think a short video should be there to teach a person how to use it
15			
16			
17			The colour of the application is too bright, and I think you should be able to search the price you want

Participant ID	Screen a	Screen b	Other
18	When I searched for the tea, it gave me the tea so I didn’t pay any attention for anything else in the filters		
19			
20			I just got confused

Supporting notes
Blank rows indicate the absence of verbalisations that fit the two recorded categories.
Screen alphabets in the column headers correspond to the figures in their respective chapters.
The 'Other' category includes important verbalisations that may not be specific to a single screen.
These tables represent FXI verbalisations exclusively.
For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.

Table 54: Researcher notes on search filters in mobile shopping – Study 2

- Screen ID <b> Participants could not understand how to filter price. The concept of filtering seems not understandable, leading some to do a manual search by scrolling through search results to find products that fit the filter criteria rather than using the function [P10, P2, P11, P16, P19, P20]
- Screen ID <a> Using the search engine mental model for filtering. The filters are entered within the search field [search.sort/filter, P1, P3, P5, P7, P10,]
- Other: participants think there is a network problem when the filter options do not work in the search bar [P10, P7]
- Screen ID <b> Experiencing trouble with entering/understanding ‘from and to’ as a range for price filtering [P12, P14,
- Screen ID <b> Not understanding terminologies used for filtering - e.g., rating. What it means to ‘rate’ a product is not known [language/concept. P4, P8, P9, P14
- Screen ID <b> Expecting to see the filter options after seeing the results of the searches [P5, P18]

Supporting notes
Screen alphabets in the “< >” correspond to the figures in their respective chapters.
For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.

Appendix P

Table 55: FXI users verbalisations during checkout in mobile shopping – Study 2

Participant ID	Screen a	Screen f	Screen h
1			I am looking for where to continue. I am hoping to see ‘continue’)
2			
3			
4	I want to see where I post it. I can’t find the items I bought		
5			
6			
7			
8			
9			
10		How am I going to pay them cash what if I no get cash when they bring it	
11			
12			
13	I think we have to add to basket and it’s still showing the same <reference: trying to access checkout>		
14	I want to take it and pay with cash		
15			
16			
17			
18			
19			
20			
Supporting notes Blank rows indicate the absence of verbalisations that fit the two recorded categories. Screen alphabets in the column headers correspond to the figures in their respective chapters. These tables represent FXI verbalisations exclusively. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.			

Table 56: FXI users post-study verbalisations in checkout in mobile shopping – Study 2

Participant ID	Screen a	Screen f	Other
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11	I was looking for a place that says ‘pay now’ instead of ‘add to basket’		
12			
13			
14			
15			I thought you have to pay before you order
16			
17			
18			
19	I think I didn’t have one to buy and I expected to see go and pay		
20			
Supporting notes Blank rows indicate the absence of verbalisations that fit the two recorded categories. Screen alphabets in the column headers correspond to the figures in their respective chapters. The 'Other' category includes important verbalisations that may not be specific to a single screen. These tables represent FXI verbalisations exclusively. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.			

Table 57: Researcher notes on checkout in mobile shopping – Study 2

• Screen ID <b> the participants had difficulty transitioning from search result to checkout. Some may have missed the animation, not noticed the basket or not understood the metaphor in using the basket representation [P1, P4, P13, P19] • Screen ID <h> participants did not notice the buy now button – possibly confusing the summary information on the page as order confirmation as it contains the list of selected items [P10, P14]
Supporting notes Screen alphabets in the "< >" correspond to the figures in their respective chapters. For a detailed explanation of the analysis leading to these tables, refer to Section 4.2.

Appendix Q: Ethics approval confirmation and application form

Subject: Re: Ethical approval for PhD research
Date: Monday 5 December 2022 at 15:16:16 Greenwich Mean Time
From: Paul Jones
To: Khadijah Danjuma Mohammed (Research Student), Aston Ethics, BSS Research Office, AARM
CC: Victoria Uren, PGR General Enquiries
Attachments: image001.png, image002.png, image003.png

Hi All,

Yes, confirmation was given to Khadjah.

It is below. Ethics application number was 276-3-22 and this was in April this year. This was under the old system before the new processes kicked in.

As for travel, the International Travel Risk Assessment forms come through me to approve for PGR students in BSS. I have Khadjah's application for travel and will be looking at that later this week.

If you need anything else please let me know.

Paul.

Research Ethics Application - Mohammed - 276-3-22 - Approved

AARM <abs_aarm@aston.ac.uk> Monday, 4 April 2022 at 11:58
To: Khadijah Danjuma Mohammed (Research Student); +2 more

Hi Khadijah,

I am pleased to confirm that we have had feedback from both ethics committee members.

The feedback was excellent, and they are very pleased to confirm that you are free to proceed with your research.

Good luck! We all hope that the research goes well.

If you have any queries or questions, please do get in touch.

Many thanks,

Paul.

Many thanks,

Paul
Paul Jones BSc (Hons), MSc, PG Dip, PG Cert, Assoc CIPD, FHEA
Senior Research Manager

Appendix R: Overview of How HCI4D Studies Define or Represent Functional Illiteracy and Related Terms

Table 58: A review of current representation of FXI in HCI research

No.	Authors	Year	Title	Who (IL -Illiterate, SL -semi-literate, LL – low literate, Med L – Medium literate, HL - high literate)	FXI Definition	FXI Measurement
1	Medhi et al.	2013	A comparison of list vs. hierarchical UIs on mobile phones for non-literate users	LL and IL	None of the participants had any formal education and could not read or write, though all of them were numerate and inexperienced with touch UIs.	Nil
2	Dodson et al.	2013	Minding the gaps: Cultural, technical and gender-based barriers to mobile use in oral-language Berber communities in Morocco	LL , IL, SL women	Nil	Self-identified as illiterate or low-literate
3	Cuendet et al.	2013	VideoKheti: Making video content accessible to low-literate and novice users	LL	LL (<= 5th standard ed) and HL (>6 ed grade).	Self-identification by level of education
4	Chandel et al.	2013	A comparative study of voice and graphical user interfaces with respect to literacy levels	SL vs. HL	SL (class 7th to class 11th pass) vs. HL (undergraduates to PhD students)	Nil
5	Medhi et al.	2013	Some evidence for the impact of limited education on	LL, Med L, HL	LL (between level 0-1) Level 0 corresponded to no ability to read; level 1	Self-developed reading and writing tests with grade levels and Raven's Progressive

			hierarchical user interface navigation		corresponded to the ability to read and write grade I content	Matrices (test for abstract reasoning)
6	Ahmed et al.	2013	Ecologies of use and design: individual and social practices of mobile phone use within low-literate rickshawpuller communities in urban Bangladesh	LL	Illiterate (unable to read, write, and understand short simple messages) and semi-literate (struggling to read, write, and understand short simple messages). We use the term “low-literate” to refer to these two classes of people	Self-reported education levels and observed difficulties in reading or writing full words (no cut-off or test included)
7	Nabi	2013	Raabta: low-cost video conferencing for the developing world	LL	Nil	Nil
8	Agrawal et al.	2013	Exploring suitable interfaces for agriculture based smartphone apps in India	LL farmers	Nil	Nil
9	Suen et al.	2014	Interactive Experiences Designed for Agricultural Communities	SL farmers	Nil	Nil
10	Robinson et al.	2014	AudioCanvas: internet-free interactive audio photos	IL, LL	Nil	Nil
11	Ahire et al.	2014	Media player for Semi-illiterate users	LL, SL	Users with educational level of standard 8 or below and who had not formally learnt English language.	Self-reported based on recruitment criteria
12	Gupta et al.	2015	KrishiPustak: A Social Networking System for Low-Literate Farmers	LL farmers	Nil	Nil
13	Ninsiima	2015	Buuza Omulimisa" (ask the extension officer): text	LL farmers	Nil	Nil

			messaging for low literate farming communities in rural Uganda			
14	Doke and Joshi	2015	Mobile Phone Usage by Low Literate Users	LL	Education is equal or more than Standard Four and less than or equal to Standard Eight in the Indian State education system	Nil
15	De et al.	2015	An Assessment of QR Code as a User Interface Enabler forMobile Payment Apps on Smartphones	NL, SL, LIT	Semi-literate users had rudimentary knowledge of English alphabets, which is used to design the buttons in the screens.	Nil
16	Ahmed et al.	2015	Suhrid: A Collaborative Mobile Phone Interface for Low Literate People	LL	None of them could read or write a complete sentence in any language. They were familiar with Bangla and English digits, but they could not read numbers when two or more digits were put together	Nil
17	Ghosh	2016	Contextualizing intermediated use in the developing world: Findings from India & Ghana	LL	Nil	Nil
18	Rhodes and Walsh	2016	Recommendations for Developing Technologies that Encourage Reading Practices Among Children in Families with Low-literate Adults	LL parents	Reading at or below the eighth grade level	A REALM score of 60 or less is considered low-literate, or reading at the eighth grade level or below
19	Islam et al.	2016	Poster: Smart Adaptive User Interface of Mobile Applications for Semi-Literate People	SL	Nil	Nil

20	Belay et al.	2016	Claims-to-Patterns Approach to Leverage Mobile Interaction Design for Low-Literacy Users	LL	LL classified into (m-literate, m-semi-literate, and m-illiterate)	Nil
21	Adama et al.	2017	Towards designing mobile banking user interfaces for novice users	LL novice	Significant challenge faced by novice users in interacting through mobile phones in general	Characterization forms to primarily establish that they are novices
22	Medhi.	2017	SIGCHI Social Impact Award Talk -- Designing for Low-Literate Users	LL	The inability to read or write with ease.	Nil
23	Ahmad et al.	2017	Scrolling, Navigation, and Selection: How New Smartphone Users discover it	LL novice	Education level 10^{th} and below with no prior experience of using smart phones	Nil
24	Idrees et al.	2017	Weather Forecast Information Dissemination Design For Low-Literate Farmers: An Exploratory Study	LL farmers	Does not define but identified participants as no education: 7primary: 4, above primary: 5 (showing now diff between IL and LL)	Nil
25	Idrees et al.	2018	Urdu language based information dissemination system for low-literate farmers	L, SL, IL farmers	Nil	Nil
26	Mehmood et al.	2018	Towards Digitization of Collaborative Savings Among Low-Income Groups	LL	Education (Primary (up to 5th grade) to Graduation (12th grade))	Nil
27	Coetzer.	2019	Application of HCI design principles in overcoming information illiteracy:	IL SL	Nil	Nil

			Case of a M-health application for a rural community in South Africa			
28	Tandon et al.	2019	Designing a financial management smartphone app for users with mixed literacies	Mixed literacies (LL)	Nil	Nil
29	Madaio et al.	2019	Everyone Brings Their Grain of Salt": Designing for Low-Literate Parental Engagement with a Mobile Literacy Technology in Côte d'Ivoire	LL parents	Nil	Nil
30	Islam et al.	2020	Chakuri-bazaar: A mobile application for illiterate and semi-literate people for searching employment	IL, SL	Nil	Nil
31	Tulaskar	2020	Study of Instructional Illustrations on ICTs: Considering persona of low-literate users from India	LL	An adult with the ability to read and write with difficulty or effort, have low levels of formal education and have less or no experience with personal computers and use mother tongue as a primary communication language	A pilot study was conducted to assess their reading & writing ability, competency with mobile device, and current knowledge on growth monitoring and common diseases
32	Skarlatidou et al.	2020	Experiences from Extreme CitizenScience: Using smartphone-based data collection tools with low-literate people	LL	Nil	Nil

33	Srivastava et al.	2021	Actionable UI Design Guidelines for Smartphone Applications Inclusive of Low-Literate Users	LL	Illiterate (unable to read, write, and understand (short simple messages) and semi-literate (struggling to read, write, and understand short simple messages). We use the term low-literate to refer to these two classes of people."	N/A
34	Guimarães et al.	2022	Interface design guidelines for low literature users: a literature review	LL	Acknowledges confusion around 'low literate', 'non-literate', and 'functional illiterate. adopts 'low literate (LL)' to mean functionally illiterate but avoids the term 'functional' due to its ambiguity.	Nil
35	Cheema et al.	2022	IoAT Enabled Smart Farming: Urdu Language-Based Solution for Low-Literate Farmers	Urdu-speaking low-literate farmers	Describes users as 'low-literate' but gives no reading comprehension measure. Adapts UI to language, not measured literacy.	Nil
36	Rayed et al.	2023	FS Design in Appstore-enabled Smart Featurephones for Low-literate, Marginalized Communities	LL	Nil	Nil
37	Melo et al.	2024b	Inspecting the Accessibility of Chatbots and Mobile Banking for Emergent Users in the Context of People with Low Literacy	LL/emergent users	Refers to low-literacy and emergent users but provides no operational definition of reading/writing skill. Focuses on digital literacy and notes that low-literate users may still engage with tech through non-verbal modes	Nil
38	Melo et al.	2024a	Inspecting the Accessibility of Instant Payment Systems from the Perspective of Low Literacy People	LL	Uses 'low literacy' without measurement or clarity, no criteria for classification.	Nil

39	Teran and Mota	2024	Design Considerations for Real-Time Payment Systems and Emerging Users	LL/emergent users	Mentions barriers to formal education and digital use. 'Emerging users' is not explicitly defined in literacy terms.	Nil