Designing usable mobile forms for collection of health data in Uganda

Alice Nandawula Mugisha

Thesis for the degree of Philosophiae Doctor (PhD)
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To my husband Sam Mugisha,
Children Matthew, Mark, Micah and Malta,
And mothers Mrs. Esther Kizza Mpagi and Ms. Joanna Kabuleeta Abwooli.

Scientific environment

This research is a result of the collaboration between Makerere University, Uganda (www.mak.ac.ug), the University of Bergen, Norway (www.uib.no) and Moi University, Kenya (www.mu.ac.ke), under the Health Informatics Training and Research in East Africa for Improved Health Care (HI-TRAIN) (www.hitrain.org) project. HI-TRAIN, supported by the Norwegian Agency for Development Cooperation (Norad) (www.norad.no), through the NORHED programme funded the PhD scholarship.

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Abbreviations

ACM	Association for Computing Machinery
CHW	Community Health Workers
CRF	Case Report Forms
CSUQ	Computer System Usability Questionnaire
DHIS	District Health Information Software
DHS	Demographic and Health Surveys
DS	Design Science
DSR	Design Science Research
DSRP	Design Science Research Process
EDC	Electronic Data Collection
FUS	Form Usability Scale
GPS	Global Positioning Systems
HCI	Human Computer Interaction
HIS	Health Information Systems
ID	Identification
IEEE	Institute of Electrical and Electronics Engineers
IT	Information Technology
NORHED	Norwegian Programme for Capacity Development in Higher Education and Research for Development
WHO	World Health Organization
ODK	Open Data Kit
OpenMRS	Open Medical Records Systems
OSS	Open Source Software
RA	Research Assistants
SAD	Specific Application Domains
SMS	Short Message Service
STEQ	Study Tailored Evaluation Questionnaire
SUS	System Usability Scale
QUIS	Questionnaire for User Interaction Satisfaction
UCD	User Centred Design
UI	User Interface
UPA	Usability Professionals Association
UX	User Experience
WYSIWYG	What You See Is What You Get
WYSIWYN	What You See Is What You Need

Definitions

Direct data capture: Is a type of electronic data capture in which the digital data collected by a specific device, for example a mobile phone is directly transferred into the study database without the need for further human entry [1].

Fidelity of the prototype: Indicates the level of details and functionality built into a prototype [2]

Heath Information System: Is an "integrated effort to collect, process, report and use health information and knowledge to influence policy-making, programme action and research"[3].

Heuristics: Are rules of thumb or general principles and recommendations that should be taken into account when a product is being designed and developed in order to obtain the highest level of usability [4].

Mobile data collection: Is a format of collecting data using mobile devices like phones and tablets (hardware) together with a number of different possible programs (software) [5] in a direct format [6].

Mobile health: Refers to the use of mobile devices such as mobile phones to deliver health care [7].

A prototype: Represents limited functionality of the desired product and is focused on answering specific questions about the feasibility and appropriateness of a product's design [8].

Usability: Is defined as the "capability of a product to be understood, learned, operated and be attractive to users when used to achieve certain goals with effectiveness and efficiency in specific environments" [9-12].

Usability evaluation: Is a method of identifying specific problems in Information Technology (IT) products with a specific focus on the interaction between the user and the task in a defined environment [13].

Usability testing: Is a "process that employs participants who are representative of the target population to evaluate the degree to which a product meets specific usability criteria" [14].

User Centred Design: Is a description of design processes where end users influence how a design takes shape [15] by involving them at every stage of the design process [16].

User Experience (UX): Is concerned with getting a more comprehensive understanding of the users' interactive experiences with products or systems [17].

Abstract

Background: Data collection entails obtaining quality and useful information by different organizations and institutions for purposes of answering a research question, establishing facts, making better decisions and solving major problems. Recently, here has been a rise in the use of mobile forms to collect data in health research, and more broadly in the delivery of healthcare using mobile devices. However, in spite of this increase in usage, mobile forms still pose some usability challenges specifically for users in rural areas. These usability challenges may be attributed to design limitations caused by small screen sizes of mobile phones, technology transfer from more industrialized countries, time constraints which do not favour form developers and sometimes incapability of form creation software. In addition, usability challenges crop up due to the low aptitude of form users and the type of content in the mobile forms. The major aim of this research therefore was to explore strategies that can be adopted to design more usable mobile forms which are used to collect health data in low resource settings in order to improve end user experience.

Methods: The research was anchored on the design science research methodology (DSRM). We explored the design flaws in existing mobile forms and the subsequent usability challenges, assessed existing design principles for mobile applications and obtained input from both form developers and software developers who are all key stakeholders in the mobile form development process. In addition, we involved form users by collecting their design preferences using mid-fidelity prototypes. High-fidelity prototypes were also developed based on these design preferences and the end user experience assessed after interaction with the prototype using the group usability testing approach.

Results: Some of the common design challenges in the forms included: lack of progress disclosure amidst the many pages in the form, no indicator on how to navigate the form, data validation problems and feedback delays among others. These design limitations led to usability challenges such as the inability of the form user to know where in the form they are and prolonged scrolling before accessing the required content. This research thus proposes 16 design principles to guide the design of mobile forms. The principles are categorized under 6 major themes namely: *communication, visibility, navigation, form layout, content characteristics* and *information*. Each of the design principles seeks to address some of the major usability challenges form users face during interaction with mobile forms. The principles are hinged on human computer interaction theories of discoverability and ergonomics which seek to address designing for effortless user interaction and for the most appropriate environment.

Conclusions: Designing for usability particularly for low aptitude users in rural areas is still a challenge because of the small screen sizes and the continued technology transfer from the more industrialized countries. The use of design principles during form design and evaluation can assist form developers create more usable mobile forms. In addition the use of prototypes as a means of involving form users in the design of mobile forms can be a basis for capturing implementing and evaluating user needs at minimal costs, hence leading to better mobile form designs and improved user experience during data collection.

Original papers

The thesis is based on the following papers:

I. Mugisha A, Babic A, Wakholi P, Nankabirwa V, Tylleskar T. Usability in Mobile Electronic Data Collection Tools: Form Developers' Views. Studies in health technology and informatics. 2017; 238:72. DOI: 10.3233/978-1-61499-781-8-72.

II. Mugisha A, Wakholi P, Babic A. Design Features for Usable Mobile Electronic Data Capturing Forms: The Form Developers' Perspective. InWorld Congress on Medical Physics and Biomedical Engineering 2018 2019 (pp. 463-466). Springer, Singapore. DOI: 10.1007/978-981-10-9035-6_85.

III. Mugisha A, Nankabirwa V, Tylleskär T, Babic A. A usability design checklist for Mobile electronic data capturing forms: the validation process. BMC medical informatics and decision making. 2019 Dec; 19(1):4. DOI: 10.1186/s12911-018-0718-3.

IV. Mugisha A, Krumsvik OA, Tylleskar T, Babic A. Data Collectors' Design Preferences for Mobile Electronic Data Capturing Forms. Studies in health technology and informatics. 2018; 251:93-6. DOI: 10.3233/978-1-61499-880-8-93.

V. Mugisha A, Babic A, Wakholi P, Tylleskär T. High-Fidelity Prototyping for Mobile Electronic Data Collection Forms Through Design and User Evaluation. JMIR human factors. 2019; 6(1):e11852. DOI: 10.2196/11852

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Chapter 1

1 Introduction

Data collection is the process of obtaining quality and useful information by governments, organizations and business institutes in order to answer a research question, establish important facts, make better decisions and to solve major problems [18]. For decades, paper based data collection followed by manual data entry into a computer database application for analysis [19] has been the most used method to collect data. With this method of data collection however, errors are frequent, storage and double entry costs are equally high [20], and time constraints inhibit the volume and the speed of needed research [19]. The errors may be as a result of inability to read the data collector's handwriting or simply un-checked human mistakes during data entry [21]. Consequently, the data is sometimes not readily available for decision-making due to the lengthy procedures involved in entry and analysis. As a result, there has been an increase in the use of mobile forms for data collection in health research and more broadly, health care systems using mobile devices. With mobile forms, the mobile devices make it possible to collect data while walking, while in different weather conditions and at different places [22]. In the subsequent sub sections, we discuss the use of mobile forms in the collection of health data, the design limitations and the usability challenges incurred when collecting data using mobile forms. We also highlight our contribution from this research and the justification of undertaking this study.

1.1 Mobile forms for collection of health data

There has been an increase in the use of mobile interactive technologies [23] such as mobile forms. Mobile forms are interactive elements on a mobile device that act as a contact point between the user and the source. They are also referred to as elements on a mobile device which enable user interaction through data entry. Mobile forms can be used to register, transact or simply, to search or share information. However, the major role of mobile forms is to collect data and to send results back to the source [24]. Lately, mobile forms are increasingly being adopted for collection of health data [25] during health research for example in surveys, in health monitoring and in testing new drugs and procedures in clinical trials. Health research includes testing ideas, answering questions, improving treatment options and increasing knowledge about human health [26, 27]. Mobile forms are also being used to collect data at the point of care by health care providers like doctors [28] and nurses at the health facilities. In this setting, a mobile form is described as an electronic form application in form of a questionnaire on a mobile device whose major role is to collect data.

Mobile forms are gradually replacing paper data collection. As a result, delays in data analysis and subsequent decision making are minimized because of the direct data capture, since it lowers the cost and time of data monitoring management, and cleaning [29]. Direct data capture also reduces on the potential human errors that may be committed during typing hence leading to better quality data. For example rules maybe set for the type of data to be entered, or controls in data submission may be set to prevent a user from submitting an incomplete form [18]. There are also savings made on the printing costs specifically where the study participants are many and questionnaires are long. And with large surveys consisting of study participants from different areas with different spoken languages, there is no need to print additional translated copies because preferred languages can be accessed on the mobile form if available [18]. Movement between clinical wards or households with mobile phones compared to big files of hard copy questionnaires is easier for form users who usually have to trek long journeys amidst extreme weather conditions and topological challenges. It is also possible to upload the often long health questionnaires onto the mobile phone without worrying about the space it will consume on the phone.

Programs like Demographic and Health Surveys (DHS) (dhsprogram.com) conducted in many low-income countries in close collaboration with the national bureau of statistics or community-based studies involving rural households are frequently using mobile forms to collect data. The data collected may include personal details of the interviewee, measurements of vital signs or diseases the patient may be suffering from, or allied information like photographs and recordings [30]. In addition, some organizations are monitoring their programs using mobile forms such as the World Health Organization (WHO), the World Bank and the International Federation of the Red Cross [21].

The collected data is used to track patients and to monitor disease outbreaks and programs by organizations [25]. The data may also be used to influence policy and decision making [28] by the Ministries of Health in the various countries. In addition, healthcare providers like doctors may use the collected data to make evidence-based discoveries and decisions at the point of care [28]. The availability of patient information and decision support at the point of care has the potential to reduce errors and improve workflow irrespective of the practice environment [31, 32].

Mobile form users who collect data in low resource settings include members of Village Health Teams (VHT) or Community Health Workers (CHW) with some training in community public health. The VHTs and CHWs are commonly lay community members that act as links to the formal health systems. They conduct home visits, assess and treat minor illnesses like uncomplicated malaria, educate, counsel and sometimes refer patients for further care [33]. This is because of their access to the rural communities and their accrued trust and confidence from the communities.

1.2 Challenges of using mobile forms for health data collection

In spite of the benefits of using mobile technology, mobile forms still pose some usability challenges. This can be attributed to design limitations caused by the small screen sizes of mobile phones, the shortcomings of the form creation software and usability design gaps due to technology transfer from industrialized countries to low income countries. This breeds usability challenges especially for low aptitude form users [34]. In addition, the form content may also lead to usability challenges because of the length of paper forms and the varying data requirements e.g. data types in the different sections. As a result, many mobile forms are abandoned because filling them is either too hard or tedious [35]. We elaborate on these in this section.

Mobile devices, especially phones generally provide small screens compared to A4 paper size or desktop computers, which poses a challenge related to display of the questionnaires on the phone. Condensing the content from an A4 size questionnaire to a small mobile phone screen creates design challenges in the form layout, the form navigation, progressive disclosure, table presentation and target selection. Form users invariably expect to see a replica of the hardcopy questionnaire on the mobile phone, which is often not the case because of the narrow screen width, which affects the form layout, hence creating many pages. Other challenges include interruption because mobile phones handle many other tasks e.g. phone calls due to their portability. Also, the single window view does not support multi tasking like on a desktop because a user can only access one view at a go [36]. This may affect continuity during data collection especially if the form user is not able to save the entered data. Furthermore, accessing the same paper information on a mobile form creates a higher interaction cost because the data is condensed and presented differently in order to fit on the small screen [36]. In addition, navigating a hard copy questionnaire only requires one to open a page and scroll through. However, seamless navigation in mobile forms is sometimes not catered for because the slide-shows to insinuate swiping or the navigation buttons are omitted. Designing progressive disclosure e.g. progress buttons for one to know where they are in the form particularly when there are many pages is also a challenge. This creates a different interaction experience from that of the paper based questionnaires where pages are numbered for easy identification. Also, presenting tables especially with many columns results in endless horizontal scrolling [37, 38]. Fitting a table in a single view on the screen reduces the readability of the content due to a scale down of information in order to curb down on the endless scrolling. Lastly tapping the wrong target on the screen comes easy especially because of the "fat finger" syndrome. Form users find themselves clicking the wrong targets because the touchable elements are not large enough and not adequately spaced to favour target selection [38].

The challenge of technology transfer from industrialized countries for use in low economic settings also breeds usability problems. Technology transfer refers to the transfer of technology e.g. artifacts from the richer or industrialized countries to the poorer ones [39]. Usability challenges occur because most of the developers of these technologies are not well versed with the contextual factors that could affect usability in such settings [40] e.g. technology infrastructure, demographics of the intended users, etc. The form users usually have little experience in the use of computers and mobile technology [34], making it difficult for them to use mobile forms. In addition, form users at the community level, particularly CHWs and VHTs are very often semi-literate [19]. In other words, the context of production is not the same as the context of use, which leads to the *design-actuality* gap [41]. This gap represents a mismatch between the local actuality (where we are now) and the system design (where the design wants to put us) [41]. The contexts of the developers and users are distant physically, culturally and economically, making their contextual inscriptions in the technology they develop different from user actuality [41]. For example technologies that require internet connection e.g. for real time updating of mobile forms [34] may not be viable in low economic settings due to the slow and intermittent internet connection. In addition, some design interaction features that are obvious to power technology users may not be so for novice or intermittent users, and if left out or not given proper instructions may cause usability problems. So, in the event that mobile forms are not designed to cater for the needs of such category of users, usability challenges are most likely to be present.

Finally, health questionnaires often have different sections with different data requirements, for example tables are designed differently from the usual row and column format. In addition, some of these paper questionnaires are long, and converting them to mobile forms creates many pages which lead to a lot of swiping during navigation.

1.3 Usability challenges in health information systems

A health information system is an "integrated effort to collect, process, report and use health information and knowledge to influence policy-making, programme action and research"[3]. Users however still face challenges during interaction with health information systems. A study conducted by Kushniruk and Borycki [42] applied usability problem codes to describe usability problems and issues identified when analysing video usability data. These codes were derived from HCI literature, resources on evidence-based user interface guidelines and the authors' over 20 years' experience of video coding in healthcare usability [42]. The video usability data consisted of the recorded user verbal expressions and the actions the user was doing on the computer during interaction with a health information system. Table 1, an excerpt from [42] indicates that usability challenges are still evident during interaction with technology.

Table 1: Usability problem codes and how they relate to the various usability problems

Usability Problem code	Indications of when the code is used after review of video data
Navigation	When the user has problems moving through a system or user interface.
Consistency	When a user has problems due to a lack of consistency in the user interface.
Meaning of icons/terminology	When the user does not understand the language or labels used in the interface.
Visibility of system status	When the user does not know what the system is doing.
Understanding error messages	When the user does not understand the meaning of error messages.
Understanding instructions	When the user does not understand user instructions.
Workflow issues	When there are issues with the system workflow which negatively impacts on the user interaction.
Graphics	When there are issues with graphics.
Layout	When there are problems with the layout of the screens or information on those screens.
Speed/response time	When the system is slow or response time is an issue.
Color	When the user does not like the color or color schemes used in the interface.
Font	When the font is too small or not readable.
Overall ease of use	When the user comments on overall usability of the user interface.

1.4 Designing mobile forms for better user experience

The challenges presented above indicate the gap in mobile form design and the need for better designed forms. In order to increase the chance of mobile forms being completed, the effort the form users put in to fill the mobile form and the information they need to remember must all be minimized [35]. As such, mobile forms should be easy to learn and remember, intuitive, easy to operate, understandable, accessible and pleasant to use [43]. These can all be addressed through user experience (UX) design. A UX design process aims at enhancing user satisfaction with a given product by improving the usability, accessibility and pleasure during the interaction process with the product [44]. UX design incorporates Human Computer Interaction (HCI) to address the needs of the users, because HCI applies psychological requirements of the users to software design [45]. Considerations during design include the nature of interaction between people and technology. It is thus important to know the technology that is going to be used and the kind of form users that are going to use the technology. For example, the form layout on a mobile phone is different from the layout on computer with a wider screen. Thus adopting user centred design (UCD) could be the solution. UCD is an evidence-based approach which is informed by the needs and a clear understanding of a particular end-user group [16], and can thus be a basis for good design.

Good design is characterised by discoverability and understanding [46]. Discoverability seeks to enable the user to figure out the possible actions and where and how to perform them during interaction. Understanding on the other hand seeks to attach meaning to the interaction, controls and settings and on how the product is supposed to be used [46]. Since mobile forms are used individually, form users have to do a lot of discovery on the form by themselves. Applying discoverability considers five concepts namely: *affordances, signifiers, constraints, mappings,* and *feedback.* "An affordance is a relationship between the properties of an object and the capabilities of the agent that determine just how the object could possibly be used" [46]. The relationship in *affordances* can be referred to as the possible actions during interaction. The focus of this thesis therefore was on finding ways of generating better form designs in order to improve affordances. Thus understanding the abilities of the agent (form user) could lead to better definition of properties of an object (mobile form), which would in turn make the user experience better during interaction. *Affordances* can be improved by including concepts such as *signifiers, mappings* and *feedback* in mobile forms and addressing the *constraints* that limit interaction. *Signifiers* communicate appropriate or inappropriate behaviour to a person during interaction. *Mapping* also needs to be natural in the way the form is laid out to quicken understanding. *Feedback* is concerned with communicating the results of any action and constraints are those things that tend to limit the user during interaction.

Thus the research question guiding this study was "how can mobile forms for health data collection in low resource settings be designed to improve end user experience?" To answer this question, we sought to determine usability implementation challenges and design flaws in the existing mobile forms used for collection of health data in low resource settings. We also sought to determine the most important usability design features in mobile data collection forms according to form developers and software developers. In addition, we sought to determine the user design preferences that define usability from the mobile form users' perspective. And lastly, we sought to determine the mobile form users' experience after interaction with a mobile form prototype that was developed based on the form users' design preferences.

1.5 Research contribution

Our contribution in this work was the usability design principles that can guide the design of usable mobile forms for collection of health data in low resource settings in order to improve user experience. Some of the principles included visibility of progress status, immediate and clear feedback in case of errors, accessibility of help instructions, visible table rows and columns with labelled fields and unique identification for the different entities in the form. We also propose the use of prototypes in the collection and evaluation of user design preferences as a way of involving the form users during the design of mobile forms where there is scarcity of resources such as time and money.

1.6 Justification of the study

Data collection is one of the most important activities in the health discipline because data is the basis on which decisions are made, short of which life can be lost. As a result, the data collection process is governed by rules and regulations to ensure reliable and quality data. Thus the design of mobile forms must be done to support the characteristics of health questionnaires, some of which include:

linkage of responses to each other, variations in the content layout, varied health terminologies and privacy during data capture, transmission and storage, among others.

Research to improve usability of mobile forms is scanty and yet their uptake in the collection of health data is steadily increasing. This is supported by the existence of UI design patterns specific to the desktop paradigm as opposed to the scarcity of standards for the mobile UI [47]. The success of any study is hinged on the quality of data collected, which in turn is partly dependent on the data collection tools. Data quality affects decisions that are made at both clinical and policy levels, and any wrong decisions made could lead to loss of lives [48]. This research addressed one of the data quality components which is usability. The findings from herein will contribute to designing better data collection forms, which in turn will boost better decision making in health.

Nayebi et al. [49] argue that there is need to evaluate mobile usability with more specific and systematic measurement methods. A lot of research on usability has been centred on mobile applications with a focus on web designs, mobile game applications, online forms, etc, [50] and not on mobile data collection forms. The content and the form users in those different web and gaming contexts certainly differ for example in terms of age and technology experience from low aptitude mobile form users who collect data in low resource settings. In addition, the intention of interaction differs and the consequences of poor interaction have far more reaching effects. The dynamics surrounding designing mobile forms for data collection in this regard are very different from the mobile applications or web context and these have not been fully exploited, thus making the basis of this research.

While form users play a vital role in the outcomes of the health data collection activity, they are barely the focus in many studies. Form users are merely recipients of mobile forms and their major role is to collect data, in whatever state the mobile form is. Health questionnaires are often lengthy and collect sensitive data which is of various data types. For example, some health studies may involve following up study participants for over 1 year, which requires form users to interact with the forms for longer periods of time. As such, mobile forms need to be designed to minimize frustration and boredom [37]. Also, health forms are sometimes used by health practitioners to make decisions at the point of care, and thus should be designed to minimize errors during data entry. It is thus important that interaction and interfaces are devised around the target users in order to cater for their needs and capabilities [51, 52]. Thus there was a need to involve form users in the design of mobile forms in this study in anticipation of more usable forms, hence a better user experience.

Therefore this thesis identified ways of improving end-user experience through designing more usable mobile forms that are used to collect health data in low resource settings. We explored the usability design flaws in existing mobile forms and the subsequent usability challenges, assessed existing design principles for mobile applications and obtained input from both form developers and software developers who are all key stakeholders in the mobile form development process. In addition, we involved form users by collecting their design preferences using mid-fidelity prototypes. High-fidelity prototypes were also developed based on these design preferences and the end user experience assessed after interaction with the prototype using the group usability testing approach. We later proposed design principles some of which were centred on *signifiers, mappings* and *feedback* that could be adopted during design of mobile forms.

1.7 Thesis summary

This chapter has introduced mobile forms and their use in health data collection, the justification and research contribution of this study. Chapter 2 describes the limitations in mobile form design and the subsequent usability challenges in data collection using mobile forms. Chapter 3 emphasizes the theoretical work that has been used in this research. Chapter 4 outlines the aims and objectives for this research. Chapter 5 presents the main research methods and data collection techniques that were used to conduct the research. Chapter 6 shows the results specifically from the five different studies. Chapter 7 indicates the discussion of the main findings and the methodological considerations of the research. Chapter 8 concludes and makes recommendations for future research.

Chapter 2

2 Challenges in designing mobile forms

"……. good designs fit our needs so well that the design is invisible, serving us without drawing attention to itself. Bad design, on the other hand, screams out its inadequacies, making itself very noticeable[46].

Designing mobile forms involves developing electronic forms where data is collected using mobile devices. However, this comes as no easy feat because of the small screen sizes of mobile phones compared to paper sizes, limited input capabilities, large heterogeneity in models [53], and design limitations in form creation software. In this section, we introduce the challenges in designing mobile forms. We describe in detail what mobile forms are and compare them to traditional paper based forms in relation to size, content, number of pages, navigation, data entry, editing, progress disclosure, tables and error handling. We further define mobile phone limitations that bring about design challenges in mobile forms, and in addition discuss the usability challenges caused by these design issues.

2.1 Characteristics of mobile forms

Mobile forms consist of features like: menus, tabs, tables, icons, text, images, scroll bars and text fields. On top of navigation, menus and tabs support the designer to make use of the small screen size to present as much information as possible by layering information. Tables are also used to present content on the screen in form of rows and columns, and images e.g. thumb nails may be used in addition to text to aid the user in target selection. Icons such as buttons are a visual representation used to indicate a target destination, indicate the system status or change in system behaviours [37]. For example, submission buttons may be greyed out to indicate that the button has already been pressed. Scroll bars assist in horizontal and vertical scrolling on a single page, while navigation buttons assist in back and forth movement between pages in a mobile form.

Mobile forms may also consist of single and multiple select questions, numeric and text fields, selection lists, drop down menus, inbuilt logic, geo tags, date and time questions and search fields which aid the form users in the data collection process. Online and offline data validation checks can also be implemented at the point of entry [54] to check for correct value types and value ranges in order to reduce on the chances of erroneous input due to a wrong target or logic that is not properly implemented [19]. Hardware dependent features like Global Positioning Systems (GPS) [34] are also used to capture the geographical location of the form user, which information is useful during data analysis. The use of selection lists restricts data entry to predefined options which prevents typing and data entry errors [19]. However, in some cases e.g. when uses select the *'other'* option, form users need to type text to support their input, hence the need for numeric and text fields. When designing mobile forms, it is possible to insert quality checking tools like filter logic to cater for skipping rules in the process hiding irrelevant detail [19]. These forms can also be coded not to allow forms that have not been filled or incomplete forms to be submitted [5]. Completed and submitted forms can only be accessed after authorization which enhances the privacy of sensitive data [19].

2.2 Contrast between mobile and paper forms
Mobile forms differ from traditional paper forms in the display size. Paper forms have a display equivalent to an A4 size paper while mobile forms are placed on mobile phones with a display of about 1/8 of a paper form, depending on the size of the phone screen. Because of the large display size, paper forms are more likely to have readable content and much bigger images compared to mobile forms. In addition, a mobile form tends to have many more pages compared to the same content in a paper form. Navigation of paper forms to enter data or in search of information involves simply turning pages back and forth, while mobile forms involve swiping or scrolling using buttons to navigate the form. Search fields are also deployed to enable information search [38]. Editing or updating of information in case of an error in paper forms involves deleting the unwanted response, which may not be possible in a mobile form especially if there is no indicator on how to do it e.g. having a button with an 'x' on every row [38]. However, it is important to note that one may not know if they have entered the wrong data in a paper form [18] e.g. numeric in place of text data because data validation is not instant unlike in mobile forms. Tables with properly labelled columns and rows are easily designed on paper due to the large paper width compared to mobile forms with a narrow view port. It is also possible for an incomplete paper form to be submitted, unlike in a mobile form which may deny submission of incomplete forms [18].

2.3 Designing mobile forms
Mobile electronic data collection (EDC) involves the use of mobile devices like phones and tablets (hardware) together with a number of different data collection software (programs) to collect data [5]. Examples of health information systems (HIS) and applications with a data collection component include: the District Health Information System (DHIS2) (www.dhis2.org), Open Data Kit (ODK) (www.opendatakit.org), but also more specialised tools like Open Medical Records Systems (OpenMRS) (www.openmrs.org), mUzima (www.muzima.org) and REDCap (www.project-redcap.org). The above technologies, also known as form creation software, are used to create electronic forms which are downloadable on either mobile devices or computers.

Different softwares are comprised of varying design features as shown for example in table 2. We compare some of the features in the ODK-collect, mUzima and DHIS2 form creation software.

2.4 Limitations in designing mobile health data collection forms
Designing mobile forms has a number of limitations, many of which may be attributed to different factors such as the characteristics of the mobile devices, form creation software, the form developers and the content in the paper questionnaire or form. Some of the common design challenges included: lack of progress disclosure amidst the many pages in the form, no indicator on how to navigate the form, data validation problems and feedback delays.

2.4.1 **Phone limitations in mobile form design**
Phone limitations can lead to challenges in the design of mobile forms. The biggest phone limitation in design is the small screen size which in turn leads to design challenges in: content layout, navigation, lists, target selection, table presentation, pages and information control. We discuss these in this section. The small screen size makes it difficult to cater for both the content and the chrome in a single view. Chrome contains the user interface elements which are instrumental when interacting with a site or application e.g. menus, buttons, tabs, etc and is not part of the content [36].

Table 2: Design features as represented in mobile forms of some of the most commonly used form creation software

Design feature	ODK-Collect	mUzima	DHIS2
Feedback after every interaction	Yes	Yes	Yes
Progress disclosure	No	No	No
Language selection	Yes	No	Yes
Logic implementation	Yes	Yes	Yes
Table presentation with rows and columns	No	No	Yes
Data validation	Yes	Yes	Yes
Help function accessibility	No	No	No
Proper spacing between text	Yes	Yes	Yes
Automated saving of form during data entry	Yes	Yes	Yes
Access to summary of entered data	Yes	No	Yes
Indication of navigation style	Yes	No	Yes
Adjustment of input modes during data entry	Yes	Yes	Yes
Provision for specific input styles in text boxes	No	No	Yes
Pop-up windows to display error messages	No	No	Yes
Use of expandable menus	No	Yes	Yes
Initial positioning of cursor before typing of text	No	No	Yes
Ability to search of filter information using pneumonic codes	No	Yes	Yes

1) Content layout

The small screen size of the phones affects the layout of content on the screen. For example, a linearized layout where blocks of information are stack on top of each other, often causes challenges for content with many columns because of the narrow phone width, making the content unreadable after scale down. The grid layout, where the screen is divided into multiple blocks which work as touchable buttons could be a good option particularly for presenting images, but does not favour long text [38].

2) Navigation

Navigation across the mobile application can be done using various techniques such as swiping, menus, navigation buttons, slide shows, vertical and horizontal scroll bars. Menus are used to navigate mobile applications and further reduce content on the screen such that it can be accessed only when needed by the user. However, designing long menus without covering the content when tapped is often difficult on a small screen because of the narrow width, and yet content is considered more important than navigation [24]. With narrow widths of the screens, some of the progress disclosures like slide shows and tabs are left out, making it hard for the user to know how to navigate. Too many pages in the application may also lead to a lot of swiping, and applications that do not fit on the screen size may culminate into unending vertical and horizontal scrolling for each screen.

3) Lists

Content in a mobile application can be presented using lists e.g. interactive links, menus, grids or tables. Vertical lists are the most commonly used lists in order to make use of the vertical space. However, this comes with a lot of vertical scrolling. In addition, a very extensive vertical list can be heavy on the mobile phone especially if displayed at once, hence slowing down the interaction process. Further still, with a long vertical list, it may be difficult to know the item to select especially if it's only text with no icons or images appended. Some vertical lists also end up blocking the rest of the content on the screen [38].

4) Target selection
It is important that all touchable elements like icons and links in the application are large enough, and have enough space in order to be easily triggered. However, the space that is left in between icons is usually not large enough to cater for the fat finger syndrome. In addition, ice berg tips that emphasize a target are sometimes also left out, which may also lead to tapping the wrong target [38].

5) Table presentation
Designing tables, particularly with many columns and rows is challenging on a mobile screen. A table which does not fit on a screen would lead to horizontal and vertical scrolling, which can be frustrating for the user. In addition, tables that are automatically fitted onto the screen lead to unreadable content [38].

6) Pages
Mobile applications tend to have many pages or screens because of the amount of content they harbour on a small screen. Links, menus and swiping are some of the ways through which these pages can be accessed [36, 38]. However, sometimes there are no indicators on how to access this information due to space issues e.g. no slide-shows to indicate the swiping option. In addition, links or menus can only be useful if there is internet connection, but may not be useful for offline applications. These many pages would also require progress disclosures, which are often left out due to the small screen sizes.

7) Information control
Information control consists of activities such as zooming, searching or filtering through the content for a user to access the information of interest [38, 55]. Due to space challenges, the search fields may be left out of mobile forms and would require the user to scroll through a lot of content until they get to what they want.

2.4.2 Case example: Survival Pluss
To discuss these design limitations further, we are going to use Figure 1 which shows an extract from a follow up paper questionnaire for Survival Pluss that was used to capture hospitalization details of a child on day 28 after their birth. The researchers sought to determine if a child had been hospitalised since birth, and if so, the number of times and the reason for admission each time. The number of days and the treatment for each hospitalization were also required. We shall use that extract to explain some of the limitations that occurred during the design of the subsequent mobile forms due to the factors already mentioned.

Survival Pluss, a NORHED funded mother and child project conducted a study (2015-2019) in Lira, Northern Uganda to examine the effect of an integrated intervention on the frequency of facility based births and perinatal mortality. The Survival Pluss study was a cluster randomized community based intervention whose results would be useful in framing the national policy in regards to the promotion of the use of health facilities during child delivery [56].

In this study, data was collected by research assistants (RAs) using Samsung galaxy J1 ace mobile phones of length 4.3 inches and with a view port size of 320*452. The mobile phones had a resolution of 480*800 pixels. The initial hard copy questionnaire which was converted to a mobile form was a survey questionnaire, which comprised of 70 pages before any updates to the original questions, with a font size of 12, line spacing of 1, with landscape orientation and a letter page size. The content comprised of single choice and multiple choice questions, data and time questions and repeating groups all of which had been translated into Langi, a language spoken in Northern Uganda. The paper questionnaire had the 2 languages presented side by side i.e.it was presented as 2 questionnaires in one. The mobile data collection forms were designed based on the paper version by one form developer over a period of 3-6 weeks before the piloting and training sessions.

An individual expert design review of the ODK-collect based mobile data collection form the RAs were using in the piloting session on the Survival Pluss project revealed several design issues [57] (Table 3)

Table 3: Design issues in the ODK-collect data collection form used on the Survival Pluss Project

No.	Usability issues
1.	No progress indicator was available.
2.	No navigation buttons. Navigations between screens were solely limited to swiping.
3.	Data validation challenges e.g. ability to enter numerals in place of text.
4.	The user needed to fill in numbers manually for a response such as “Don’t know”, which had to be filled in as “99”.
5.	One question per screen regardless of the question and the selection options.
6.	Some error messages were not consistent with labelling. “Participant Id no” was referred to as “PID” in the error message.
7.	Feedback in case of error was not immediate.
8.	Logic implementation challenges e.g. users having to respond to questions they would not have otherwise had to respond to because of the previous response.
9.	Unfriendly design of the date which required a lot of scrolling through years and months particularly for older participants.
10.	The form user was required to manually enter the participant ID even on follow up visits.

SECTION VI: HOSPITALIZATION
Dul VIII: Gamo atin itana idakatal

QUESTION ENGLISH	ANSWER ENGLISH	QUESTION LANGI	ANSWER LANGI
SVI-1. Since birth, has the child ever been hospitalized?	1. [ ]Yes 0. [ ]No	SVI-1. Ogamo atin itana anak?	1. [ ]Ee 0. [ ]Pe
SVI-2. How many times has the child been hospitalized?	________(##)	SVI-2. Ogamo itana tyen adii?	________(##)
SVI-3. How old in weeks was your baby when he/she was in hospital?	_______(##)	SVI-3. Atin onwongo tye cabit adii ikare ame obedo game itana iyore iyore?	________(##)
SVI-4. What was the reason for hospitalization each time?	0. [ ] No reason 1. [ ]Baby's body too hot 2. [ ]Baby's body too cold 3. [ ]Inability to drink or breastfeed 4. [ ]Vomiting everything 5. [ ] Convulsions or fits 6. [ ]Temperature < 35.5C or ≥ 37.5C 7. [ ]Skin pustules or a big boil 8. [ ] Movement only on stimulation 9. [ ] Eye problems 10. [ ] Ear discharge 11. [ ] Yellow skin or eyes 12. [ ]Yellow palms or soles 13. [ ] Diarrhoea 14. [ ]Visible blood in stool 15. [ ]Vomiting 16. [ ]Malaria 17. [ ]Umbilical infection 18. [ ] Other specify____________	SVI-4. Atin obutu itana idaktal pi nino adii iyore iyore	0. [ ]Tyen kop pe 1. [ ]Lyeto dwong atek 2. [ ]Kom atin ngic atek 3. [ ]Pe mato pe dot 4. [ ]Ngoko jami duc 5. [ ] Kange kom kede gweye 6. [ ]Lyeto kome < 35.5C or ≥ 37.5C 7. [ ]Kome tut kede gwenyo adongo 8. [ ] Yenge ka ogudu keken 9. [ ] Wange baltye iye 10. [ ] Yite cwer 11. [ ] Wange kede pyene yelo 12. [ ]Yii cinge kede tyene tye yelo 13. [ ] Cado 14. [ ]Remo nen inyongo 15. [ ]Ngokere 16. [ ]Malaria 17. [ ]Pene two omako 18. [ ] Okene pok yore ________________
SVI-5. For how many days was the child in hospital?	_________(##) Days	SVI-5. Atini obutu itana idaktal pi nino adii iyore iyore?	_________(##Nino)
SVI-6. Do you have medical records?	1. [ ]Yes 0. [ ]No	SVI-6. Itye kede balo me dakatal?	1. [ ]Ee 0. [ ]Pe
SVI-7. What treatment did the child receive at each hospitalization?	_____________	SVI-7. Kony me cango ango ame omio atin ikare man apatpat itana?	_____________

Figure 1: Section VI of the Survival Pluss paper copy questionnaire used to capture a child hospitalization record

1) Limitations due to mobile device characteristics

The Samsung galaxy J1 ace mobile phones had a narrow view port size of only 320*452. And therefore capturing many questions per screen was not possible because of the length and width of the phone. Thus ODK-collect form presented a single question or a set of instructions per screen (Figure 1), resulting into 280 pages/screens. This led to a lot of back and forth swiping during data collection and editing of the form because of the many pages.

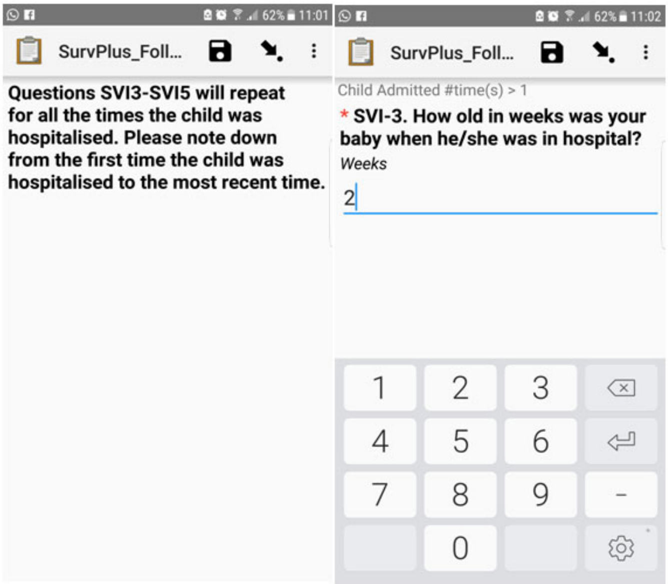

Figure 2: Screen shots showing question layout and instructions in mobile forms

2) Limitations due to the form creation software

ODK-collect had some limitations in design as shown in the navigation techniques, lack of progress disclosure and search fields, setting the dates, table presentation and manual unique identification of study participants. So the form developers designed forms based on the capabilities of ODK-collect which include: input prompts based on form logic, entry constraints and repeating sub structures. ODK-collect also supports location audio, barcodes, images, videos, multiple choice, free text and numeric answers [58] . With ODK software, form navigation was done by swiping, which is the default, and by the use of navigation buttons, which could only be selected in the settings. Otherwise, there was no other indication on how the user was meant to move from one screen to another. In the ODK-collect form, there is no indication of progress e.g. page numbers, progress status, amidst the many form pages, so the user is not able to know where in the form they are.

Much as it was possible to view all the data a form user had entered by clicking on the arrow in the header of the left screen, filtering using a search field was not possible except through vertical scrolling or swiping (Figure 2). This became a challenge especially where a user needed to edit after entering a lot of data.

Much as it is possible to automatically generate unique identifiers for the study participants using ODK-collect, these identifiers are too long and not user friendly. In addition, a unique identifier is appended to a particular filled mobile form, rather than to a specific participant, such that, a form with details of a particular participant obtains a new identifier each time the form is opened. This makes it hard to link longitudinally collected participant information and data in cases of follow up over time.

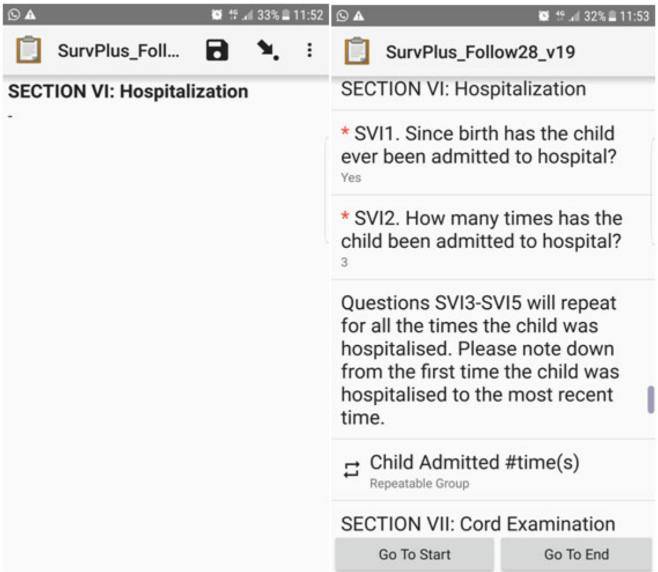

Figure 3: Screen shot showing a sample of a repeating group in ODK-collect designed mobile form

In addition, ODK-collect did not have a clear way of presenting tables, hence presenting questions as repeating groups (questions SVI-1 to SVI-6 in Figure 1 indicate repeating groups). The questions in the repeating groups were designed and presented in form of a loop, where RAs repetitively responded to the given questions based on the number of times the child had been hospitalized (Figure 4). Filling this section was tedious and it was also difficult for one to know on which loop they were especially if there were more than 2 hospitalization visits. In addition, if a user made any errors in one of the visits and needed to correct it, they would have to scroll backwards through the loops to correct that error.

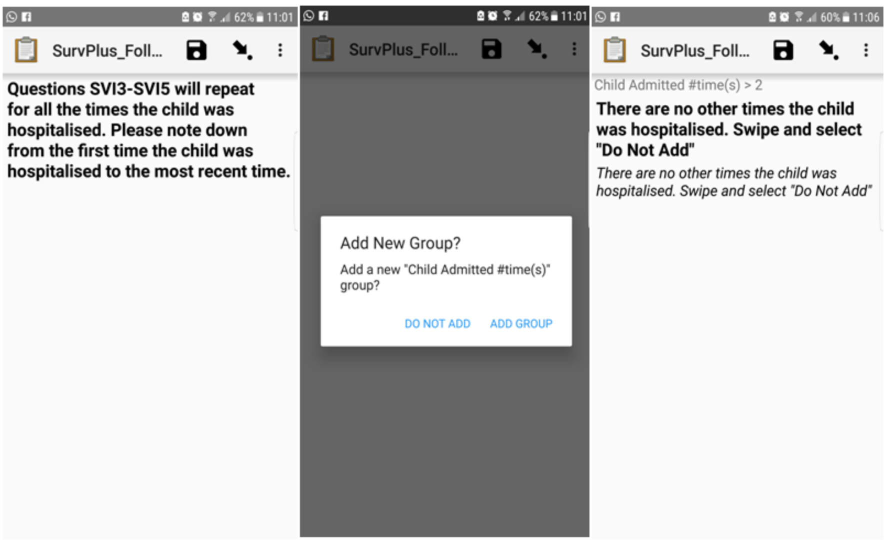

Figure 4: Screen shots indicating beginning and ending loops for repeating questions in the mobile form.

Some questions required the RAs to record the dates e.g. date of the interview or to record the study participant's date of birth. The date was designed in such a way that the RA had to scroll through the months and years of the date application until they got to the birth date of the study participant i.e. from 20^{th} March 2019 to 10^{th} October 2001 (Figure 5). This was tedious.

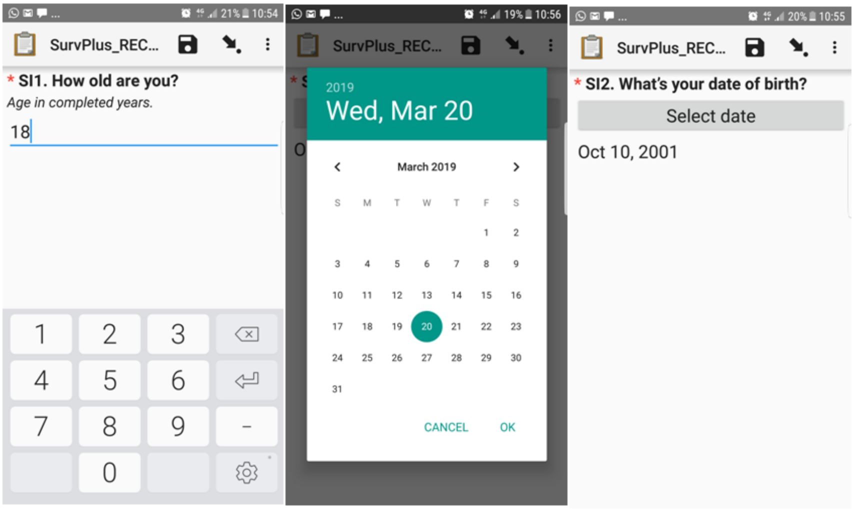

Figure 5: Screens showing the age and date of birth recordings

3) Limitations due to the paper questionnaire content

The content in the hard copy questionnaire also posed some design challenges for example the long selection lists, the language translation issues and the response options. These content challenges originated from the research implementers who are the sources of the questionnaire content. Some of the questions had long selection lists, which could not fit in one screen view without scrolling downwards (Figure 6, screen 1). For example question SVI-4 in Figure 1 *"what was the reason for hospitalization each time?"* had 18 options a form user could pick from. These options could not fit in a single screen view without scrolling up and down.

Furthermore, a respondent had to give an answer to each question and yet the option *'don't know'* had not been considered in the hard copy form in cases where the respondents did not know. For example all the questions in Figure 1 (SVI-1 to SVI-6) do not cater for a study participant who has forgotten or does not know the answer to a given question (Figure 6, screen 2). This encourages study participants to sometimes give wrong information so that the data collection process can continue because a user is then unable to proceed to the next screen.

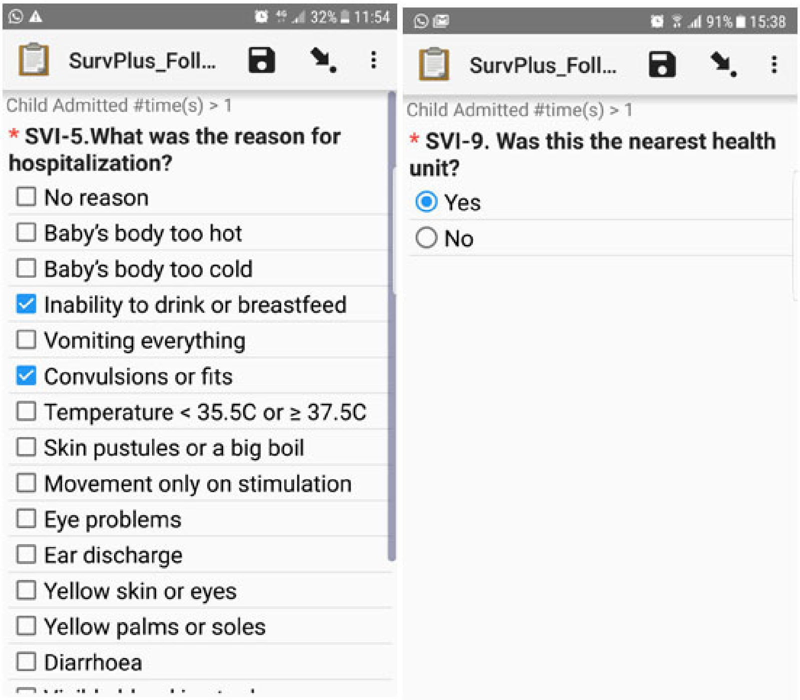

Figure 6: A question with a long selection list and the lack of an alternative response in the screen shots

4) Limitations caused by mobile form developers/designers

The last category of design limitations was attributed to the form developer's mistakes and oversights. These mistakes could be attributed to the short time between designing and delivering the completed mobile forms because of the stringent deadlines. Some of the questions were not validated, for example a user could put numerals instead of text in the input field, or a user could put in wrong information and still be able to proceed, such as a child being admitted 41 times (Figure 7). Secondly, RAs could also access the questions that were not meant to be accessed because of the previously selected options, an indicator that the skip logic had not been properly implemented.

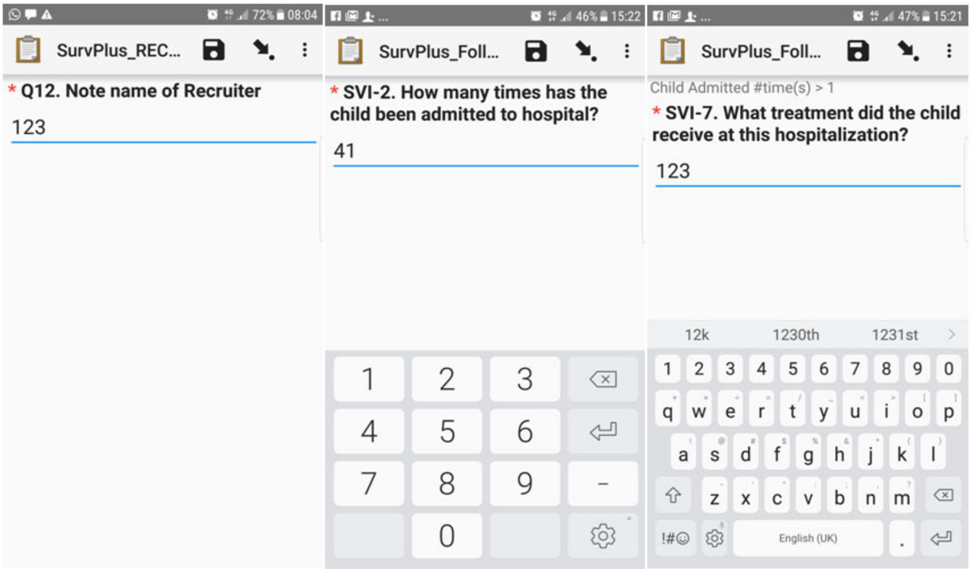

Figure 7: Screens showing some of the validation problems in the form

These design limitations could lead to usability challenges during data collection. We discuss these challenges in the next section.

2.5 Usability challenges caused by mobile form design limitations

"Forms are no fun. They require users to do a lot of work" [35]. As such, they need to be designed in the most appropriate manner to ease completion. Design limitations are one of the causes of usability challenges in mobile data collection forms. In this section, we introduce some of the features or issues that are common in mobile forms, we indicate the approaches being used to design the mentioned features and lastly state the usability challenges caused by such designs to the form users (Table 4).

Table 4: Usability challenges faced by form users due to limitations in design

Issues/Features	Design approach	Usability problems
1. Form layout	One question per screen especially if the sentences are long.	• Too many pages are created if the questions are many leading to prolonged swiping throughout the form. • Form users may not able to know where in the form they are especially if the pages are many and unlabelled.
2. Vertical lists	Use of vertical lists to represent response options in multiple choice and single choice questions.	• Continued vertical scrolling if the lists are long in order to read the content that cannot be viewed on the narrow screen.
3. Navigation	Use of swiping, navigation buttons and slide shows. There is often no indication on how the user is supposed to navigate the form.	• It is not obvious to the users how to navigate the form. • Navigation may become tedious and boring especially if the pages are too many. • The phone screen may freeze especially if the pages are many.

Issues/Features	Design approach	Usability problems
4. Tables	Use of rows and columns	• Too many rows and columns lead to readability problems due to a scale down of content to fit on the screen. • It also leads to horizontal and vertical scrolling because of the narrow screen width and the short mobile phone length.
	Use of repeating groups	• Editing of data e.g. deleting in the table is tedious because there is no delete function. • If the groups are many, the form user may lose track of the loop.
5. Information control	Use of zooming, searching or filtering options to assess intended data.	• There are usually no search fields, so the user is left to scroll through the data. This can be tedious if the pages are many. • Zooming is only possible if the data of interest is on the screen, otherwise a user sill needs to manually search through the data.
6. Data input mode and target selection	Text and numerical fields	• Without placeholders or text labels, users do not know what to put in the text box, and the format in which it should be input. • Entry errors happen when the keyboard is not changed to depict the expected data format e.g. text or numerals.
	Radio buttons and check boxes used for selecting response options.	• They do not use iceberg tips because of space problems. It thus becomes easy to select a wrong target due to the big finger sizes and lack of adequate space between content.
7. System confirmation	Use of icons such as submission buttons may not turn inactive after tapping.	Confirmation is meant to indicate a system's status, or change in system behaviour but this does not happen sometimes. Thus the user is not able to know if the intended action has been successful or not, which may prompt multiple pressing by the form user.
	Use of error and feedback messages which are not instant, unclear and invisible to the form user due to positioning.	• Errors that can only depicted when a form user fails to proceed to the next page cause frustration. • Unclear or invisible messages leave the user unaware of how to proceed with addressing the issue at hand.

These usability challenges are an indicator that there is still a gap in the design of mobile data collection forms used in health information systems which needs to be addressed. However, designing for usability will require focusing on the specific category of users, understanding the tasks to be performed and appropriate handling of errors, among others. Thus a clear description of who the target users are is necessary in order to design appropriate products [43]. Users from the same user communities in essence have different knowledge and usage patterns, thus user profiles that reflect the age, gender, education and training are vital in understanding the user [59]. These differences may further be escalated if users belong to different countries, different economic levels, technology use differences and attitude.

In addition some of the users may have different skill levels and thus their varying needs have to be catered for during design. For example first time or novice users need a product that will inhibit their anxiety and fears during interaction in order to carry out simple tasks successfully and with confidence. Knowledgeable and intermittent users need to be able to work with the product with ease even after a period of non-interaction. And lastly expert, frequent or power users seek to finish their work quickly because they are usually familiar with the interface and the tasks to be done [59].

We therefore propose that mobile forms are designed to be intuitive and easy to use depending on the level of usage of a user. We discuss the theoretical principles that may be adopted to address this issue in the next chapter.

Chapter 3

3 Theoretical background

"Good design requires good communication, especially from machine to person, indicating what actions are possible, what is happening, and what is about to happen" [46].

The usability of any product is usually demonstrated through its interfaces [50]. In fact the usability challenges identified in the mobile forms indicated that there were still interaction problems which needed to be addressed. Human computer interaction (HCI) is a theory that can be adopted to improve usability and is focused on improving the interaction between humans and computers through design, development and evaluation of the products. This chapter therefore describes HCI and the principles it deploys to ensure usable products. We also elaborate on the principles of ergonomics and discoverability which introduce an intuitive approach to computer interaction in the most appropriate and comfortable environment.

3.1 Human computer interaction

Human computer interaction (HCI) is a multidisciplinary field of study focusing on the design of computer technology, particularly on the interaction between humans and computers. HCI designs aim at creating interactive products that are easy and enjoyable to use [60]. HCI involves designing, developing and evaluating computer-based interactive systems so that users are able to use them effectively and efficiently with satisfaction [61]. Evaluation in HCI provides relevant findings on the user experience during and after interaction which aids in the improvement of systems and devices [37]. HCI consists of a number of principles which are meant to guide the design of usable products which we discuss below. These principles include: *knowing the target users, understanding the tasks at hand, reducing the memory load, naturalness, error prevention and reversal, consistency* and lastly *refreshing the users' memory* during interaction.

1) Knowing the target user

Interaction and interfaces should be devised around the target users in order to cater for their needs and capabilities [51]. For example, VHTS or CHWs who collect data in rural settings are usually advanced in age, with low education levels and with hardly any experience in the use of technology like mobile phones because they cannot afford them. Such category of users would need mobile forms that are very basic and simple to use. It is thus necessary to collect and analyze information such as age, gender, education level, computing experience and cultural background about the representative target users. This helps determine the users' probable preferences, tendencies, capabilities and skill levels. Knowledge from cognitive psychology, ergonomics and anthropomorphic data may also be used to understand the target users in cases where a direct field study is not possible [51].

Interfaces could also be designed based on the knowledge level of the form users i.e. novice users, intermittent, frequent or power users. Thus shortcuts, particularly for frequent users, should be provided on the basis that they are meaningfully related to longer procedures [62]. This is because as the frequency of use increases, the users desire to perform a similar task in a much shorter time. Nurses could for example be rated as power users because of their higher education levels and frequency of use, while VHTs are novice or intermittent users because of their lack of expertise with technology. So while VHTs may need frequent and easy access to help instructions and would thus need a help button appended to the text box, nurses may be more interested in easy navigation through the form.

2) Understanding the task

The interface design should be based on understanding of the task to be handled. A task is a job to be accomplished by the user through the use of the interactive system. It involves identifying the sequence and structure of the subtasks the way the target user would follow through [51]. The system should be designed to make users the initiators of actions rather than responders. For example, a form user filling a table in a mobile form should be able to relate it to the actual table in a paper form especially with activities such as editing or updating the table. In addition, navigating a paper form is a matter of turning pages and thus form users are always abreast with where in the form they are at any particular time because of the page numbering. So even in mobile forms, users need to know where they are. This can be done by using a graphical progress indicator, percentage or a simple chronology whenever a submission is made or a particular section of the form is saved [63]. Important to note is that the task model or interaction model should ideally come from the user to ease implementation for all users, but this is more often not the case as different users have different mental models of the same task based on their experiences. The onus is thus left on the designers and developers to determine the most suitable flow based on the general human capacity [51]. For example filling some body's date of birth in the ODK-collect Survival Pluss form required one to scroll through all the dates, months and years until the target date. This is generally frustrating to any form user.

3) Reduce memory load

Memory load must be kept at a minimum as humans are more efficient in carrying out tasks that require less memory burden, whether long term or short. This will make completion of a task through the interface quicker and easier. Keeping memory load at a minimum also reduces on erroneous behaviour. One way of achieving this is by reducing on the number of menu items on the interface, which helps the user easily follow through the task. Multiple page displays must also be consolidated and window-motion frequency reduced. In addition, reminders, training and status information may also be provided continuously during the interaction, to keep the user up to date with what is happening [51]. For example because there was no search field in the ODK-collect form that was used in the Survival Pluss project, if the users needed to edit anything, they would have to recall the section where the question to be edited was and then scroll through the filled form to get to it. Users should also not be overwhelmed with information on the screen that they may not need at a particular time. However, all the needed options and information to accomplish a given task must be explicit and visible to the user as and when they need them. The goal is to go beyond *what you see is what you get* (WYSIWYG) to *what you see is what you need* (WYSIWYN) [62]. The content displayed on the screen at any one time should reflect the previous user activities.

4) Strive for consistency

Maintaining consistency is a solution to reducing on memory load [46, 51]. Consistency within and across mobile electronic forms allows the user to build expertise faster [64]. This is attributed to the sense of familiarity created as the user navigates the mobile form and also makes it easy for one to achieve their set goals. Consistency and standardization involves: using similar graphical elements and terminologies across the form [65], using same format, alignment and colour scheme and consistent response options, for example when using Likert scale responses. There should also not be any differences in the way questions appear as a result of different screen configurations and operating systems [65]. If the same sub-task is involved at different times, using different interaction steps, a user is likely to get confused and exhibit erroneous responses. This in turn can affect the acceptability and preference of the application because users cannot easily get familiar with the application. It therefore calls for consistency in the interaction model and in the interface implementation, irrespective of whether the application is the same or different [51]. Furthermore, identical terminology must be used in prompts, menus and help screens, together with employing consistent commands as and when necessary.

5) Remind users and refresh their memory

Interfaces should give continuous reminders of important information so as to refresh the user's memory. This is more relevant especially in cases where a number of tasks are being handled simultaneously. Informative, momentary or continuous feedback is also necessary to support easy and smooth completion of the task [51]. For example, some content could be fixed on the header e.g. menus and tabs such that even when a form user scrolls through the form this fixed content can still be seen through the viewport. Additional information like page numbers could be placed on the headers or footers of pages.

Feedback should also be concise and in an unambiguous language, should be noticeable, legible and correctly interpretable by the users [62]. Feedback involves sending back information to the user about what action has been done and what has been accomplished, which allows the person to continue with the activity [46]. The start, middle and end of any task during interaction with technology must be clear for a user to complete a task [62]. For example a user should be notified after a successful or failed interaction. Feedback should be readable and understandable by the user and should be given in a timely manner [59]. This gives a user the satisfaction of accomplishment, a sense of relief and is an indication to proceed with the next task or group of tasks.

6) Prevent errors/reversal of action

It is always important to have an error free task completed irrespective of the timelines. Therefore the interaction and interface should be designed to avoid confusion and mental overload, thereby reducing on the possibility of making errors. One way of addressing this is by presenting only the relevant information or action at a given time. For example by using inactive menu items when not needed or having the user choose from a menu list instead of direct text input [51]. Furthermore, the system should be in position to detect the error, and provide simple and comprehensible solutions to handle that error. However, in the event that a user makes a mistake, there should be a feature that allows for easy reversal of action through undoing and redoing of a given action [65-67], also known as the tolerance principle. For example in case one wants to delete a table row, a button with an *'x'* or *'reset'* could be placed adjacent to each of the table rows. This will increase the user's confidence and satisfaction knowing that errors can be undone, hence encouraging exploration of unfamiliar options [62].

7) Naturalness

The interaction and the interfaces must be natural, and not so different from what the users are used to. In other words, the users must be able to relate with the way operations are carried out in everyday life. A natural interface will also have affordance that appeals to one's innate perception and cognition, making it so intuitive that the interface almost does not require learning [46]. For example the direction of pointers on a vertical scroll bar is an indicator of upward or downward flow along the page. In addition, the navigation or swiping direction could be indicated by using forward or backward pointing arrows or navigation buttons with '*next*' to show forward movement and *'previous'* to indicate backward movement.

3.2 Principles of interaction in human computer interaction

On interaction with a good design, any user should be able to figure out how to work with the product effortlessly. In other words discovering what the product does, how it works and what operations are possible [46]. This is known as *discoverability*. Discoverability is made possible by applying six fundamental concepts namely: *affordances, signifiers, constraints, mappings, feedback* and considering *conceptual models* [46].

1) Affordance

An affordance is defined as the relationship between properties or qualities of an object and the capabilities of the agent which determine how the object could possibly be used [46]. An object or organism is able to perceive the affordances of its environment which then determine the possible actions of the object [68]. The existence of an affordance depends on the properties of both the object and the agent. Affordance in this case defines the positive interaction or the possible actions, where the form user is the agent and the mobile form the object. The capabilities of the agent represent the aptitude levels and the context of use, while the qualities of the object are the mobile form designs. Anti-affordances are the actions that are not possible during interaction due to certain constraints e.g. failure to enter one's name because of the input mode indicating integers. Affordance is thus an important concept in design [68].

In mobile forms, affordance refers to the possible activities the form user is able to perform during interaction with the mobile forms. Some of these include: navigation, text typing, reading content, editing and deleting of content, saving, content searching and target selection e.g. buttons, lists, etc. However, in order for affordances and anti-affordances to be effective, they must be discoverable by the form user [46]. In other words a user should be able to tell with ease what is possible and what is not possible during interaction. For example a submission button which has already been tapped should be greyed out to prevent multiple taps and subsequent submissions [67, 69].

2) Signifiers

In the event that affordances or anti-affordances are not discoverable or perceivable, signifiers may be used [46]. Signifiers act as communicators to where and how any form of action should take place. Signifiers play the same role as *scripts* [68, 70], which are used to prescribe the possibilities and impossibilities of the designed products using materials and products that are inscribed with particular purposes by designers [68].

Signifiers may be represented as a mark, or words to communicate a user's expected behaviour [46]. For example a date icon should be indicated and activated where a date is supposed to be placed, or placeholders may be put in text boxes to indicate the data input format. Signifiers are also tasked to communicate any anti-affordance tendencies which block interaction. For example a system popping a confirmation request before someone completely deletes an item. Signifiers thus support affordances to enable the desired interaction.

3) Mapping

Mapping should be natural in the way the form is designed to quicken affordance. In other words the set of possible actions should be visible and the controls and displays should exploit natural mappings [46]. For example, upward or downward scrolling should be indicated by appropriate arrows.

4) Feedback

Feedback is concerned with communicating the results of any action i.e. all actions need to be confirmed. For example errors and constraints are those things that tend to limit the user during interaction which must be communicated and addressed. The feedback needs to be immediate and informative in terms of what has happened and what can be done to rectify the problem if any. However, it must be done in regulation in order not to frustrate or cause anxiety [46].

5) Conceptual model

A conceptual model is an interactive and visual representation which is designed to depict a concept or a number of connected concepts, to support conceptual learning via multimedia and manipulation and interrogation processes of presented properties and relationships [71]. A well designed object should elicit the same conceptual model across a variety of users, which would favour closely related operations [46]. For example one of the most crucial steps in designing a user interface for a software application is to design a coherent, task-focused conceptual model. Such a model enables designers to design better, developers to develop better and users to learn and use better and thus should be based on the users' task domain rather than on the underlying technology [72].

However the limited screen sizes affect the delivery of effective conceptual models [71] due to the following issues as outlined by Albers and Kim [73]. These include: a) increased difficulty of reading text on a small screen compared to paper, b) limited graphical presentation of information as regards the size and complexity of image and c) interactivity limitations due to the lack of keyboard and mouse and yet the small screen size limits display of interactive elements [73]. To address these challenges therefore, conceptual models may need to consider the following recommendations by Albers and Kim[73]:

Recommendation	Description
• **Design for full screen presentation**	To increase the amount of screen space and improve user experience.
• **Design for landscape presentation**	To create more flexibility for design due to increased space.
• **Minimize scrolling**	Avoid or minimize scrolling.
• **Design for one-step interaction**	Ability to visualize and interact through a single display that fits in the mobile screen, irrespective of the interaction at hand.
• **Provide zooming facility**	Ability to enlarge and drag the screen in any direction for easy accessibility of the information beyond the screen size.

• **Design movable, collapsible, overlapping, semi-transparent and interactive panels**	This helps to maximize the amount of information presented on the display.
• **Present information visually**	Predominantly make use of illustrations, diagrams, graphs, icons and symbols.
• **Design for interaction**	Display relationships in an interactive ways to allow users to manipulate parameters and observe outcomes e.g. using sliders, clicking on buttons or data or text inputting.
• **Design for a single screen**	A conceptual model should be most often presented in a single screen.
• **Design for small space**	Utilize the available screen space to represent the required information, properties, relationships and interactive elements.
• **Use colour in moderation**	Avoid sharply contrasting colours, but different shades may be used.
• **Avoid unnecessary decorative elements**	To prevent complexity which could result in increased cognitive load, thus should be avoided or used in moderation.
• **Design with a single font**	To keep the presentation simple.
• **Use frames to logically divide the screen area**	Interactive elements like sliders and buttons may be grouped together in one part of the display area, leaving the other part for output information.

3.3 Designing mobile forms for usability

It is therefore imperative that mobile forms are designed to be discoverable in order to improve on their usability and the form users' experiences during and after interaction. In order for objects to be discoverable and thus usable, it is important that the object characteristics are known, and the design fits the context at hand [61, 74]. Ergonomics is a discipline in HCI which is hinged on handling such issues. For mobile forms, ergonomics can be implemented by using design patterns that are specific for mobile forms. We discuss usability, ergonomics and design patterns in this section.

3.3.1 Usability

From a broader perspective usability is defined as a good and usable interface [75]. A usable interface is considered to be easy to learn and remember, intuitive, easy to operate, understandable, accessible and pleasant to use by the intended users [43]. Thus, a usable product must be easy for users to become familiar with during the first contact, users must easily achieve their objective through using the product and lastly users should be able to recall the user interface with ease on later visits [76]. Usability is thus the ability to use a product with effectiveness, efficiency and satisfaction in a specific context of use [10]. In other words, it should be able to cater for the different types of form users and form usage experience. However, usability is not absolute, and thus has no absolute measures, but can only be defined or achieved in reference to a particular context [74]. For example the measures of usability for a desktop application may not apply to a mobile application because the usability requirements for the 2 types of applications differ due to the variations in screen sizes. Secondly, the usability of a system can only be defined when its intended users are known, the tasks to be performed by those users are defined and the characteristics of the physical, organisational and social environment in which it will be used are all defined [74].

3.3.2 Ergonomics

Ergonomics is focused on designing devices, work stations and work environments so that they fit the people who use them [61]. It involves refining the design of products to optimize them for human use. Ergonomics thus goes beyond the functionality of a product to consider comfort during interaction with the product. Thus in the case of mobile form design, a clear knowledge of who the target users are, the kind of interaction and the type of device during interaction is key in ergonomics. The target users may differ in technology exposure, in interaction experience in age or in literacy levels. On the other hand, devices may differ in size and capabilities. All these must be catered for during design.

3.3.3 Design patterns in mobile applications

Design patterns can be implemented to improve discoverability and hence usability in mobile form data collection specifically for low aptitude users. Design patterns are defined as "the description of a problem which occurs infinite times in our surroundings, along with its solution, so we can reuse it a million times in the future without re-thinking" [77].

Solving a problem involves resolving or balancing the 'forces' that are conflicting in a given context [38]. Forces are the constraints that drive the design, and that must be answered if the system is to function appropriately. The forces that drive design in mobile forms used for health research in low resource settings include: the small screen size of the mobile phones, the questionnaire content, the form creation software limitations and the shortcomings of the form designers and developers.

Advantages of design patterns include provision of common vocabulary and technology to both designers and non designers which aids in team communication and less misunderstandings [78]. There is also a reduction in design time and effort on new projects because designers adopt a set of reusable and already proven solutions. And to the users, there is a reduction in cognitive load required to interact with new interfaces because of the familiarity that results from using similar design patterns in development [38].

There are different design patterns depending on the context of use. For example web design patterns for mobile devices include: layout, menus, lists, progressive disclosure, tables, searching and target selection [38]. Design patterns for usable touch screen based mobile devices include: the thumb rule, performance and feedback, explicit user control, recognizable icons, clean form fields and shape of buttons [55]. Furthermore, mobile user interface design patterns include: page composition, display of information, control and confirmation, revealing more information, lateral access, navigation, button, icon, information control and input/output mode [37]. These design patterns are meant to improve the usability of mobile interfaces.

Thus adopting some of these design patterns to address the challenges in designing for mobile devices will help address issues such as limited screen size, ubiquity, and small virtual keys [37] that are common with mobile phones. The design patterns further propose solutions on how to utilize screen space and also devise interaction mechanisms [55], some of which can be adopted for the mobile form context.

3.4 Heuristics and heuristic evaluation

Heuristics are rules of thumb or general principles and recommendations that should be taken into account when a product is being designed and developed in order to obtain the highest level of usability [4]. Several methods/techniques are available to ensure usability with performing heuristic evaluation on the interfaces being among the commonest, even though it may not be as effective as it claims [79]. Using this technique, "reviewers, preferably experts, compare a software product to a list of design principles (or heuristics) and identify where the product does not follow those principles"[80]. Heuristic evaluation is popularly used because of its fast speed, low cost, low resource consumption and accurate results [23, 81, 82]. It also has the ability to find more usability problems compared to other methods [83].

The most commonly used heuristics are Nielsen and Molich's desk-top oriented heuristics [84]. These consist of 1) visibility of system status, 2) match between system and the real world, 3) user control and freedom, 4) consistency and standards, 5) error prevention, 6) recognition rather than recall, 7) flexibility and efficiency of use, 8) aesthetic and minimalist design, 9) help users recognise, diagnose, and recover from error, and 10) help and documentation. However, these may not always be appropriate during evaluation of the different types of mobile interfaces and in addition may lack mobile-specific interface characteristics [85]. In fact Heo et al. [86] reaffirm the limitation in revelation of many mobile usability issues despite the big number of usability heuristics.

3.4.1 A sample of methods used to develop usability heuristics for mobile applications

The most common steps in the creation of usability heuristics include *extraction of information* and *transformation of the extracted information* into heuristics [87]. For majority of the studies the extraction of information was done based on review of literature studies, developing a corpus of usability issues and also on studying the context of use and identifying aspects relevant to the user [87]. However, some studies combined the different methods (Refer to table 5), but generally there was no indication on why researchers chose to use a given method or a combination of methods. The transformation of the extracted information into heuristics is not very clear from literature; however, 3 main approaches were stated. The first one was to list all the extracted information like guidelines, usability issues, and existing heuristics and omitting any redundancies and irrelevancies, and using the outcome as the final set of heuristics [87]. The second approach involved categorization of the already extracted information into themes. These are then translated into heuristics using opinions from experts. The last approach was comparing the listed extracted information with the general set of heuristics e.g. Nielsen's which led to a modification of the list or addition of new heuristics. The heuristics were also validated by being used by experts to evaluate the target domains in order to determine the usability challenges and their severity. Also results from the evaluation using the new heuristics could be compared with results from the already existing heuristics, or with results from usability testing by the end users [87]. Additional details in table 5.

3.4.2 Usability evaluation heuristics for various mobile application domains

Gomez et al. [88] proposed 13 heuristics and 230 sub-heuristics for evaluating the usability of mobile interfaces. Sub-heuristics refer to specific guidelines [88] that describe a given heuristic. The heuristics include 3 additional heuristics on top of Nielsen and Molich's 10 heuristics [84]. The sub-heuristics consist of 158 sub heuristics and 72 mobile-specific most of which were taken from [89-91]. Using statistical experiments, the checklist showed its usefulness even for untrained developers who perform heuristic evaluation [88]. Omar et al. [92] proposed a checklist to evaluate the usability of mobile Enterprise Resource Planning (ERP) user interfaces (UIs). They reused the checklist from Gomez et al [88] and enriched it with 6 additional heuristics and 230 sub-heuristics, making a total of 19 heuristics and 460 sub-heuristics. The new sub-heuristics were meant to address ERP functionality and included [92]. Thitichaimongkhol et al. [80] developed a checklist for android applications that is comprised of 12 heuristics and 146 sub-heuristics. Ninety four sub-heuristics were taken from Pierotti's heuristic evaluation system check list [89], and the 52 sub-heuristics were introduced by the authors. The check list was found to be statistically more efficient than traditional heuristics in the rate at which it detected design problems [80]. More mobile application heuristics are found in table 5 below.

Table 5: A description of usability heuristics sets for various mobile applications and the methods used to develop them between the years 2014 and 2019.

Heuristics set	Methods used to develop the heuristics	Number of heuristics and sub heuristics
A checklist to evaluate the usability of mobile interfaces [88].	[1] Definition of problem scope to identify and classify the specific mobile interactions. [2] Rearranging of existing heuristics from literature into a new compilation. [3] Compilation of different proposed sub-heuristics. [4] Enriching of the list with different mobile-specific sub-heuristics from the various mobile usability studies and best practices from literature. [5] Homogenizing the redaction and formatting of sub-heuristics to make them useful for non-experts. [6] Evaluation of the checklist's ability to assist in mobile design.	13 heuristics and 230 sub-heuristics. Include Nielsen and Molich's 10 heuristics [84] together with 3 additional heuristics namely: *Skills, pleasurable and respectful interaction with the user* and *privacy.*
A checklist to evaluate the usability of mobile Enterprise Resource Planning (ERP) user interfaces (UIs) [92].	[1] Definition of problem scope to identify and classify the special characteristics of mobile ERP interactions and the specific usability challenges stemming from the UIs. [2] Analysing and enriching the existing heuristics from literature and compiling them into a new list inclusive of specific heuristics for the mobile ERP context. [3] Enriching the heuristics with a compilation of different proposed sub-heuristics for clarification purposes. [4] Homogenizing the redaction and formatting of sub-heuristics to make them useful for non-experts.	19 heuristics and 460 sub-heuristics Include the 13 heuristics from from Gomez et al [88] together with 6 additional heuristics to address the ERP functionality. The additional heuristics include: *Navigation and access to information*, *presentation of screen and output, appropriateness of task support, intuitive nature of system (learnability), ability to customize* and *the ability to support adaptive user interfaces.*
A usability checklist for android applications [80].	[1] Review of existing usability heuristics and comparison of Nielsen's, Schneiderman's and the iOS and android design principles. [2] Construction of a checklist of yes/no questions from literature in order to judge their compliance with usability design heuristics for android mobile applications. Additional questions are obtained from the authors' experience in android mobile development. [3] Validation of the checklist by 5 android developers. [4] Definition of use of checklist.	12 heuristics and 146 sub-heuristics. Include Nielsen and Molich's 10 heuristics [84] together with 2 additional heuristics namely: *pleasurable and respectful interaction* and *privacy.* Ninety four sub-heuristics were taken from Pierotti's heuristic evaluation system check list [89], and the 52 sub-heuristics were new and introduced by the authors.
A set of usability heuristics for u-learning in ubiquitous computing [93].	The methodology was based on Rusu et al. [94]. [1] Exploratory stage: Collection of data about u-Learning applications, their characteristics and any related usability heuristics.	Comprises of 16 heuristics derived from distinctive u-learning features and particularization of Nielsen and Molich's heuristics. The additional heuristics include:

Heuristics set	Methods used to develop the heuristics	Number of heuristics and sub heuristics
	[2] Descriptive stage: Highlighting of the most important characteristics so as to formalize the main concepts related to the research. [3] Correlational stage: Identification of special characteristics that usability heuristics for u-Learning applications should have based on traditional heuristics and case studies analysis. [4] Explicative stage: Formal specification of the proposed heuristics based on a standard template. [5] Validation stage: Checking the new set of heuristics against the traditional ones using experiments, case studies, etc [6] Refinement stage: Refining of the heuristics based on feedback from the validation stage.	*Learning measurement, situated learning, collaborative learning, continuity of learning resources, connections and resources, synchronous* and *asynchronous interaction.*
A set of smartphones' usability heuristics (SMASH) [95].	The methodology was based on Rusu et al. [94]. [1] Exploratory stage: Collection of data about smart phones, their characteristics and any related usability heuristics. [2] Descriptive stage: Highlighting of the most important characteristics so as to formalize the main concepts related to the research. [3] Correlational stage: Identification of special characteristics that usability heuristics for smart phones should have based on traditional heuristics and case studies analysis. [4] Explicative stage: Formal specification of the proposed heuristics based on a standard template. [5] Validation stage: Checking the new set of heuristics against the traditional ones using experiments, case studies, etc [6] Refinement stage: Refining of the heuristics based on feedback from the validation stage.	Consists of 12 heuristics, where 8 are from Nielsen and Molich's set. The additional heuristics include: *Customization and short cuts, efficiency of use and performance, aesthetic and minimalist design and physical interaction and ergonomics*
Usability heuristics for smart phone (EUHSA) [96].	The methodology was based on Rusu et al. [94]. [1] Exploration of smart phone features and examination of relevant studies of heuristic development. [2] Identification of the most significant features of the obtained information and formalization of the concepts related with the study. [3] Cross linking of the usability flaws with the existing heuristics in order to identify features that usability heuristics should have in order to address the usability flaws. [4] Formal specification of the proposed heuristics based on a standard template. [5] Validation by performing heuristic evaluation with experts against SMASH [95] and Joyce and Lilley [97] sets of heuristics. [6] Refining of proposed heuristics based on feedback from the experts.	Comprises of 13 heuristics. They include: *Visibility of the system status, match between system and the real world, realistic error management, help and documentation, efficiency of use and performance, aesthetic and minimalistic design, flexibility and efficiency of use. handling varied context of use in mobile environments. fingertip size controls and ergonomics, effective design to lessen user's workload, recognition rather than recall, user control and obviousness* and *consistency and standards*.
Set of usability heuristics for quality assessments for mobile	Systematic literature review (SLR) approach was used.	Consists of 13 heuristics namely:

Heuristics set	Methods used to develop the heuristics	Number of heuristics and sub heuristics
applications on smart phones. [98].		*Visibility of system status, correspondence between the application and the real world, user control and freedom, consistency and standards, error prevention, minimize the users' memory load, customization and short cuts, efficiency of use and performance, aesthetic and minimalist design, help users recognize, diagnose and recover from errors, help and documentation, pleasant and respectful interaction with the user.*
A set of heuristics for evaluating multi-touch gestures in mobile applications [99].	[1] Analysis of existing heuristics proposed by different researchers. This resulted into a set of 15 heuristics. [2] Adjustment of selected heuristics to appropriate them for evaluating multi touch gestures for mobile applications. [3] Evaluation of multi-touch gesture interaction in a mobile app by 5 evaluators. This was done by comparing them to the heuristics set proposed by Joyce and Lilley [97].	Consists of 15 heuristics. These include: *Visibility of system status, matching between the system and the real world behaviour, navigation and user control, consistency and standards, realistic error management, allow configuration points and short cuts, aesthetic and minimalist design, help and documentation, joy of use, learnability, cognitive workload, fatigue, recognition rather than recall, do not lie to the user and screen orientation.*
A set of usability heuristics for mobile learning applications [100].	The methodology was based on Pinelle et al. [101] which was divided into four phases namely: [1] Data source: Involved selection of relevant papers from which the usability problems were to be extracted. [2] Problem categorization: Extraction of usability problems and mapping to traditional heuristics. [3] Heuristic development: Development of new heuristics through thematic analysis of usability problems. [4] Heuristic validation: Validation of the proposed heuristics to assess the potential benefits of using the new heuristics.	Consists of 13 heuristics, 10 of which are from Nielsen and Molich's set whose description has been modified to assist in easy interpretation by the developers. The 3 additional heuristics include: *Selection of driven commands, content organization and visual representation.*

3.5 Research gap

Overtime, Nielsen and Molich's heuristics [84] have proven to be quite generic to be applied to specific interfaces belonging to particular domains [87], and thus not very effective if applied to mobile applications and interfaces [86, 102]. As a result, a number of studies have opted to establish domain specific heuristics that can address their specific usability to ensure that the specific usability issues of certain domains are not overlooked [103]. Considerable research has been done to improve the usability of mobile interfaces using heuristic evaluation and design principles as depicted by the various heuristics and sub-heuristics for the different mobile applications. However, some of these principles do not address issues specific to the design of mobile forms in relation to the type and size of content, the size of the mobile phones and the nature of form users in rural areas.

Chapter 4

4 Aims and objectives

Overall aim

The overall aim of this thesis was to explore and recommend strategies that can be adopted to design more usable forms in order to improve end user experience when collecting health data using mobile data collection forms in low resource settings such as in Uganda.

Specific objectives

i. To explore the design and implementation of mobile forms used to collect health data in low resource settings (Paper I).
ii. To explore the most important design features which define usability in mobile data collection according to the form developers and software developers (Paper II and III).
iii. To collect form user design preferences for a mobile data collection form using a mid-fidelity prototype (Paper IV).
iv. To assess the form user experience after interaction with the high-fidelity prototype built based on the form user design preferences (Paper V).

Chapter 5

5 Methodology

In this chapter we describe the research process, methods and techniques that were used to conduct the studies within the thesis. We describe the design science research approach which was the umbrella for this research, and further discuss how we applied this approach to our work. We also discuss the epistemologies and ontologies, design and evaluation theories and techniques such as the user centred design, prototype development and group usability testing that were deployed. We further discuss the methods that we used to collect and analyse the data for each objective.

5.1 The Design Science Research approach

The main focus of design science research is to solve a specific problem in form of an artifact or recommendation [104]. Design Science (DS) also aims to create knowledge that can be applied to solve real problems, hence reducing the gap between theory and practice [105]. The overall goal of DS therefore is to develop and design solutions in order to improve existing solutions, to solve problems and to create new artifacts that contribute to human performance [104]. Design science research is anchored on three main concepts, namely *relevance, rigor* and *design*. *Relevance* is concerned with the problem area to be addressed. It provides requirements from the contextual environment and in turn introduces research artifacts to the environment [106]. *Rigor* consists of the relevant scientific knowledge while *design* feeds from both rigor and relevance to design a solution to the problem at hand in an iterative manner. The *design* concept houses the *design cycle* which makes use of techniques such as case studies, simulations and field studies to construct, evaluate and refine artifacts and theories. It also seeks and provides feedback from and to the environment and to the existing knowledge base [106]. In this study we developed and evaluated prototypes, assessed user experience using field studies and used Survival Pluss as our case study.

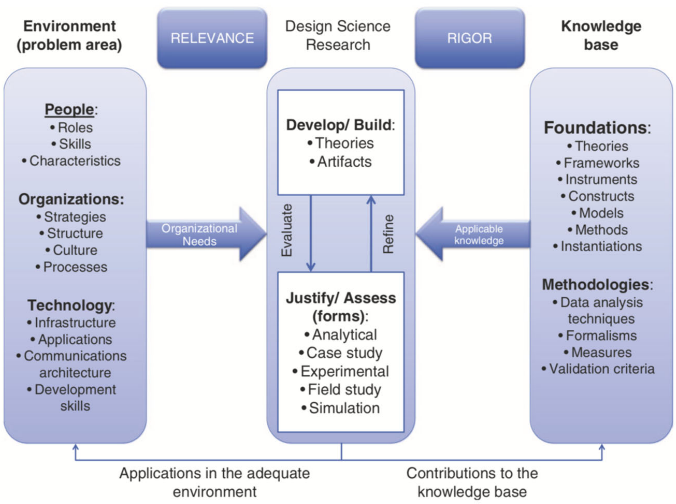

Figure 8: The Design Science Research Model [104], Page 69.

Considering figure 8, any given study derives its *relevance* from the *environment*. The *environment* is described as the place where the problem is situated and it is where the phenomenon of interest to the researcher is obtained [104]. It consists of people, the organization and technology [107]. The *environment* in this study comprised of form users who collect health data using mobile forms in communities in low resource settings. The developed artifact must be relevant to the environment for which it is created. The study in addition derives its *rigor* from the *knowledge base.* The *knowledge base* consists of raw materials such as theories, models or methods that can be used to build and evaluate the artifact and to develop new research [107]. The *knowledge base* in our study comprised of theories such as the UCD, HCI principles, evaluation e.g. group usability testing plus data collection and analysis methods. The *environment* and *knowledge base* are integrated into design such that the artifact is built and evaluated based on the *knowledge base (rigor)* while aiming at solving a relevant problem in the *environment (relevance)* [108].

5.1.1 Epistemology and ontology in design science research

Design Science Research is guided by three epistemological choices namely; positivism, interpretivism and pragmatism [109] with corresponding ontological positions [110]. Guarino [111] defines epistemology as "the field of philosophy which deals with the nature and sources of knowledge" and defines ontology as "a branch of philosophy dealing with the priori nature of reality". Epistemology deals with or describes how knowledge is acquired while ontology is concerned with the nature of reality.

1) Positivism

Positivism assumes that "the truth is out there" and that it can be reached through the methods of science [109]. In other words, there exist pre-fixed relationships within phenomena and the social world. These phenomena can be studied and examined using quantitative-empirical methodological procedures derived from those in natural science in search for regularities and causal relationships [109, 110]. It thus aims at verifiability or falsification of theories [112]. Positivism is based on the ontological position of realism and stresses rationality, universality, objectivity, and value-free knowledge as is the case in natural sciences [110]. Design science research in information systems may not be associated with positivism [109] because theoretically it excludes the researcher influence from the research process. And yet one of the steps in the DSR process is reflection which is done by the researcher or artifact designer. Hirschheim [112] greatly criticizes the positivist epistemology referring to it as naïve realism because it restricts science to mathematical formulations of empirical regularities with disregard for historical and contextual conditions in the search for causal relations [113].

2) Interpretivism

Interpretivism aims at obtaining in-depth understanding compared to positivism which aims to achieve generalization [109, 113]. However, reality cannot be understood independent of the social actors (including the researchers) that construct and make sense of that reality [113]. Rather, the participants' perspectives make the primary sources of information which are analysed against cultural and contextual circumstances [114]. The interpretation is done by the researcher and the human actors in the phenomenon under study [109]. In other words, the researcher is the means through which reality is revealed. Interpretivism is often related to qualitative research [115] and to the ontological position of relativism which holds that reality is a subjective construction of the mind

[112]. Some of the critics of interpretivism observe that its lack of generalization undermines science and rationality [116], leads to acceptance of false beliefs, fosters individualism and rarely leads to specific outcomes that can be acted upon [110].

3) Pragmatism

Pragmatism is essentially a practical activity aimed at producing useful knowledge [116] by critically evaluating and transforming the social reality being studied. In other words, knowledge is a tool for action which should be evaluated against the desired interests [115]. Pragmatism aims at identifying and exposing contradictions and conflicts that may exist in social systems structures by critically analyzing and assessing them [113]. In fact the pragmatists believe that there is no need to prove or show that one's findings or statements represent a given reality, but rather that the knowledge obtained is a tool for action to be used for a given interest [115]. Pragmatism makes use of both quantitative and qualitative methods also known as pluralist research methods. These methodological options are partly dependent on what is being achieved as reflected in the neopragmatic view [112, 116]. Pragmatism takes on the ontological position of *critical realism* which can be best described as having a realist view with consideration of the relativism of knowledge as being socially and historically inclined [116]. Pragmatism may be criticized on grounds of lacking common philosophical standards for theory evaluation [113], leading to ambiguity in evaluation followed by not accepting the results that constitute useful or valid knowledge as defined by the positivism epistemology.

This research adopted the pragmatism and intepretivism epistemology and was influenced by the critical realist ontological position. This is because measuring the usability of any product is subjective and varies within form users, making it partly an interpretive study. In addition, the knowledge that was obtained from this study is meant to create better mobile forms with a focus on improving user experience after interaction, emphasizing the pragmatic part of this work. This study was also highly contextualized for mobile form users in low income settings, intimating that the results could differ in a different setting. This supports the critical realism ontology.

5.2 Study subjects and methods

Table 6 describes the study subjects and participants for each of the sub studies.

Table 6: An overview of study participants and data collection methods by paper

Paper	Study participants	Data collection methods
I	Form developers (n = 8)	Interviews
II	Form developers (n = 15)	Structured electronic questionnaire
III	Novice Software developers (n = 20) Expert software developers (n = 20)	Validation of a usability evaluation checklist Literature review by researcher
IV	Research assistants (n = 48)	Mid-fidelity prototypes Structured questionnaire
V	Research assistants (n = 30)	High-fidelity prototype Group testing approach Structured questionnaires

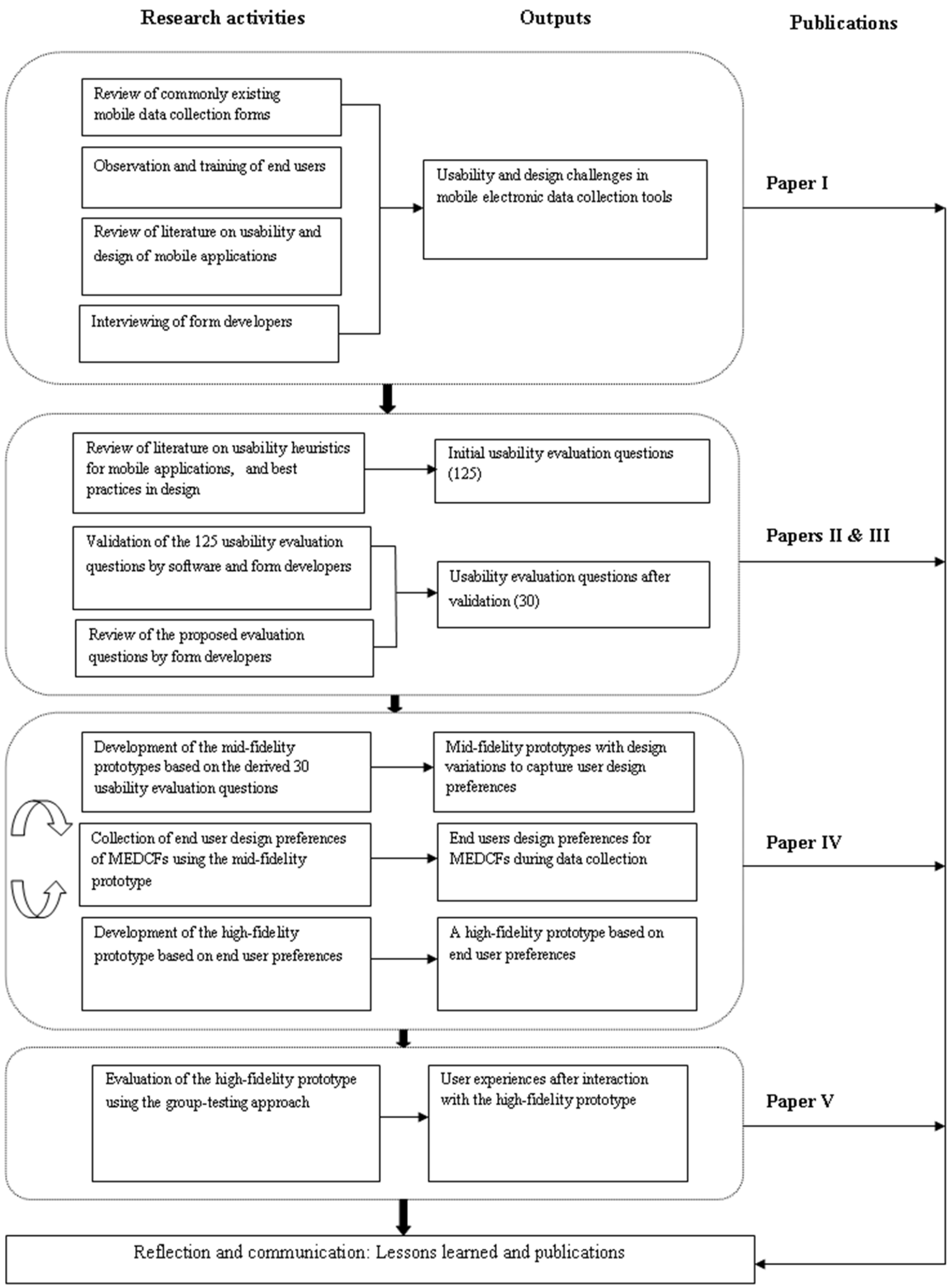

Figure 9: The research process used in this thesis

5.3 Relevance cycle

Objective 1: To explore the design and implementation of mobile forms used to collect health data in low resource settings.

We explored the form developers' understanding, implementation and evaluation of usability during the development of mobile data collection forms. This was motivated by the fact that the source of usability challenges during data collection is sometimes brought about by coding mistakes in the mobile forms which are made by the form developers [117]. Form developers are responsible for creating mobile data collection forms using form creation software. Eight purposively selected form developers who had developed data collection forms for health data using OSS were interviewed in December 2016. The interviews (Appendix I) were semi structured and were based on thematic questions such as experiences, limitations and challenges in the form designs, the use and type of guidelines during form development and the understanding of usability and its implementation in form design. The interviews lasted between 25-30 minutes and were recorded using a voice recorder and later transcribed. Analysis was done using the qualitative content analysis method and we manually derived the sub categories and categories based on the codes derived after transcribing the interviews.

5.4 Design cycle

Objective 2: To explore the most important design features that define usability in mobile data collection according to the form developers and software developers.

Form developers' features

First we sought to discover what the form developers felt were the most important features to consider during form design. We created a structured electronic questionnaire using Survey Monkey an online data collection tool and distributed it to fifteen (n = 15) mobile form developers between November 2016 and January 2017 (Appendix II). The questionnaire comprised of 55 structured questions, which were derived from literature on mobile application heuristics [80, 89] and some from best practices (18). The questions were categorized under Nielsen's 10 usability heuristics [118]. We received responses from fourteen (n=14) form developers, after 1 opted out. We put our findings in an excel sheet, categorized the frequencies and determined the number of design features for each category.

Software developers' features

To get the software developers' views, we had them validate a proposed usability evaluation checklist consisting of 125 usability evaluation questions, which had been derived from a literature review process in 2016 (Appendix III). We conducted a validation exercise with twenty (n = 20) novice and twenty (n = 20) expert developers using a validation tool in a bid to refine the checklist and also to determine those questions that the developers felt were very important to be included. The first assessment of the initial usability evaluation questions was performed by novice software developers in March 2017. These developers had developed mobile applications for a period of less than a year. The second assessment was done by expert developers between October and November 2017, and they had developed mobile forms for collection of health data for varying periods of time, ranging from 1 year to 8 years.

The validation tool was created as an excel file and each of the 125 usability evaluation questions was scored on a scale of 5 where the options were presented in form of a drop down list. These included *strongly disagree, disagree, somewhat agree, agree* and *strongly agree* with a score of 1,2,3,4 and 5 respectively. The criteria for the validation tool included *utility, clarity, question naming, categorization and measurability*, with *utility* and *measurability* having a higher weight respectively.

We determined the proportion of participants who *agreed* (scored 4 or 5), *disagreed* (scored 1 or 2) and were *neutral* (scored 3) to a given criteria regarding a particular question for each of the experts and novice developers. Finally, we selected questions that had an average of 85% agreement (scored 4 or 5) across all the 5 criteria by both novice and expert developers. '*Agreement*' stands for capturing the same views or sentiments about the perceived relevance of an evaluation question.

Objective 3: To collect form user design preferences for a mobile data collection form using a mid-fidelity prototype

5.4.1 Prototype development

A prototype represents limited functionality of the desired product and is focused on answering specific questions about the feasibility and appropriateness of a product's design [8]. Prototypes also give very good indication of a user's experience after the interaction. The fidelity of the prototype indicates the level of details and functionality built into a prototype [2], hence a prototype may be a low or high-fidelity prototype. A mid-fidelity prototype has lower technology implementation compared to the high-fidelity prototype, and is mostly used to get quick feedback which may be used to improve the product [2]. A high-fidelity prototype on the other hand is a computer-based interactive product with implementation of some of the functionality and also has a close resemblance to the design of the final product [2]. It gives an insight into what the user experience would be on interacting with the final product.

5.4.2 The mid-fidelity prototype

We designed the mid-fidelity prototype using Axure RP8 software, and the prototypes had no back-end functionality. The mid-fidelity prototype was based on features such as visibility, consistency, feedback and affordances. The variations in design patterns for each of the screens were found in the radio buttons, check boxes, date formatting, progress visualization, font type, field labels, data input validation and navigation buttons. The design patterns were based on the most agreed on design features by the form developers and software developers.

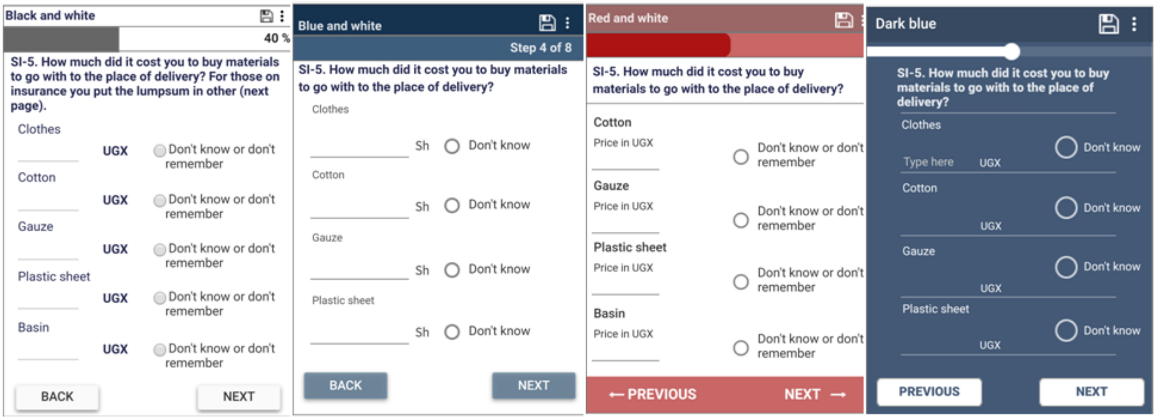

Figure 10: The design variations in the mid fidelity prototype

The prototype building was an iterative process and on further refining, the mid-fidelity prototypes included additional variations in the design patterns in the question layout, color layout, data validation, data format and different table presentations (Figure 10). The table was a new feature that was added for data that had repeating groups (Figure 11). Based on the design implementations from the mid-fidelity prototype, the research assistants were able to identify their design preferences.

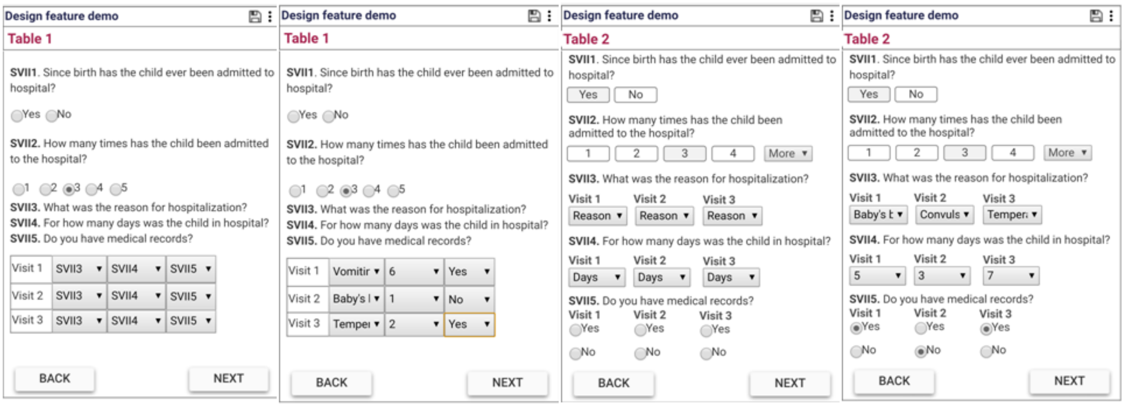

Figure 11: Two types of table designs in a data collection form, first blank and then populated

Collection of form user design preferences

We aimed to collect the design preferences the RAs felt would improve their data collection experience using mid-fidelity prototypes. Mid-fidelity prototypes were used to implement and display variations in the mobile form design patterns and features. The design features were a result of the validated checklist derived from the software developers and form developers. A structured questionnaire consisting of 30 questions (Appendix IV) based on Nielsen's usability heuristics was used by the form users to indicate their preferences. The form users were forty eight (n = 48) research assistants who were collecting data on the maternal and child health projects and clinical trials implemented in Kampala, Mukono and Lira districts in Uganda. The data for this study was collected between December 2017 and January 2018 after obtaining consent from the research assistants (Appendix V). To analyze the responses on the design options, the questions were entered in an excel spread sheet and responses with the highest number of participants agreeing to them considered as the most preferred design features particularly for the single choice questions. For multiple choice questions, the responses that had more than half of the participants were considered.

5.5 Rigor cycle

Objective 4: To assess user experience after interaction with the high-fidelity prototype built based on the form user preferred design features.

5.5.1 Group usability testing

Usability testing can be defined as a "process that employs participants who are representative of the target population to evaluate the degree to which a product meets specific usability criteria" [14]. It is also defined as a process of learning about a product's usability from the users while observing them when using the product [119]. Usability testing developed as a result of limited time resources and the availability of many users gathering together in one place[120]. The motivation for usability testing is based on the assumption that any system that is designed for people to use should be easy to learn and remember, contain the functions that people really need in their work and also be easy and pleasant to use [43].

Group usability testing on the other hand involves several participants individually but simultaneously performing given tasks, with one or more testers observing and interacting with the participants [120]. The number of representative users ranges from 5 to7 as these are able to identify about 80% of the usability problems [120] during the design phase. Generally usability testing plays a useful role in unveiling major usability problems caused by human error, which may often lead to termination of interaction with the system coupled with frustration [121]. Such small numbers of participants were further endorsed by Nielsen [122]. With this approach, it is possible to validate the criticality of the identified problems based on the frequency with which a problem is pointed out by the participants [121]. The group usability testing approach was used during evaluation of the high/fidelity prototype.

The group testing exercise was conducted in February 2018 in Lira, Uganda. The study participants were thirty (n = 30) research assistants (RAs) and all of them were collecting data on a maternal and child health project in northern Uganda. The research assistants were required to complete some tasks (Table 7) during interaction with the high-fidelity prototype. This was meant to create uniformity in the prototype evaluation and also to be able to measure the time it took for each of the RAs to complete the same tasks. In addition to carrying out the tasks, they were also meant to read the feedback given as a result of the actions carried out and to respond appropriately until they correctly submitted the form. It was a requirement to complete all the tasks before submission of the form, and the participants were expected to record their start time before and finish time after the testing exercise.

5.5.2 The high-fidelity prototype

Based on the user design preferences, we created a high-fidelity prototype using the UCD approach. User centred design (UCD) is a description of design processes where end users influence how a design takes shape [15]. UCD is informed by a clear understanding of a particular end-user group and the user needs [16]. Alternative design solutions are then proposed by the designers and evaluated by the would-be users [15]. The involvement of users varies both in time and activities. For example some UCD types consult users about their needs and involve them during requirements gathering and usability testing. User involvement aims at improving the acceptance and success of the designed products [8].

The design patterns in the high-fidelity prototype included: colour variations, question layout, progress visualization, table representation, data input format and navigation buttons.

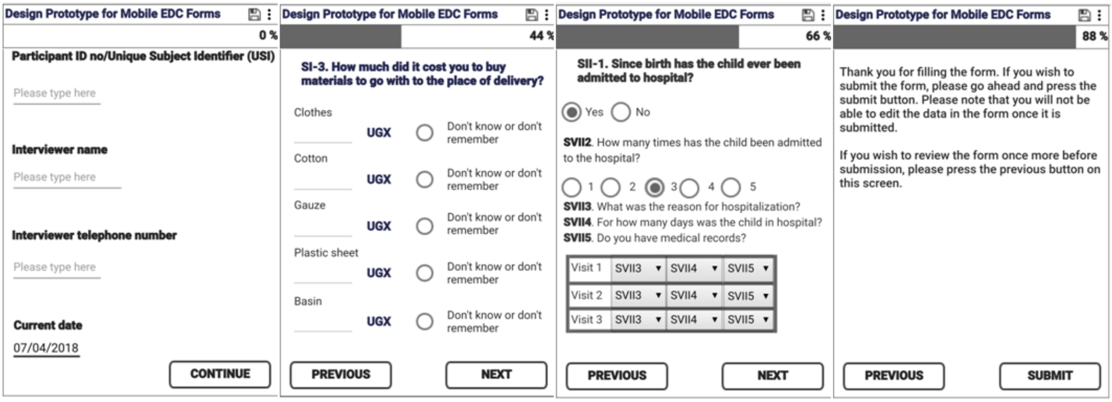

Figure 12: (a) The demographic section (b) The list pickers (c) The child's sickness record (d) The submission screen

The prototype had 3 main sections based on the Survival Pluss project's content which included; the demographic section, section I and section II. The demographic section had text fields for the participant Identification (ID), interviewer name and interviewer telephone number and the date which automatically updated (Figure 12a).

Section I of the prototype had list pickers (single choice and multiple choice pickers) (Figure 12b). In the single choice list picker, the participants were required to select only one option here, and if they chose the 'other' option, they were required to specify that option. This section also had text fields where members were required to fill in the cost of materials they used when going to the hospital. In case they didn't know or couldn't remember how much they spent, the 'don't know' or 'don't remember' option was available.

Section II of the prototype showed different table designs capturing a child's sickness record (Figure 12c) using a dropdown list. A summary of the entered data on the child sickness based on the previous entries was available for the users to crosscheck and *agree* or *disagree* to its correctness, after which they were prompted to submit (Figure 12d). Before submission, the users were warned of the inability to edit the data once it has been submitted.

5.5.3 Interaction with the high-fidelity prototype

Interaction with the high-fidelity prototype was done based on a given set of tasks to create uniformity (Table 7). In the first task the RAs were meant to test the *validation process* as they entered the data in the prototype based on the time taken to validate the input and the way feedback was presented. The second task tested the use of the *'other'* option among the list picker options. The third task tested *error handling* which involved error messaging and recovery from error. The fourth task tested the *logic implementation* in the form. The RAs did not know the basis on which these tasks were selected, and therefore did not know what was being tested. Two observers were present to record the exercise and to attend to any questions that might arise. The start time and end time was recorded for each participant in each session.

Table 7: Tasks for the high-fidelity prototype evaluation of Mobile data collection forms.

Task	Task description
1.	• Enter a participant ID number with 3 digits. • Type your first name • Fill in your telephone number
2.	• Press the next button without selecting any option • Select 'Other specify' • Press 'next' without typing anything for 'other specify' • Press the next button without selecting any option • Select as many options as you want • Select 'Other' and proceed
3.	• Type any text under clothes, cotton and gauze. • Select 'don't know' for plastic sheet and basin and press next • Fill out the amount spent on clothes, cotton and gauze. • Select 'don't know' on plastic sheet, and leave basin option empty. • Press next
4.	• Select 'No' for child admission • Press the 'previous' button twice and go back to question SII-1 • Select 'Yes' for child admission • Select '3' for number of admissions • Fill the rest of the table appropriately
5.	• Check the summary generated on the next screen. • Proceed

Figure 13a displays a validation incidence where a user enters a number less than 10000, enters only one name instead of 2 names. The error message is clearly indicated in red and what the user is supposed to do to rectify the error. A correct telephone number is indicated the date when the information was captured is automatically indicated. Figure 13b shows feedback when a user leaves a text field blank, and when a user enters a very low cost of cotton which is not possible in the Ugandan currency. Screen 13c shows implementation of logic where a child who has been admitted to hospital 3 times has room to fill in all the information for the 3 visits. And all this information can be viewed in a summary form in screen 10d just before the user submits a form.

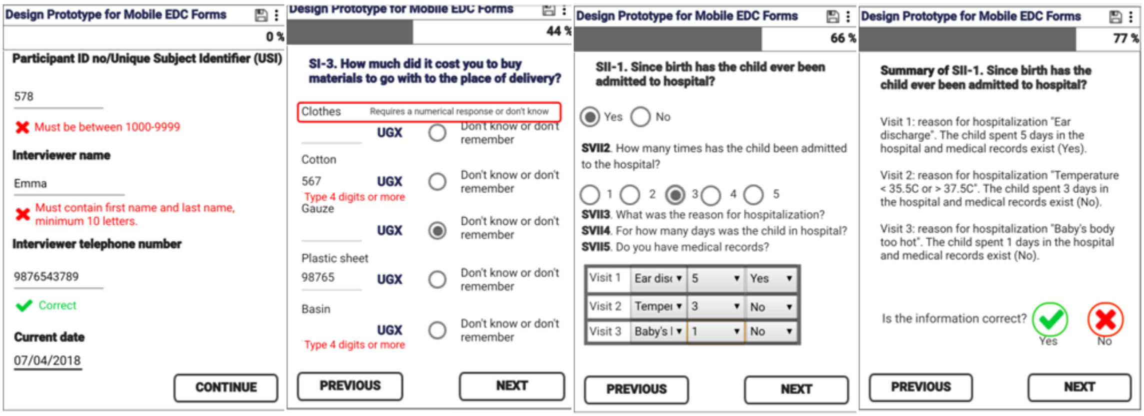

Figure 13: (a) Validation testing screen (b) Screen indicating feedback (c) Screen showing logic implementation (d) Summary of information entered from screen 12c.

5.5.4 Evaluation of the high fidelity prototype

After interacting with the high-fidelity prototype the participants were required to evaluate it to assess the form user experience using 2 post-test questionnaires. User experience (UX) is concerned with getting a more comprehensive understanding of the users' interactive experiences with products or systems [17]. It includes all the users' emotions, preferences, perceptions, behaviours and accomplishments that occur before (pre-interaction experience), during (actual interaction experience) and after use (post-interaction experience) of the product [17, 123, 124]. The goal of designing for UX is to encourage positive feelings like satisfaction and enjoyment and minimizing negative feelings like frustration and boredom towards the product [37].

Evaluation is essential in conducting rigorous design science research (DSR) as it provides evidence that a newly created artifact achieves the purpose for which it was designed. Otherwise, the results from the DSR would be unsubstantiated assertions that the artifacts if implemented will achieve their intended outcomes [125]. Evaluation is therefore defined as "the process of determining how well the artifact performs" [126]. Another purpose of evaluation is to evaluate the formalized knowledge about a designed artifact and its utility, and this is mainly concerned with design principles and technological rules [127, 128]. Evaluation may either be naturalistic or artificial depending on the way it is carried out. Naturalistic evaluation involves evaluating an artifact in its natural or real environment i.e. with real people, real systems and real settings [129], and is always empirical. Artificial evaluation on the other hand includes laboratory experiments, field experiments, simulations and others which are all done in a controlled environment. The evaluation in this research was naturalistic because it involved the actual users of the mobile data collection forms who were the RAs. The evaluation exercise also happened in Lira, the research site in Uganda where the data was going to be collected. We therefore aimed to test the ability of the preferred design features in improving the usability of mobile forms. We used high-fidelity prototypes because they not only test the visuals and aesthetics of a product but also the user experience aspects in relation to interaction with the product [2].

Two instruments were used to evaluate the prototype usability, one was the System Usability Scale (SUS) (Appendix VI) a standardized questionnaire and the other was a Study Tailored Evaluation Questionnaire (STEQ) (Appendix VII). By combining the two, we expected to gain more detailed insight and also to test our generated questionnaire against the standardized one.

The STEQ comprised of 13 statements and was developed based on literature with a purpose of making an alternative instrument, other than the SUS, that could be used for testing in similar projects. The evaluation statements were selected from 4 usability evaluation questionnaires namely: the Computer System Usability Questionnaire (CSUQ) [130], Form Usability Scale (FUS) [131], Questionnaire for User Interaction Satisfaction (QUIS) [132] and statements from the Usability Professionals Association (UPA) [133]. The System Usability Scale (SUS) is a balanced questionnaire comprising of 10 alternating positive and negative statements [74], and acted as a complementary scale to the STEQ. The SUS has been experimentally proven to be reliable and valid [134] because of its ability to control against acquiescence bias and extreme response bias [135, 136]. The word ‘system’ was replaced with the word ‘form’ for some of the statements in both questionnaires.

Results from the two instruments were compared. The STEQ was summarized using frequencies in an excel sheet where the evaluation statement with majority *agreeing* to it was taken as the most preferred option. On the other hand, SUS scores are calculated based on the statement being scored [74], and we did the same in this study. For the positive statements 1,3,5,7 and 9, the score contribution was what the user had selected minus 1. For the negative statements 2,4,6,8 and 10, the score contribution was 5 minus what the user had selected. The total sum of the score contributions was obtained and multiplied by 2.5 [74]. This gave the overall result of the form usability from each participant.

Chapter 6

6 Results

This section provides a summary of key findings highlighting the design, implementation and use of mobile data collection forms in health research. It also shows the software and form developers' most important usability design features, the form users' design preferences and the results after evaluation of the high-fidelity prototype.

6.1 Design and implementation of mobile data collection forms in the collection of health data in low resource settings (Paper I)

The mobile form developers knew about usability but implementing it in form design was a challenge due to the usually short time between the development and delivery of the forms to the implementers, coupled with the usually long health questionnaires. The form creation software had different functional capabilities which influenced the way forms were designed. For example some form creation software do not disclose progress, do not present tables with rows and columns, nor indicate how navigation is done. This limits the designer during form design, which in turn leads to usability challenges. Forms are often designed to meet the data needs of the intermediary users like the hospital managers, but not the usability needs of the form users who collect the data. There are hardly any standards to measure usability of mobile data collection forms that are used in low resource settings. Instead the usability of a form is judged by the amount of feedback received during training of users, piloting or after roll out.

6.2 Most important usability design features for form developers and software developers (Paper II and III)

6.2.1 Form developers' design features

Several design features were of great importance to the form developers. In particular, 18 of 54 design features had maximum frequency score of 80-100% and were thus referred to as the most important features to consider during form development. These features included feedback after saving or completing a form, proper handling of errors, automatic implementation of skip and filter logic and proper selection of background colours to minimize interference with the visibility of the questions. In addition form navigation through swiping was considered easier, limited number of questions on the screen, unique identifiers of the study participants using special identifiers and clear labelling of tables in the form if any. It was also important to have consistent use of terminologies throughout the form, accurate content translation if any and clear data input format requirements and automatic adjustment of input modes where necessary. Refer to table 8.

Table 8: Ratings in the importance of usability design features according to form developers

Design feature	Frequency scores (%)
Progress	
Importance of showing progress during form completion	50%
Feedback	
Feedback receipt when a respondent completes a form	100%
Feedback receipt when a respondent submits a form	85%

Design feature	Frequency scores (%)
Question Presentation	
Grouping of related questions or questions asking about similar content especially for long surveys	71%
Importance of simple words to interpreting and answering of questions appropriately	67%
Clear and consistent numbering of questions in the form	75%
Relatively short questions with minimal content	67%
Logical arrangement of questions eases response to questions	83%
Prediction of the visual flow of the questions	54%
Big enough text size	80%
Limited number of questions on the screen ease reading	90%
For questions that requiring typing responses, placement of the question above the text box	60%
For abbreviated words, accessibility of full text	70%
Table presentation	
Clearly visible rows and columns	67%
Adequate spacing between rows and columns	58%
Minimal text in the table	67%
Clearly labelled fields	83%
List pickers and response options	
The response options should not be very many for multiple choice questions	58%
Use of checkboxes to reduce errors brought about by typing	75%
Use of radio buttons to reduce errors brought about by typing	67%
Unique Identification	
Importance of unique identifier	83%
Automatic generation of the unique identifier	58%
Automatic retrieval of relevant data when user enters unique identifier	60%
Spacing	
Text fields in the mobile form should have enough space for the data being entered	67%
Space between questions in the form must be sufficient	45%
Editing responses	
Ability for respondent to edit responses when necessary	45%
Form navigation	
Most convenient ways of navigating a mobile form being swiping	90%
Use of tabs or links to navigate the form	63%
Terminologies	
Use of similar terminologies throughout the form	81%
Language translation	
Language translation should be a true representation of the original language	81%
Language change should be accessible at any point in the form	45%
Questions need to be translated to a language the user understands.	50%
Help instructions	
Appearance of help instructions before the questions	45%
Data input format requirements	
Importance of data input format requirements	81%
Presentation of data input requirements as help instructions above the text box	45%
Recognition of specific data input types and automatic adjustment of input modes is important	80%
Data validation	
Immediate validation of data after entering text in the text box	54%
Presentation of validation results in form of text below the text field	81%
Logic implementation	

Design feature	Frequency scores (%)
Automating the skip and filter logic is very important	90%
Importance of implementing logic and consistency checks during form filling	90%
Presentation of only the information the user needs at the time	60%
Error handling	
Most ideal time to inform the respondent after committing error	100%
Position of error message in the mobile form below or beside the text box	40%
For easy identification of errors, the colour of the error message should stand out from that of the other text	50%
Place cursor at the position where the correction is required for ease of error correction	70%
Error message should be written in a polite manner	90%
Error message should contain an indication that an error has occurred	100%
An error message should have a description of what the mistake is	80%
An error message should indicate how the mistake can be corrected in the shortest time possible	90%
Form saving and submission	
The form should show the user a summary of all entered data just before submitting the form	60%
Form should allow the user to resume filling the form in case they do not fill it in one go	70%
Colour	
The background colour on the screen should not interfere with the visibility of the questions.	90%

6.2.2 Software developers' most important design features

This checklist consists of 30 evaluation questions of which 9 were categorized under the form layout, 12 under form content, 2 under the input process, 6 under error handling and 1 under form submission. The important features with scores between 85-100% that were agreed on included: summary of all the data captured in the form at any given time (94%), clear labeling of mandatory and optional fields (94%), use of device information such as geo location (94%), feedback after user interaction (92%), clear indication of error signals to avoid errors (92%) and disabling of submit button after submission (90%). Others included visibility of the help function (90%), consistent navigation across orientations (88%), validation of entered data (87%), and clear and appropriate language use for the target users (89%). The results after the validation indicate that expert developers appeared to agree more on the utility, clarity, question names, categorization and measurability of the questions than the novice developers. According to both groups of developers, the questions were found to be useful, clear, with proper names and correct categorization: however, both sets of developers felt that the measurability of the questions was not satisfactory.

6.3 Form users' design preferences for mobile data collection forms (Paper IV)

Based on the mid-fidelity prototypes, the form users were able to choose their design preferences and how they would want them presented. The most preferred features included: viewing progress status during data collection (n = 33/48), immediate receipt of feedback in form of a text message after moving to the next screen (n = 35/48). Data validation in real time with the data validation results being presented in form of text below the text box was also highly preferred by (n = 19/48) form users. The form users preferred to type short responses where need be, and easy access to help instructions would ease their work. Data input instructions were equally important, specifically presented as placeholders in the text box, or as help instructions above the text box for (n = 39/48) form users. Ability to edit their responses at any time was also very important to more than half of the form users. The use of simple words in the content and proper translation of the original language was also important to (n = 32/48) users and swiping was the most preferred way of navigating the form compared to the use of navigation buttons. The rows and columns in a table should be clearly visible, with clearly labelled fields. Having unique identification for the different entities in the form was extremely important to (n = 36/48) users, with (n = 25/36) agreeing to an automatically generated identifier as compared to a manually generated one. Error handling was equally important to (n = 46/48) form users and in particular immediate notification in case of an error, and not being allowed to proceed with the rest of the form until the error has been rectified. The error message needed to be outstanding and placed in a strategic position with a clear indication of what the mistake is and how the issue can be resolved according to more than 20 form users.

Some of the features that the form users did not agree with included: re-entering already recorded data into the form (n = 10/48), using phone buttons to navigate the form (n = 4/48), presentation of help instructions as links next to the text box (n = 4/48), data validation after completing a section in a form (n = 3/48) and placement of error message besides the text box (n = 7/48).

6.4 Evaluation of the high-fidelity prototype using the STEQ (Paper V)

This section presents results evaluation of the high-fidelity prototype using the Study Tailored Evaluation Questionnaire (STEQ). Table 9 indicates the summative scores of the 30 participants.

Table 9: The 13 statements in the tailor-made evaluation questionnaire and the number of respondents (n = 30) in each category from 'strongly disagree' to 'strongly agree'.

Evaluation statement	Strongly disagree n(%)	Disagree n(%)	Neutral n(%)	Agree n(%)	Strongly agree n(%)	Don't know n(%)	Total [a]
• The form informs about its progress during interaction.	0(0.0%)	0(0.0%)	2(6.7%)	8(26.7%)	20(66.7%)	0(0%)	30
• The information e.g. on screen messages provided in this form were clear.	1(3.6%)	0(0%)	3(10.7%)	4(14.3%)	18(64.3%)	2(7.1%)	28[a]
• It was easy to move from one page to another.	3(10.0%)	2(6.7%)	1(3.3%)	8(26.7%)	15(50.0%)	1(3.3%)	30
• The overall organization of the form is easy to understand.	1(3.3%)	1(3.3%)	2(6.7%)	13(43.3%)	12(40.0%)	1(3.3%)	30
• I knew at every input what rule I had to stick to e.g. (possible answer length, date format, etc).	2(6.7%)	3(10.0%)	7(23.3%)	5(16.7%)	13(43.3%)	0(0.0%)	30

Evaluation statement	Strongly disagree n(%)	Disagree n(%)	Neutral n(%)	Agree n(%)	Strongly agree n(%)	Don't know n(%)	Total [a]
• Reading of characters on the form screen is easy.	1(3.3%)	3(10.0%)	9(30.0%)	17(56.7%)	0(0.0%)	0(0.0%)	30
• The form gave error messages that clearly told me how to fix the problems.	3(10.0%)	1(3.3%)	1(3.3%)	2(6.7%)	21(70.0%)	2(6.7%)	30
• I was able to fill in the form quickly.	2(6.7%)	3(10.0%)	3(10.0%)	8(26.7%)	13(43.3%)	1(3.3%)	30
• It was simple to fill this form.	1(3.3%)	1(3.3%)	5(16.7%)	10(33.3%)	13(43.3%)	0(0.0%)	30
• Whenever I made a mistake when filling the form I could recover easily and quickly.	0(0.0%)	1(3.3%)	2(6.7%)	5(16.7%)	21(70.0%)	1(3.3%)	30
• This form is visually appealing.	0(0.0%)	2(6.7%)	6(20.0%)	10(33.3%)	10(33.3%)	2(6.7%)	30
• Overall, the form is easy to use.	1(3.3%)	2(6.7%)	1(3.3%)	8(26.7%)	17(56.7%)	1(3.3%)	30
• Overall I am satisfied with this form.	0(0.0%)	0(0.0%)	7(21.0%)	8(26.7%)	14(46.7%)	1(3.3%)	30

a Some respondents did not reply to all statements

Ninety three percent (n = 28) of the RAs agreed that the form progress was visible, 77% (n=23) agreed that form navigation was easy and that the error messages clearly indicated how to fix problems and 83% (n=25) agreed that form organization was easy. Twenty three RAs also agreed that the form was simple, 26 agreed that it was quick and easy to recover in case of a mistake, and 25 agreed that overall the form was easy to use. In addition, 60% (n =18) of the RAs also agreed that they knew the rules to stick to when inputting the data and also found reading characters on the form easy (Table 9).

However, 16% (n = 5) of the participants disagreed to the form being easy to navigate and to the ability to fill the form quickly. Further still some of the participants were neutral to some of these evaluation statements i.e. they neither agreed nor disagreed. For example, 30% (n = 9) of the participants were neutral about easy reading of characters on the screen and 23% (n = 7) of the participants were neutral about knowledge of the rules to stick to when inputting data. In addition, 30% (n = 6) neither agreed nor disagreed to the form's visual appeal (Table 9).

6.5 Evaluation of the high-fidelity prototype using the SUS (Paper V)

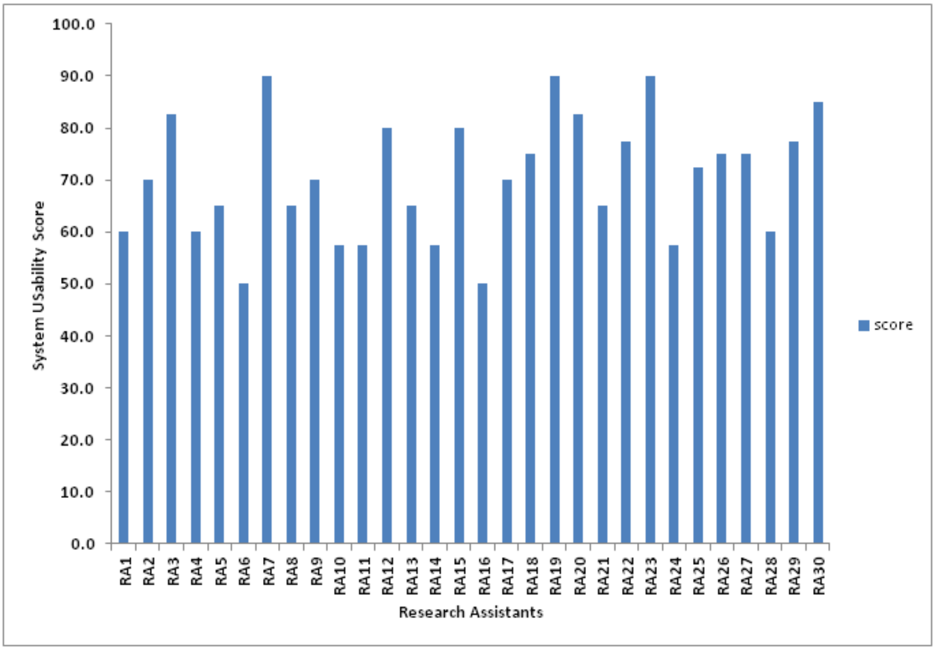

Figure 14: Results from the research assistants' evaluation using the SUS (n = 30)

The individual sytem usability scores ranged from 50 to 90 (Figure 14), with an average score of 70.4 and standard deviation of 11.7. This value was above the recommended average SUS score of 68, which showed that the RAs were fairly satisfied with the usability of the prototype. Sixty seven percent (n = 20) of the RAs found the form easy to use and would like to use it more frequently. There was also proper integration of various functions in the form and the RAs felt very confident about using the form.

Chapter 7

7 Discussion

The design of mobile data collection forms involves developing electronic forms that are used to collect data using mobile devices such as mobile phones. This research set out to explore methods of improving form user experience during data collection by designing more usable mobile data collection forms, in particular for collection of health data in low resource settings. Unless users understand the user interface and how to interact with it, they cannot handle the stipulated tasks with ease. It is thus imperative that users understand the different elements on the user interface and what the alternative actions are during interaction with any product or service. These actions must be intuitive and easily accessible and reversible to the users. In other words, there must be good communication particularly when things go wrong, visibility of content, proper navigation, appropriate form layout, clear content characteristics and accessible information. This makes the basis for this section.

7.1 Discussion of the main findings

7.1.1 Usability design principles for mobile data collection forms

Sixteen design principles were generated by input from the software developers' (novice and expert), form developers' important usability design features and the form users' design preferences (Table 10). The design features which were agreed upon by all the stakeholders included: effective language translation, timely and appropriate feedback, proper error handling and consistent navigation across the form. Both software developers and form users felt that data validation and access to help instructions were important. In addition, form developers and form users both agreed to the importance of unique identification and clear indication of data input format requirements. There was no uniform position on the presentation of summaries after form filling, indication of optional and mandatory fields, skip and filter logic implementation and labelling of the tables. However, data collectors felt strongly about indication of progress status, ability to edit responses, use of simple words and the visibility of rows and columns of tables. The differences in opinion may be attributed to different experiences: for example form developers create forms but may never get to use them to collect data in the field. In addition software developers may never get any feedback on the usability of the software they create and thus may not be aware of what the users actually want or need. In fact the focus from the different software developer online communities is mainly on the functionality, and rarely on the usability of the software.

These design principles are categorized into 6 themes (Table 10) which focus on enhancing *communication* between the user and the mobile forms, *visibility* of the appropriate content when needed and proper *navigation* through the form. In addition, the *form layout*, the *form content characteristics* and *information access* when the need arises were equally important. The themes reflect the proposed design solutions to the commonest usability challenges experienced by novice or low aptitude form users and we hope they will support design and improve interaction in the most basic way.

Table 10: Usability design principles for mobile data collection forms.

Design principle	Description
Communication:	
Communication is concerned with appropriate, clear and timely communication from the mobile data collection form to the form user based on a performed task or activity.	
Feedback	Feedback is any kind of message a user receives after completing an activity or task during interaction with the mobile form. The user should receive immediate feedback after every task e.g. saving, completing or submitting the form. The feedback should be noticeable both in presentation and in positioning on the screen.
Data validation	Data validation is important in ensuring that the data put in each field of the data collection form is of the right type and format, hence improving data quality. There should be real time data validation immediate feedback to indicate the results of the validation.
Error handling	Error handling is concerned with handling errors when they occur. The user should be informed immediately in case an error is committed using an error message. This message should be visible, should clearly indicate that an error has occurred, what the mistake is and how it can be resolved in the shortest possible time.
Help function	A form user needs to be able to access help as and when the need arises. This can be in form of help instructions next to the text fields.
Data input format requirements	Data input requirements are meant to ensure that the user enters the data in the appropriate format with ease, thus the requirements must be known to the user e.g. by using place holders. There should also be recognition of specific data input types and automatic adjustment of input modes where applicable before the user attempts to enter data.
Visibility:	
Visibility aims at making information visible and available to users depending on what they are trying to accomplish. In other words at any one time a user should only access options and materials needed for a given task rather than being distracted with a lot of redundant information.	
Logic implementation	Logic implementation is meant to ensure that users only access what is relevant for them to answer based on the previous answer. Skip and filter logic should be automatically implemented. Form users should not be tasked to recall information that could otherwise be done in the backend.
Unique identification	A unique identifier is a special number that is assigned to a person e.g. a patient and is unique to that person. This number should be automatically generated and assigned to a study participant to reduce on the errors caused by manual entering of information by from users. This would also reduce on participant data misallocation particularly in follow-up studies.
Content navigation and browsing:	
This is the ability for a user to start at their point of origin and end up at the desired destination. In addition a user at any one time needs to know where in the form they are.	
Form navigation	Navigation is the ability to move through the form in a forward and backward manner, and between levels. There needs to be an indication of how to navigate e.g. through swiping or use of navigation buttons. In case

Design principle	Description
	menus are used, they must be clearly distinguishable from the rest of the content and visible by the form user.
Progress disclosure	A form user needs to know where in the form they are at any point in time. Progress disclosure is meant to show the user how much of the form has been filled and how much is left before completion. This is very important particularly in mobile forms with many pages. Progress disclosure is also necessary when a form user navigates a form using menus and needs to get back to the original page

Form layout:

Form layout is concerned with the way content is classified, organized, structured and presented to enable a meaningful and effective interaction. It reflects logical presentation of the icons, interface layout and output readability.

Table presentation	Tables may be used in the form when there is a need to capture data about an event in a repeated manner. The rows and columns must be visible enough and the fields clearly labelled to give the form user a true picture of a table.
Colour	The background colour on the screen should not interfere with the visibility of the content in the mobile form, and neither should it be a distracter during interaction. In addition the choice of colours should represent the anticipated activities e.g. green is an affirmative indicator while red represents denial.
Content layout	Content layout is concerned with the way questions, images and vertical lists are presented in the form. The number of questions on the screen should be limited, must be logically arranged, with readable text, consistently numbered and with a clear indication of compulsory and optional fields. There should also be enough spacing between content and specifically around icons to facilitate target selection.

Content characteristics:

Form content depends on the data being collected. Some forms may be in form of questionnaires and images whereas others may be in tabular form, hence the variation in content. However, for data collection forms, the main content is usually questions and labels or fields of text entry.

Terminologies	There is a need for consistent use of terminologies throughout the mobile form especially for technical terms. This will help the users not to misinterpret questions during data collection.
Language translation	In cases where the questions in the form have to be translated into a language the user understands, the translated language should be a true representation of the original language of the form.

Information access:

Information access is the ability for a user to focus on intended information by choice while minimizing unrelated information. This may be done through zooming, dynamic searching, sorting and filtering, or through a direct request.

Information control	A form user should be able to search through the mobile form or filter the collected data with maximum ease. The user should be able to edit a

Design principle	Description
	response as and when they need to. It should also be possible to save the content and resume filling the form at an opportune time in case the user is not able to complete the form in one go.
Summary presentation	Summary of all the information entered should be accessible after completion but before submission of the form.

7.1.2 Stakeholder involvement in the design of usable mobile data collection forms

It is important to note that sufficient implementation and realization of these design principles will require involvement by the different stakeholders. For example implementation of error messages and skip logic is the responsibility of form developers. Proper navigation ability and unique identification of the entities would require consideration by the software developers who develop form creation software. In addition, the implementers would have to ensure consistent use of terminologies and language translation before data collection commences. Refer to table 11.

7.1.3 Evaluation of the high-fidelity prototype by the form users

Evaluating the high-fidelity prototype was done to establish how comfortable the form users were during interaction with the prototype, an aspect of ergonomics. The main focus of ergonomics is to ensure that a product is designed to be fit for use by the target users [61]. The prototype was designed based on the design preferences of the form users which had earlier been captured using a mid-fidelity prototype. The results from the evaluation of the high-fidelity prototype using the SUS questionnaire and the STEQ questionnaire show a 70% level of satisfaction with the mobile data collection form. The form users were generally satisfied with the simplicity of the newly designed forms, the ability to visualize their progress and ease of recovery from errors, however, navigation and filling of the form was not easy. The visual appeal and general satisfaction with the form was not sufficient either. Usually, form designers do not have an influence on the form navigation and visual appeal because these are determined by the form creation software developed by the software developers. However, it is important to note that usability is not an absolute concept but depends on the task and the user [137]. This means that with different tasks and different users, the results from this study could have been different. In this case the user experience may be attributed to the levels of education, the exposure to technology and the years of experience in mobile data collection.

7.2 Methodological considerations

7.2.1 The design science approach

This research was anchored on the design science approach whose major focus is to create artifacts which are relevant to a given community, while at the same time contributing to the body of knowledge. Design Science is made of 7 research guidelines which include: *design as artifact, problem relevance, design evaluation, research contribution, research rigor, design as a research process* and *communication of the research* [104]. We further explain these principles and how we addressed them below:

Table 11: Tasks that support mobile form usability to be addressed by the different stakeholders

Stakeholder	Design feature	Tasks to be addressed
Software developers	• Feedback	Location and frequency of feedback messages
	• Help function	Location and design of help icon
	• Data input format	Location and presentation of data input format requirements
	• Error handling	Position and design of error message
	• Data validation	Timing of data validation
	• Logic implementation	Ability to implement logic
	• Unique identification	Automatic generation of unique identifiers
	• Form navigation	Clear indication on how to navigate forms
	• Progress disclosure	Clear indication of location of the page the form user is at and any progress made during interaction
	• Table presentation	Clear table designs
	• Content layout	Ability to display readable content
	• Colour	Appropriate choice of colour both in the background and in the depiction of anticipated activities
	• Information control	Ability to search, save and retrieve information
	• Summary presentation	Ability to summarise all the entered data before submission
Form developers	• Error handling	Clarity and length of error message content
	• Data validation	Insertion of proper data validation rules
	• Logic implementation	Proper logic implementation
	• Table presentation	Properly labelled fields and readable content
	• Content layout	Logical arrangement of questions with an indication of optional and compulsory questions
Implementers	• Terminologies	Consistent use of terminologies
	• Language	Proper and complete translation into appropriate language

1) Design as artifact

Designing as an artifact ensures that the research must produce an artifact which may be a construct, model, method or instantiation [104]. This research produced 16 design principles, which were categorized into 6 themes that can be used to design more usable mobile data collection forms.

2) Problem relevance

With problem relevance, the research aims at developing solutions to solve important and relevant problems for organizations [104]. Design of usable mobile forms is still a challenge because of the small screen sizes of mobile forms. This leads to mobile form designs that are not appropriate specifically for low aptitude users because the content is not presented appropriately and more so some of the information which could support the interaction is left out due to space challenges. In turn, such mobile form designs bring about usability challenges. We found this problem to be relevant as health research is moving towards using mobile data collection forms.

3) Design evaluation

Design evaluation focuses on the use of well executed evaluation methods to show the utility, quality and efficacy of the artifact [104]. The use of the high-fidelity prototypes in the evaluation of the design principles coupled with the typical end users of the forms was a good way of measuring the design of the forms. We also used the STEQ and the SUS questionnaires to evaluate the high-fidelity prototype which both produced results that were consistent irrespective of the questionnaire. In addition, the use of group usability testing during evaluation cannot be overlooked especially in low resource settings. We thus found our evaluation to be appropriate and well executed.

4) Research contribution

The research contribution aims at showing that the research conducted using the design science approach provides clear and verifiable contributions in the particular areas of the developed artifacts and presents clear grounding on the foundations of design and methodologies [104]. This research generated design principles that can be a basis for designing usable mobile data collection forms. These design principles were a collective input from the different stakeholders involved in the form development process who included software developers, form developers and the form users. Usually design principles are from usability experts, and are most often used by usability experts.

During artifact creation, knowledge about ‘how to design’ is also generated [104]. The use of mid-fidelity prototypes to collect form user design preferences was a plus as end users are not usually involved in mobile form design because form developers feel they have nothing to contribute. In addition, the evaluation of the high-fidelity prototype using the group usability testing approach was also useful where resources such as time and finances are scarce. The use of the SUS and STEQ questionnaires was an opportunity to cross-check the usability of the high-fidelity prototype based on results from 2 questionnaires.

It is important to note that DS does not seek optimal outcomes, but only aims at a satisfactory outcome for the context in which the problem is found [138]. A satisfactory result can be defined by consensus among the parts involved in the problem or by advancement of the new solution compared to the solutions generated by previous artifacts [138]. Therefore a 70% level of user satisfaction as depicted by the 2 questionnaires was a good indicator that the proposed design principles could lead to the design of more usable mobile data collection forms.

5) Research rigor

Research rigor is meant to address the application of rigorous methods in the construction and evaluation of the artifacts [104]. The goal of generating these design principles was justified by human computer interaction concepts of discoverability and ergonomics. Discoverability ensures that a user interacts with the designed product effortlessly [46] while ergonomics looks out for the comfort and satisfaction of the users during interaction by designing appropriate products [61]. The principles are hinged on Nielsen’s desktop oriented usability heuristics [122], but are specifically adopted for mobile data collection forms.

The prototyping approach as used in the collection of form user design requirements (mid-fidelity prototype) and in checking the appropriateness of the mobile form design (high-fidelity prototype) [8] was one way of implementing the user centred design (UCD) technique. In the UCD approach, end users are involved in the design and evaluation of a given product [15]. This research further deployed the group usability testing approach where several participants individually but simultaneously performed a given set of tasks with one or more observers observing and interacting with the participants [120]. During evaluation, we used 2 instruments i.e. the STEQ which complemented the SUS questionnaire [139].

6) Design as a research process

Design as a research process ensures that proper means are used to achieve the desired purposes, while satisfying the laws governing the environment in which the problem is being studied [104]. The generation of these design principles went through the 5 major stages of DS research, namely: *awareness of the problem, suggestion, development, evaluation* and *conclusion* [140].

This research was birthed out of training of form users and piloting of the mobile data collection forms in Lira, Uganda, where a number of usability problems caused by the form design and low aptitude of users were identified. Subsequent literature studies were further carried out to support these findings and to confirm the research problem. All this informed the *awareness of the problem* phase. Generation of the design principles was done and it involved input from different stakeholders using interviews and questionnaires. Design prototypes were developed based on input from the stakeholders and design principles evaluated to determine the form user experience.

Design science research involves various cognitive processes during artifact development and evaluation. It deploys the abduction process [141, 142] at the *suggestion* phase which involves studying of facts and proposing theories to explain them [104]. Abduction is the most indicated method for understanding a situation or problem. Abduction is a creative process and the only scientific method that enables the introduction of a new idea [142] from the existing knowledge or theories. Evaluating the created artifact requires the deductive cognitive process [104] which happens at the *development* and *evaluation* phase. Reflection and abstraction are creative cognitive processes used in the *conclusion* stage to make knowledge contribution of operational principles and possibly design theories [140].

7) Communication after the research

Lastly, research conducted using design science must be communicated, which involves presenting it to a more technology oriented audience and a more management oriented audience [104]. The results from this research were presented in 5 scientific papers all of which are published. Additional dissemination of results was done in both regional and international conferences.

7.2.2 The role of stakeholders in the creation of usability design principles

Sixty seven percent of reviewed studies showed that data collection during the creation of usability heuristics for mobile applications was from literature review [87]. However, using such methods was not sufficient to design heuristics that meet the usability needs of the target users because the studies were carried out in different contexts. For example, the target users, the technology devices, the study areas and the disciplines varied between the different studies. In our research we deployed additional empirical data collection techniques such as observation when the form users were in the field for training and piloting and getting input from all the stakeholders involved in the development of mobile forms. We discuss how each of the stakeholder categories contributed to this research.

Form developers and software developers were tasked with validating the initial list of the design principles that had been derived from the various literature studies on mobile applications. It is from the findings from the stakeholders and from the literature review that we developed the mid-fidelity prototypes we used to collect the form users' design preferences. This was very important because we were able to integrate what had been tested and used by usability experts with the stakeholders' opinions and best practices to generate the usability design principles for mobile data collection forms.

In this study we had both novice and expert developers because in evaluation or validation it is important to have a mix of users with different skill levels e.g. the beginners or novice users, the average level users and the power or expert users to test a given product. This prevents skewing of the design requirements towards a particular group because users have varying needs based on their experience [143]. The software developers were used to validate the initial checklist of 125 design principles in order to improve on their presentation and usability. It was evident after the validation that the principles were very many and needed to be reduced to include only the most important in order to make them usable during form development.

We also collected data from the form users based on the user centred design (UCD) approach. It is important to know the kind of users (novice, intermittent or experts) collecting the data, their skill levels and the tasks they will be expected to perform [59] together with the context in which the data is to be collected [45, 59] in order to attain a good design [144]. The involvement of the form users in form design further gives them the confidence during data collection as the interfaces are not entirely new to them.

7.2.3 Use of mid and high-fidelity prototypes

We created four mid-fidelity prototypes with different designs that are typically seen in newer applications to enable the end users decide on preferences like colours, navigation buttons progress bars and list pickers among others [57]. The mid-fidelity prototypes were further used to introduce the form users to the major usability designs and concepts in data collection forms, which helped the form users appreciate usability from a practical point of view. Choosing of design preferences by the form users to include in the high fidelity prototype was also made easier because it was done with a basic understanding of what usability is.

Based on these preferences, a high-fidelity prototype was created with more functionality. We purposed to give the users a feeling of a new data collection tool, where the differences amongst the prototypes were evident, but at the same time giving the user a feeling of a finalized data collection solution after filling in data. We also aimed at improving these prototypes by including extra functionality [57] which did not exist in the original ODK-collect SurvPlus form, but having similar simple interactions. This was implemented by putting a submission button which users had to tap after data entry. This would lead to a view of the summary of all the entered data and later followed by a submission confirmation inquiry. All these functionalities were missing in the previous ODK-collect based mobile form the RAs were using. The form users were able to compare and learn that there are various ways of designing mobile forms with similar content.

7.2.4 Group usability testing in prototype evaluation

We used group usability testing because we wanted to test the prototype in its natural setting, but with minimal costs. The ability for users to individually but simultaneously evaluate the prototype saves on the time and the money required to carry out the activity. However, evaluating usability alone may not be sufficient to improve the quality of the system without considering the emotions and feelings of the users as they interact with the systems or applications [124]. Hence when we were evaluating the prototype, we included questions that were inquiring about the satisfaction and visual appeal of the prototype to the form users.

According to Virzi, 5 participants have the ability to detect 80% of the usability problems [145]. This position was further reiterated by Nielsen [122]. In our study however, we used 30 research assistants. Using a large number of participants displayed the heterogeneity in age, data collection experience, mobile technology use and level of education all of which were vital in representing the different usability needs of the form users. With the group usability testing approach, it is possible to validate the criticality of identified problems based on the frequency with which a problem is pointed out by the participants [121]. For example more than 20% of the research assistants felt that the prototype was not appealing and were also generally not satisfied with it. More work would then need to be done to address those problems iteratively until users are satisfied.

7.2.5 Comparison of results from the SUS and the STEQ

Two evaluation questionnaires were used to evaluate the high-fidelity prototype in order to ensure consistency by comparing results from the 2 questionnaires. This was reflected in the 70% level of satisfaction with the evaluated prototype from the SUS and STEQ questionnaires.

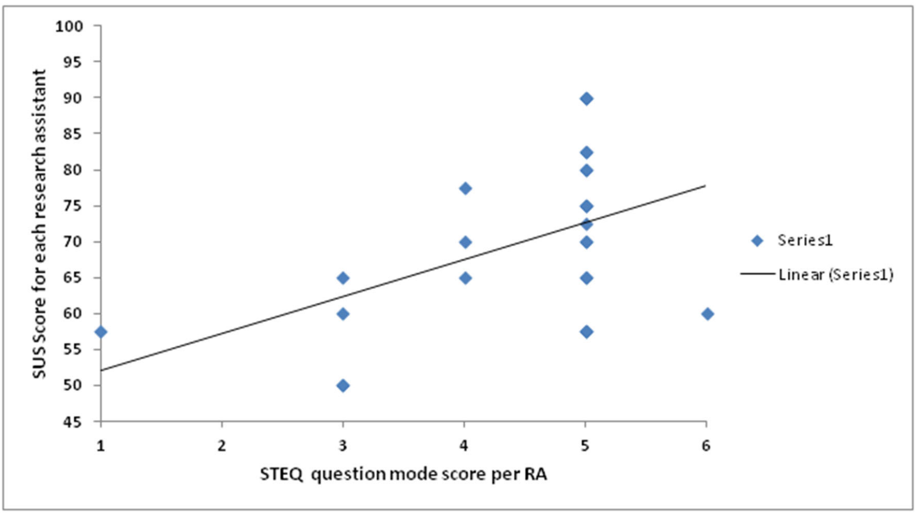

Figure 15: System Usability Scale score compared with the Study Tailored Evaluation Questionnaire score

Figure 15 indicates a positive relationship between the two variables. The participants who were satisfied with the prototype (scored 4 or 5) according to the STEQ had high SUS scores and the ones who were not satisfied (scored 1 or 2) had relatively low SUS scores. The participants with the lowest SUS scores all found that the form was not simple to fill, easy to use and were also not satisfied with it as depicted in the STEQ. Results from the bivariate Pearson correlation indicate that this relationship is significant at the 0.01 level for a 2 tailed test (p-value less than 0.01). The Pearson correlation value of 0.623 further signifies a strong association between the SUS score and the STEQ score.

7.2.6 Generalizability

Design science seeks to address problems that are specific to organizations or society, however, these solutions must be generalizable to a particular ‘class of problems’ [105]. Thus the challenges in designing mobile data collection forms are not only experienced in health data collection but in other disciplines as well like agriculture, education, etc. Therefore these design principles can be part of the solution to design challenges involving the design of mobile forms, irrespective of the particular device or screen size. In addition, some of these principles can be extended beyond data collection to designing for interaction with any mobile user interface e.g registration, online shopping, etc. Usability can also be a problem even with literate form users when mobile forms are poorly designed. These principles can thus be extended to design for the different types of users irrespective of the aptitude level.

7.3 Study Limitations

- One limitation was that the prototypes could not exhibit all the functionality as was shown in the original Survival Pluss form as is usually common with prototypes. In addition, there was no back end functionality, meaning that they could not access the submitted data. This being the first time the RAs were engaging in such an activity, it could have left some of them dissatisfied with the prototype, which could have affected the evaluation results.
- The other limitation was that the prototypes could only be accessed by the users using internet connection, which proved to be a challenge because of the intermittent network and costs in the internet procurement. As a result, the participants had to work in shifts which encroached on the time necessary to carry out the activity. Important to note is that user impressions of their experience as a whole are based on the peak-end effect i.e. the most intense and last parts of the experience whether positive or negative usually impact participants’ recollections and evaluations the most [134]. This could have affected the results from the prototype evaluation as well.
- Prototype evaluation as a means of usability testing may not comprehensively identify all the design problems in the prototype. It may instead be a time consuming and error prone task that is dependent on subjective individual variability [137]. Therefore, with a different type of users, the evaluation results may have differed.
- Much as group testing is less costly in terms of resources and time, it may be hard to observe the participants diligently, attend to all their queries and at the same time record the sessions all in one go. In our study, this was also a challenge because it was the first time the participants were taking part in such an exercise and thus needed a lot of support. The exercise in turn took longer than was anticipated.

- Group usability testing involves three stages: the user profile survey, basic tasks and exercises and a usability issues' discussion after the testing [121]. We were able to do the first 2 stages, however, we were not able to have the discussion after the testing because of time constraints since the exercises were done in shifts due to internet connection issues. However, with the right infrastructure, we would have gotten more insight into the reasons behind the evaluation.
- Form users usually range between health workers in health facilities and village health teams who collect data in communities. Our study did not cater for this range of users because it was focused on mobile data collection for health research, and thus used RAs as the study participants. It is therefore possible that with another set of users, the results would have been different.
- Implementers are part of the stakeholders involved in the design of usable forms because they contribute the content in the forms. However additional usability issues relating to the implementers' usage of the data after collection were not met. For example the data exported as 'yes' or 'no' into statistics software cannot be analysed without initial coding and attaching of integers to 'yes' and 'no'. It would be very useful if this coding was done at the form development stage. However usability after the data collection process was beyond the scope of this work, and could be exploited in further studies.

Summary of research publications and how they relate to the research objectives

Table 12: Published papers, their aims and findings and how each linked to the proceeding specific objective

Objectives	Papers	Paper aims	Findings	Link to proceeding objective
<u>**Objective 1**</u> To explore the design and implementation of mobile forms used to collect health data in low resource settings.	<u>**Paper I**</u> Usability in mobile electronic data collection: form developers' views.	We explored form developers' understanding, implementation and evaluation of usability during development of mobile data collection forms.	• Hardly any design criteria for usability implementation and evaluation of mobile data collection forms. • Usability of mobile forms is based on input from both software and form developers.	• A need to generate design features to assist in development of more usable mobile forms. • Important to involve both form developers and software developers due to their contribution to usability.
<u>**Objective 2**</u> To explore the most important design features which define usability in mobile data collection according to the form developers and software developers	<u>**Paper II**</u> Design features for usable mobile electronic data capturing forms: the form developers' perspective.	We explored the most important design features according to the form developers.	• Most important design features included feedback, logic implementation, form navigation, data input format requirements, unique identification, language translation and error handling.	• Design features were used as a basis to develop mid-fidelity prototypes • Mid-fidelity prototypes were used to introduce usability concepts to the form users.
	<u>**Paper III**</u> A usability design checklist for mobile electronic data capturing forms: the	Software developers validated a list of usability evaluation questions from literature studies with an	• Questions were found to be clear, properly named and correctly categorized. Important design features included: access to summary of all captured data, labelling of mandatory and	• It was necessary to reduce this list of evaluation questions to include only the most important design features pertaining to data collection using

Objectives	Papers	Paper aims	Findings	Link to proceeding objective
	validation process.	aim of generating a checklist that can be used to design and evaluate mobile data collection forms.	optional fields, use of device information, feedback, clear indication of errors, help function accessibility, form navigation and appropriate language use.	mobile forms. These features were also included in the mid-fidelity prototypes.
<u>Objective 3</u> To collect form user design preferences for a mobile data collection form using a mid-fidelity prototype (Paper IV)	**<u>Paper IV</u>** Data collectors' design preferences for mobile electronic data capturing forms.	Investigated the design preferences form users/data collectors felt would improve their data collection experience	• Findings included: progress status view, immediate receipt of feedback after every action, data validation in real time, use of data input instructions, error message positioning and ability to edit responses at anytime.	• The preferred design features were used to create the high-fidelity prototype, which was later evaluated by the form users to determine the user experience after interaction. • The high-fidelity prototype was a representation of the design features that make up part of the usability design principles for mobile data collection forms. • Thus evaluating the prototype was an evaluation of these design principles, and an assessment of the group testing approach to collect and evaluate form user design preferences.
<u>Objective 4</u> To assess the form user experience after interaction with the high-fidelity prototype built based on the form user design preferences.	**<u>Paper V</u>** High-fidelity prototyping for mobile electronic data collection forms through design and user evaluation	Evaluated the user experience after interaction of the form users with the mobile data collection forms to assess the ability of the proposed design principles in designing usable mobile forms.	• There was a fair level of satisfaction with the mobile form prototype based on 2 usability evaluation questionnaires. • Some of the most appreciated features included: the progress status view, form navigation and clear error messages. • The group testing approach could be adopted to assess user experience particularly where there is scarcity of resources such as time and money.	

8 Conclusions and recommendations

8.1 Conclusions

Designing mobile forms for data collection in health research still remains a challenge mostly because of the small screen sizes, the stringent deadlines, and the limitations in the form creation software. These design challenges have greatly contributed to the usability challenges that are being experienced by specifically low aptitude users in rural areas of Uganda.

The design challenges may be attributed to the lack of standards for measuring the usability of mobile data collection forms. The evaluation of the existing usability standards for mobile applications by software developers showed that there was a need to generate more customized standards for mobile forms used in rural areas. On evaluation, some of the features which scored highly included: summary of entered data, clear labelling of mandatory and optional fields, use of device information, timely feedback, proper error handling, visibility of help function, timely data validation, navigation ability and appropriate language use. And yet a number of these are hardly part of the existing design principles for mobile applications.

Collecting the most important usability design features from form developers and software developers gave insight on what they considered to be important in order to attain usability in mobile forms. The divergent views concerning some of the form users' important attributes justifies the inclusion of end users in the design process because they are the final users of the finished products. We anticipate that collaboration and constant communication between developers, implementers and end users will assist in addressing the common usability challenges in mobile data collection forms.

This research has also been original in introducing mid-fidelity prototypes to study usability issues with the intended user group. Thus the development of mid-fidelity prototypes in order to clearly understand user design preferences cannot be under-estimated. This may be more time-consuming compared to other approaches: however, the long-term benefits could lead to development of highly usable forms, increased data accuracy, and a pleasant user experience. Using high fidelity prototyping in the evaluation of the design principles turned out to be a feasible and affordable form development option too.

The involvement of end users in the development and assessment of the mobile data collection forms using the UCD approach is a cost effective and affordable way of designing usable forms. Collecting and evaluating user design preferences as a part of user experience using the group testing approach is not a very common approach in the development of mobile data collection forms. However, this could be one way of tailoring design to the user needs so as to cater for the diversity in context and user groups especially in rural Africa.

It is thus possible to design more usable data collection forms using UCD as depicted in the 70% level of user satisfaction with the high-fidelity prototype. This is an added value to the quality and accuracy of the collected data, a critical requirement in healthcare. However, user experience trials are usually costly and require additional resources which end up being a challenge in resource constrained areas. This might be an advisable investment especially when using open source software programs to tailor solutions to specific user groups. The experience also provides learning opportunities to familiarize themselves with the projects and their tasks.

8.2 Recommendations

8.2.1 **Recommendations for practice**

Using our research findings, the following recommendations can be adopted for practice:

- We recommend that software developers consider the above usability design principles when developing form creation software. This is because designing of usable mobile forms starts with the usability features that have been implemented by software developers, short of which form developers are limited in their designs. The same design principles may be used by form developers to evaluate the usability of their products before roll out for training or piloting sessions. This will reduce on the time between pilot and actual implementation of the mobile forms.

- We also recommend that form users world-wide are involved in early form design and development with an aim of the developers understanding the user group potential and their preferences in order to depict group appropriate design solutions.

- We also propose that end users are introduced to the usability discipline using artifacts such as mid and high-fidelity prototypes in a bid to identify usability related challenges during training and piloting exercises. This will reduce on the time and resources spent on refining the forms before and during the data collection process.

- We also recommend that video recordings of form users when interacting with the health systems are taken during the group testing sessions to complement the post usability testing interviews, as these sometimes tend to be subjective. This would give a true picture of the user interactions with the systems, and the usability issues faced. The data analysed from these captured recordings would inform the designers and developers on what needs to be addressed to improve usability of mobile forms.

8.2.2 **Recommendations for future work**

Based on our study findings, there is a need to further research on the following:

- The generated usability design principles need to be validated and tested further with the form users to develop actual standards that can be used as a measure of usability in mobile forms. Adoption of the agile development approach which assumes several design iterations involving user groups and development stakeholders should be embraced over the traditional system approach.
- We also recommend that a comprehensive/compact usability tool is developed based on empirical data that will be collected from prospective studies.
- We further recommend that clear workflow processes are developed to enable systematic dialogue between the stakeholders during the development of mobile data collection forms. This may call for development of measurement indexes which can be a basis for this dialogue.

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11 Appendices

Appendix I: Form developers' interview
Appendix II: Form developers' questionnaire
Appendix III: Usability evaluation questionnaires
Appendix IV: Questionnaire to collect form users' design preferences
Appendix V: Informed consent form
Appendix VI: System usability scale questionnaire
Appendix VII: Study tailored evaluation questionnaire
Appendix VIII: Ethical clearance letter

12 Errata

Page 18, 4th paragraph, second line, "members" was removed.
Page 19, line 4 "doing" was replaced by "during".
Page 23, last line "suggestions" was removed.
Page 39, second paragraph, line 6. "In addition" was removed.

Page 65: Last 2 paragraphs previously read (percentages updated):
"Eighty percent (n = 24) of the RAs agreed that the form progress was visible, form navigation and organization was easy and that the error messages clearly indicated how to fix problems. Twenty four RAs also agreed that the form was simple, that it was quick and easy to recover in case of a mistake, and that overall the form was easy to use. In addition, 50% (n = 15) of the RAs also agreed that they knew the rules to stick to when inputting the data and also found reading characters on the form easy (Table 9).

However, more than 20% (n = 7) of the participants disagreed to the form being easy to navigate and to the ability to fill the form quickly. Further still some of the participants were neutral to some of these evaluation statements i.e. they neither agreed nor disagreed. For example, 36% (n = 11) of the participants were neutral about easy reading of characters on the screen and 27% (n = 8) of the participants were neutral about knowledge of the rules to stick to when inputting data. In addition, 23% (n = 7) neither agreed nor disagreed to the form's visual appeal (Table 9)."

Paper III

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RESEARCH ARTICLE

Open Access

A usability design checklist for Mobile electronic data capturing forms: the validation process

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Abstract

Background: New Specific Application Domain (SAD) heuristics or design principles are being developed to guide the design and evaluation of mobile applications in a bid to improve on the usability of these applications. This is because the existing heuristics are rather generic and are often unable to reveal a large number of mobile usability issues related to mobile specific interfaces and characteristics. Mobile Electronic Data Capturing Forms (MEDCFs) are one of such applications that are being used to collect health data particularly in hard to reach areas, but with a number of usability challenges especially when used in rural areas by semi literate users. Existing SAD design principles are often not used to evaluate mobile forms because their focus on features specific to data capture is minimal. In addition, some of these lists are extremely long rendering them difficult to use during the design and development of the mobile forms. The main aim of this study therefore was to generate a usability evaluation checklist that can be used to design and evaluate Mobile Electronic Data Capturing Forms in a bid to improve their usability. We also sought to compare the novice and expert developers' views regarding usability criteria.

Methods: We conducted a literature review in August 2016 using key words on articles and gray literature, and those with a focus on heuristics for mobile applications, user interface designs of mobile devices and web forms were eligible for review. The data bases included the ACM digital library, IEEE-Xplore and Google scholar. We had a total of 242 papers after removing duplicates and a total of 10 articles which met the criteria were finally reviewed. This review resulted in an initial usability evaluation checklist consisting of 125 questions that could be adopted for designing MEDCFs. The questions that handled the five main categories in data capture namely; form content, form layout, input type, error handling and form submission were considered. A validation study was conducted with both novice and expert developers using a validation tool in a bid to refine the checklist which was based on 5 criteria. The criteria for the validation *included utility, clarity, question naming, categorization and measurability*, with *utility* and *measurability* having a higher weight respectively. We then determined the proportion of participants who agreed (scored 4 or 5), disagreed (scored 1 or 2) and were neutral (scored 3) to a given criteria regarding a particular question for each of the experts and novice developers. Finally, we selected questions that had an average of 85% agreement (scored 4 or 5) across all the 5 criteria by both novice and expert developers. 'Agreement' stands for capturing the same views or sentiments about the perceived likeness of an evaluation question.

(Continued on next page)

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Results: The validation study reduced the initial 125 usability evaluation questions to 30 evaluation questions with the form layout category having the majority questions. Results from the validation showed higher levels of affirmativeness from the expert developers compared to those of the novice developers across the different criteria; however the general trend of agreement on relevance of usability questions was similar across all the criteria for the developers. The evaluation questions that were being validated were found to be useful, clear, properly named and categorized, however the measurability of the questions was found not to be satisfactory by both sets of developers. The developers attached great importance to the use of appropriate language and to the visibility of the help function, but in addition expert developers felt that indication of mandatory and optional fields coupled with the use of device information like the Global Positioning System (GPS) was equally important. And for both sets of developers, utility had the highest scores while measurability scored least.

Conclusion: The generated checklist indicated the design features the software developers found necessary to improve the usability of mobile electronic data collection tools. In the future, we thus propose to test the effectiveness of the measure for suitability and performance based on this generated checklist, and test it on the end users (data collectors) with a purpose of picking their design requirements. Continuous testing with the end users will help refine the checklist to include only that which is most important in improving the data collectors' experience.

Keywords: Mobile electronic data capturing forms (MEDCFs), Usability, Specific application domain (SAD) heuristics

Background

Over the years, electronic data collection systems are increasingly being used in health care particularly for data collection and management in health surveys, surveillance and patient monitoring [1]. Electronic data collection tools consist of mobile devices like phones, computers and tablets (hardware) together with a number of different possible programs (software), also known as form creation software [2] which maybe open-source or proprietary. For mobile electronic data collection systems, data collection is done using mobile forms, known as Mobile Electronic Data Collection Forms (MEDCFs), which are developed and designed by software developers and form developers respectively. The form developers do not need to have any prior software programming training, but rely on the array of tools provided by the software [2] to create the forms. These electronic forms usually consist of numeric fields and multiple choice menus, among others [3] and their main role is to collect data through direct data capture.

Usability is considered as one of the top attributes of assessing quality and its major role is to ensure that the interfaces are easy to use and that users are supported in performing their tasks efficiently and effectively [4]. One of the ways of ensuring usability is through performing Heuristic Evaluation on the interfaces, where "reviewers, preferably experts, compare a software product to a list of design principles (or heuristics) and identify where the product does not follow those principles" [5]. Heuristic evaluation is the most popular and commonly used usability inspection method because of its high benefit to cost ratio in cases where time and resources are scarce [6]. It is important to note however that these software products vary in functionality, design and features, and thus would require different design principles that are specific to their domain. For example Nielsen's usability heuristics have been said to give inaccurate results for heuristic evaluations involving non-traditional types of software like transactional websites and mobile based applications among others [7]. This is because Nielsen's are desktop-oriented heuristics and therefore may fail to reveal a large number of mobile usability issues related to mobile specific interfaces and characteristics [8, 9].

Heuristics that are applicable in one context may not work in another, or may sometimes contradict a heuristic used in another context. Secondly, their being broad often leaves room for the individual evaluator's interpretation of what they mean, and may also be challenging to less experienced evaluators in finding pertinent design problems [5, 10]. There is therefore a need for more accurate inspections and assessment tools where evaluators can identify, beyond the generic usability problems, issues from the specific application domain [11, 12], hence a need for Specific Application Domain (SAD) heuristics.

The study therefore sought to generate and validate a design checklist for MEDCFs. We proposed a list of sub-heuristics from literature which focus on the data capturing process. We later validated this list in order to transform and refine it, so that it would be more usable to the intended users.

Methods

To develop a design checklist for mobile electronic data collection forms (MEDCFs), we used different types of techniques and involved different stakeholders. First we conducted a literature review where we generated an initial usability evaluation checklist. The initial checklist was then validated by a team of software developers using a validation instrument.

Literature review
We used the ACM digital library, Springer, IEEE-Xplore and Google scholar, together with some literature on best practices from other sources like Google. Our key terms in the search included 'usability', 'usability evaluation', 'heuristics', 'mobile', 'tool', 'checklist', 'user interface' and 'design'. The key words were chosen with a focus on improving usability in mobile electronic data collection based on the assumption that usability can be improved through proper designing and evaluation of the user interfaces by developers using heuristics/design principles that are specific to MEDCFs. The inclusion criteria included papers that were focused on computer applications, usability, heuristic evaluation, generation and validation of heuristics.. Our search generated 242 papers for review after removing the duplicates. On screening based on titles, we then removed 17 papers whose titles did not have the words *'usability', 'evaluation', 'mobile' and 'heuristic'* and were left with 225 articles. We screened the abstracts and removed those papers which were not in English and those which were not about usability evaluation of user interfaces, leaving us with 134 articles. We then omitted those papers which were not focused on generating or validating usability heuristics for mobile devices or interfaces, and we were then left with 10 articles.

Generating the initial usability evaluation checklist
We derived our usability evaluation questions from 10 papers (Thitichaimongkhol and Senivongse. 2016, Gomez et al. 2014, Omar et al. 2016, Nielsen 2001b, Pierotti 1995, Budiu and Nielsen 2011, of Health and Services nd, Parham 2013, Nielsen 2001a, Nayebi et al. 2013), the majority of which came from a system checklist by Pierotti [13]. Other sub heuristics were also derived from the ERP checklist, one of the latest mobile based checklists and also an update of the usability heuristic checklist for mobile interfaces [14]. We therefore updated this checklist by removing some evaluation questions that are specific to mobile ERP and were then left with 125 usability evaluation questions. These questions were derived from sub-heuristics for mobile applications coupled with those from a number of usability heuristic studies and usability guidelines for online web forms [15, 16].

Categorization and rearranging of the selected sub-heuristics
We selected those sub-heuristics that fitted in the 5 categories and are representative of the data capturing process as shown in the design of web forms. This included transfer of sub heuristics from their original sub-heuristic category and placed under a new one based on what they are evaluating. The categories comprised of the *form content, form layout, input process, error handling* and *form submission* [15]. We then merged the mobile sub heuristics with some of the web form usability guidelines. We however changed the 'input type' to 'input process' because the input type only relates to how data should be entered into the form [15], and yet we sought to evaluate the data collection forms beyond just inputting data, but including other features that may influence the input process like the *visual feedback* and *list pickers* among others. The 125 questions were categorized as follows. *Form content* had a total of 35 questions, *form layout* had a total of 43 questions and the *input process* category comprised of 22 questions. *Error handling* had 23 questions, while *form submission* had the least with only 2 questions.

Form content
The form content depends on the data being collected. Some forms may be in form of questionnaires, whereas others may be in tabular form, hence the variation in content. The main content is usually questions and labels or fields of text entry. However, it is very crucial to map the environment which the users are familiar with in order to ease the use of the form. In this case, designing an electronic form that is analogous to the paper forms will quicken the data collectors' understanding of the form [17].

Form layout
The form layout shows how the form is presented on the mobile user interface, and this influences the way a user interacts with it. The form layout is still determined by the nature of the content that is being collected. For example long survey questionnaires will have a different layout from a short mostly graphical form used by a clinician in a health facility. In addition, the designs, positions and lengths of the labels and input fields, the date format, number of columns and buttons among others all define the layout of the form [17].

The input type
This refers to the way data is captured or entered into the form and therefore which input type is most appropriate for a given case for example check boxes, radio buttons etc. Care should always be taken not to confuse users by using many different input types in one form [18]. In some instances, frequent use of text boxes is recommended [19], but not in cases where the number of possible answers has to be limited [20] because then radio buttons, check boxes or dropdown menus can be used comfortably. On the other hand, the use of text boxes can contribute to typing errors and delays in data collection more than when users have to select from a given set of options. The input process can also be

determined by the type of analysis one is going to perform or on the decisions to be made with the collected data.

Error handling

Users need to be guided as quickly and as error free as possible during the process of filling forms from the start by explaining restrictions in advance [17]. This includes formatting and content rules such as minimum length of numbers or words, entry formats, putting help instructions, etc. being communicated well in advance. There are various ways of communicating e.g. by indicating the format specification where a user cannot miss it for example inside the text box. Sometimes errors are unavoidable, and therefore users need to be helped to recover from them as quickly and as easily as possible by clearly stating what the error is and how it can be corrected in a familiar language [20, 21].

Form submission

The form has to be submitted after filling it using a submission button [17]. The submission button needs to be disabled after the first submission to avoid multiple submissions in cases of system response delays [20]. The positioning of the reset or cancel button should also be carefully considered or the button avoided as it can lead to a cancellation of the already completed work accidentally. After submission of the form, the recipients need to acknowledge receipt of the form [20, 22].

We chose to use these categories because they represent some of the main activities a user is involved in when filling a data collection form. And therefore were a good basis for the selection and categorization of the questions that we included in the initial usability evaluation checklist.

Validation of the derived usability evaluation questions by the software developers

Heuristics for Specific Application Domains (SAD) can be generated in a number of ways, but one of the most important steps is the validation of the heuristics to ensure that they are able to do what they are supposed to do. According to Van Greunen et al., [23] the validation phase is the second of three phases in the 3-phase process to develop SAD heuristics and it consists of 4 major tasks. These include; identification and selection of experts who have the theoretical knowledge and practical experience with regards to SAD. The second task is the application of the validation tool to assess the heuristics using rating scales to measure their characteristics these characteristics are likely to have an impact on the adoption of the new heuristics for the SAD. The third task is to analyze the results from the validation process in order to determine the necessary modifications to the heuristics. The last task involves iterating and redesigning the heuristics until the experts are satisfied with the outcome [23].

The software developers validated this initial usability evaluation set in order to refine it further and make it more usable using a validation tool. The validation tool was created as an excel file and each of the 125 usability evaluation questions was scored on a scale of 5 where the options were presented in form of a drop down list. These included *strongly disagree, disagree, somewhat agree, agree* and *strongly agree* with a score of 1,2,3,4 and 5 respectively. Furthermore, the developers were free to add a comment explaining their scores in addition to removing or adding to the usability evaluation questions. The developers could also suggest renaming a given question or re-locating a question to a different category.

The validation tool was based on 5 major assessment criteria, namely utility, clarity, question naming, categorization and measurability. The criteria was based on characteristics proposed by Van Greunen et al. [23] some of which included naming and importance of high level heuristics, grouping of checklist items under heuristic names and ease of use. Because utility is a part of usefulness, it also qualified as part of the assessment criteria [24]. We also considered measurability because it is important that the heuristics are quantifiable in order to rate them appropriately. Utility and measurability are considered to have a higher weight because the utility or measurability of a heuristic during evaluation cannot be compromised otherwise it would not be suitable for inclusion in the checklist. Other criteria that could have been considered in this study included thoroughness, reliability, effectiveness, cost effectiveness and validity [25]. However, these would be beneficial in assessing complete heuristics in real work contexts, and thus would not be very feasible in our contexts.

Utility

This tests the evaluation question's contribution and relevance to the design of the mobile data collection form.

Clarity

This tests whether the evaluation question is clear and can easily be understood by the evaluator.

Question naming

The test was on whether the evaluation question name was appropriate.

Categorization

Here the test was whether the evaluation question is placed in the right category.

Measurability

This tested the possibility of measuring and attaching a score to the design feature using this evaluation question.

Validation can be a continuous and iterative process involving novice, average and expert users. The initial assessment of the initial usability evaluation questions was performed by novice software developers in March 2017. We presented the main study objectives and the relevance of the activity the novice developers were about to undertake, after which they downloaded the checklist and the validation tool from their individual email addresses. We then trained the developers for about 10 min, after which they were given 90 min to assess the checklist and submit the completed assessment thereafter to the researchers' email address.

The second validation of the same evaluation questions was done by the expert developers in Uganda between October and November 2017. The expert developers had developed mobile forms for collection of health data for varying periods of time, ranging from 1 year to 8 years using software like Open Data Kit (ODK) ($n = 9$), District Health Information Software (DHIS2) ($n = 6$), Open Medical Records System (OpenMRS) ($n = 5$). Other applications included mUzima ($n = 2$), Medic Mobile Toolkit, CSpro, Survey CTO, koBo Toolbox, Survey Monkey and OpenXData. The 20 developers received an email each indicating the main study objective and the relevance of the activity they were about to engage in. On acceptance to be part of the study, the file with the assessment criteria was forwarded to them via email, and they were expected to submit it after one week.

Results

Validation of the initial usability checklist by the novice developers

Out of the 20 copies of validation tools that were sent out, we received 18 copies back, 3 of which were incomplete. So our results were based on the 15 complete submissions. We received a total of 9 comments from 5 developers. Five of the comments mentioned that some of the evaluation questions were not clear and therefore could possibly lead to misinterpretation or confusion. For example two developers felt that question 12 *(Is the number of colors limited to 3–4?)* was unclear and one had to read it twice to understand it. Three of the comments went on to advise on how we could improve on a given question e.g. splitting question 9 *(Is only and all information essential to decision making displayed on the screen)* into 2 segments. One developer also felt that progress disclosure in question 38 *(Is there a link to each of the individual pages rather than just to the previous and next ones?)* would not be very important in a mobile view. All the 125 questions that were validated are listed in the Appendix.

Validation of the initial usability checklist by the expert developers

All the 20 copies that were sent out to the expert developers were filled and received back after periods ranging from 2 to 4 weeks. We received more comments from the expert developers compared to the novice developers, some of which included renaming or re-categorizing the evaluation questions. For example some of the expert developers felt that questions 6, 10, 14, 15, 27, 28 and 29 needed to be put in other categories rather than the ones they were in (Appendix). In addition some of the questions were found to be inappropriate for this study e.g. (*Are all abbreviated words of the same length?).* Eight of the expert developers commented that it was not possible to have abbreviated words of the same length. Some questions were also found to be ambiguous e.g. (*Does the tool provide informative progress disclosure when filling a form?)* and *(Has the skip logic been automated?).* The relevance of some of the questions was also questionable e.g. *(Does the mobile tool's UI keep the total number of touchable UI elements to less than 10 per view?).* Some expert developers also pointed out that some of the design features' performance is influenced by other factors e.g. the feedback time during data collection may be influenced by the internet speed. However this activity is rather subjective and very individualistic and therefore the developers were likely to interpret and evaluate the questions differently based on their varied experiences.

To generate the usability design checklist, we considered questions where 80% and above of the novice and expert developers agreed to each of the utility, clarity, question name, categorization and measurability of the questions. We then selected those questions where more than 80% of the responses indicated 'agree' or 'strongly agree' across all the 5 criteria. Because utility and measurability have higher weight than the rest of the criteria, we also considered those questions which scored above 80% in both usability and measurability. We then considered those questions where both novice and expert developers affirmed to the utility of the question. And lastly, we considered those questions where only the experts affirmed to the utility of the question. This led to a total of 64 questions. We then calculated the average of responses with 'agree' or 'strongly agree' for each question across the 5 criteria, and selected those questions with an average of 85% and above. This led to 30 evaluation questions of which 9 were categorized under the form layout, 12 under form content, 2 under the input process, 6 under error handling and 1 under form submission. These 30 usability evaluation questions are all represented in Table 1.

There were no questions where both sets of developers selected 'agree' to all the 5 criteria for a particular question. However, there were 11 questions in this checklist where both sets of developers selected 'agree' to more

Table 1 Usability evaluation checklist from the novice and expert developers' evaluation with questions that both novel and experienced developers estimated as highly relevant depicted by criteria scores of '4' or '5'

No.	Usability evaluation question	Agreed %
1.	Is it possible to get a summary of all the data the user has entered at any given time?	94
2.	Are there visual differences between interaction objects (e.g., buttons) and information objects (e.g. labels, images)	94
3.	Are the data entry fields which are mandatory or required clearly marked?	94
4.	Does the tool make use of device information like data and time, geo-location, device number, etc. as input data?	94
5.	Do data entry screens and dialog boxes indicate when fields are optional?	93
6.	Does the tool show error signals and marks on the actual field that has an error and needs to be changed?	92
7.	Is there some form of feedback for every user interaction?	92
8.	Are the buttons in the form mostly or always visible?	90
9.	Is the submit button disabled as soon as it has been clicked during submission of the form?	90
10.	Is the help function visible?	90
11.	Does the tool preserve the user's work in order to correct errors by just editing their original action instead of having to do everything over again?	90
12.	Can users easily switch between help and their work?	89
13.	Can users move forward and backward between text fields or dialog box options?	88
14.	Is the language used in the form clear, effective and appropriate for the target users?	89
15.	Is navigation consistent across orientations?	88
16.	Does the tool provide the user an alternate method of authentication?	88
17.	Does a back button simply return the form to a previous view without loss of data?	87
18.	For data entry screens with many fields can users save a partially filled form?	87
19.	Are users able to interact with the form by swiping or pinching (zooming in and out) instead of only touching?	87
20.	Is all the information users enter into the data forms validated and users informed if it is not in an acceptable format?	87
21.	Are inactive menu items greyed out or omitted?	87
22.	If pop-up windows are used to display error messages, do they allow the user to see the field in error?	87
23.	Are prompts, cues, and messages placed where the eye is likely to be looking on the screen?	87
24.	Is it possible to automatically save a page in the form when a user scrolls to the next page?	87
25.	Does the system provide an example input for format-specific or complex information?	87
26.	Is the format of a data entry value for similar data types consistent from screen to screen of a given form?	86
27.	Is the user able to know where he or she is during navigation of the form?	85
28.	Can users resume work where they left off after accessing help?	85
29.	Have the forms been designed to recognize specific input types and adjust the input modes accordingly during data entry?	85
30.	Users dislike typing, is information computed for the users where applicable?	85

than one criterion for a given question. But generally expert developers affirmed to the questions based on the given criteria compared to the novice developers.

We further analyzed the data based on the criteria to determine the participants' decision for each usability evaluation question. We determined the number and the respective percentage of participants who agreed, disagreed and were neutral to a given criteria for a particular usability question for each of the experts and the novice developers.

For 25 usability evaluation questions 85% and above of the novice developers selected 'agree' i.e. *utility* had 12 questions (*8, 15, 22, 23, 27, 33, 58, 59, 90, 99, 114 and 120), clarity* had 8 questions *(6, 27, 34, 58, 59, 66, 81 and 84),* and *question naming* had 3 questions *(33, 34 and 36).* In addition, categorization had 6 questions *(6,* *16, 21, 42, 58 and 59)* while measurability had 4 questions *(20, 37, 47 and 64)*. We also had about 12 novice developers (80%) selecting 'agree' to the utility of 14 questions, to the clarity of 24 questions, to the question names of 13 questions, to the categorization of 15 questions and to the measurability of 5 questions. These results depict that majority of the questions that the novice developers agreed to were clear to them. In fact all the novice developers agreed to the clarity of question 66 *(Is it possible to automatically save a page in the form when a user scrolls to the next page?)*. The number of novice developers who selected 'disagree' against questions was relatively low with the highest being 8 developers disagreeing with the question name for question 9 *(Is only and all information essential to decision making displayed on the screen?)*. There were also 40 and 27% of the developers disagreeing with the clarity and the categorization of this question respectively. The biggest percentage of disagreements (above 27%) was made up of measurability (14 questions) followed by utility (11 questions) and clarity (11 questions), and yet these are the criteria with the highest weights.

There were 50 evaluation questions where 85% and above of the expert developers selected 'agree' for all the criteria apart from, *measurability* which was below 85%. There were incidences where all the expert developers affirmed to the criteria regarding a particular question for example utility had 5 questions *(28, 35, 45 92 and 119)*, clarity had 5 questions *(27, 28, 34, 40 and 92)*, question name had 3 questions (15, 27, and 33) while categorization had 4 questions *(65, 92, 100 and 103)*. Question 92 *(Does the tool make use of device information like data and time, geo-location, device number, etc as input data?)* however had all the expert developers agree to the utility, clarity and categorization of that question. In addition we had 7 questions *(23, 25, 33, 34, 35, 92 and 102)* where 90% and above of the expert developers agreed on the relevance of 3 criteria and 9 questions *(8, 15, 27, 28, 53, 65, 103, 119 and 124)* where 90% and above of the developers agreed on the relevance of the 4 criteria. This can be compared to questions 58 *(Are inactive menu items greyed out or omitted?)* and 59 *(Are prompts, cues, and messages placed where the eye is likely to be looking on the screen?)* where 87% of the novice developers agreed to the utility, clarity and categorization value of the questions.

We also considered those questions where less than 50% of the novice developers selected 'disagree' Measurability had 29 questions, followed by utility with 13, clarity with 9, question name with 8 and lastly categorization with 8 questions. Question 24 *(Are all abbreviated words of the same length)* had a high level of disagreement across all the 5 criteria, with utility having the highest diagreement of 50%.

The number of expert developers who gave high criteria scores for each usability question was higher than the number of novice developers. In addition, the scores across criteria also varied with the highest being utility followed by clarity, question name, categorization and lastly measurability, and for both sets of developers, utility scored highly while measurability scored least (Fig. 1).

Discussion

Principal findings

The literature search generated 125 usability evaluation questions which after validation by the novice and software developers were reduced to 30 questions. The results after the validation indicate that expert developers appeared to value the utility, clarity, question names, categorization and measurability of the questions more homogeneously as a group than the novice developers. According to both groups of developers, the questions were found to be useful, clear, with proper names and correct categorization;

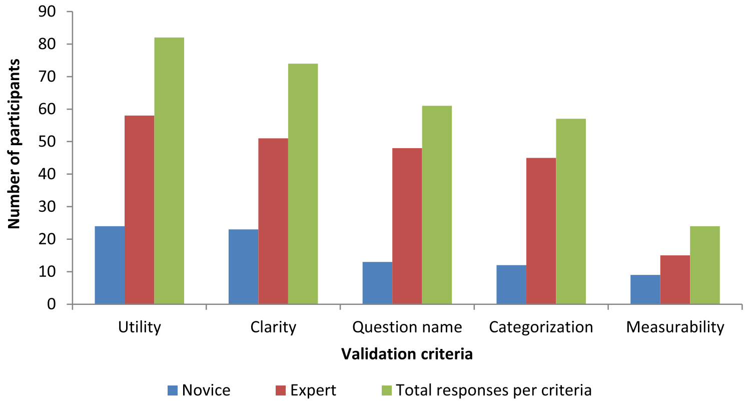

Fig. 1 Total number of responses per usability criteria

however both sets of developers felt that the measurability of the questions was not satisfactory.

The results indicate differences in the agreement and disagreement levels with evaluation criteria of the novice and expert developers, but the general trend was the same i.e. there were some questions where both evaluator groups agreed or disagreed. For example there were 20 questions where more than 85% of the developers found 3 or 4 criteria valuable. In addition, novice developers attached great importance to the use of appropriate language, omission of inactive menus, visibility of help function, prompts and messages and lastly to the ability to switch between data collection and their work. On the other hand, expert developers attached great importance to the appropriate language use as well, visual differences between interaction objects and information objects, indication of mandatory and optional fields, visibility of the help function and the use of device information like the Global Positioning System (GPS).

The variations in the levels of agreement and preferences may be attributed to differences in experience and context of operation. For example the expert developers had experience ranging from 3 to 10 years, which the novice developers did not have. Secondly the expert developers had been involved in creating MDCEFs for collection of health data in low resource settings, whereas the novice developers were more involved in mobile software development with nothing specific to Mobile data collection tools. However, in evaluation or validation it is important to have a mix of users with different skill levels e.g. the beginners or novice users, the average level users and the power or expert users to test a given product. This prevents skewing of the design requirements towards a particular group because users have varying needs based on their experience [26].

Most of the questions the developers affirmed to were in the form content category followed by the form layout, error handling, input process and the form submission categories respectively. Measurability was hardest to assess, followed by utility and clarity for both groups of software developers. This may be attributed to the fact that it was not clear to the developers what the criterion was meant to achieve. However, we still need to define ways of measuring the achievement of a particular design feature we are testing.

Expert developers had different views on more usability questions compared to the novice developers. This may be attributed to the experience they have had working on these applications such that they are able to know what is achievable or not. Secondly, some of the expert developers have had an opportunity of interacting and getting feedback from the end users especially during the training sessions, which placed them in a more advantaged position of knowing what the users may be comfortable with.

Utility of a usability question was considered most important among the validation criteria and as such, the evaluation questions with high percentages of disagreement for utility were automatically eliminated from the checklist. We argue that however clear or well categorized a usability question is, it needs to be useful in the evaluation of the MEDCFs.

Limitations

One of the limitations was the difference in the time allocated to the 2 groups of developers; the expert developers had a lot more time to validate the initial checklist compared to the novice developers who only had 90 min. However, to the best of our knowledge, this was the first exercise of its kind where intended users get to validate the tool they will use to assess their interface designs for MEDCFs, besides the user testing of the prototype or finished product that is done with the end users. Having 2 sets of developers with varying experiences and from different contexts enriched the study because software developers only develop software with a focus on particular features which is partly the reason for the weaknesses of using Open Source Software (OSS) [27].

Conclusion

The objective of this study was to compare the novice and expert developers' views regarding usability criteria. This study generated and validated a design checklist for Mobile Electronic Data Capture Forms (MEDCFs), and was thus a way of creating awareness to what should be expected of a mobile data collection tool from the software developers' perspective.

The different results from the novice and expert developers, where we registered more affirmative results from the expert developers is an indicator of their expectations as developers. This may also be an indication of their level of engagement and knowledge of the people for whom they are creating the tools as well as the experience acquired over the years. We would thus recommend the use of more experienced developers during validation of checklists for mobile data collection tools.

The checklist resulting from this study needs to be evaluated by users as software developers are not the end users of the data collection forms. We thus propose to test the effectiveness of the measure for suitability and performance based on this generated checklist, and test it on the end users (data collectors) with a purpose of picking their design requirements. Continuous testing with the end users will help refine the checklist to include only that which is most important in improving the data collectors' experience. In addition to this first study that summarized the observations, there will be a deeper data analysis based on the collected material to determine the relationships between the criteria scores on the evaluation checklist and the developer groups.

Appendix

Initial usability evaluation checklist

Table 2 Form content

1. Is there some form of feedback for every user interaction? [13, 28]
2. Is this feedback noticeable and readable?
3. Is this feedback given within a reasonable amount of time? [29]
4. Does the tool provide informative progress disclosure when filling a form e.g. percentage of completion or time to wait to complete the form? [5, 28]
5. After users complete a task or group of tasks does the feedback indicate that they can proceed to the next task? [13]
6. Are the icons used in the tool concrete and familiar? [13]
7. In the event that shapes are used as a visual cue in the tool, do they match the cultural conventions? [13]
8. Is the language used in the form clear, effective and appropriate for the target users? [14, 28]
9. Is only and all information essential to decision making displayed on the screen? [13, 28]
10. Is colour coding used for clarity where appropriate? [28]
11. Do the selected colours used in the form correspond to common expectations about colour codes? [13]
12. Is the number of colours limited to 3–4? [28]
13. Are different presentations adopted for each of the headings, subheadings and instructions?
14. Do the information elements e.g. images and labels stand out from the form background? [5]
15. Are there visual differences between interaction objects (e.g., buttons) and information objects (e.g., labels, images) [5]
16. Can the questionnaire be broken down into sections?
17. Can each section have a section name with a small introduction?
18. Are the rows and columns of a table designed to be clear and understandable by the users?
19. If the form has multipage data entry screens, do all pages have the same title? [13, 28]
20. Do help instructions appear in a consistent location across all the form screens? [13]
21. Is there a consistent icon design scheme and stylistic treatment across the form? [5, 13]
22. Is there consistent location of the menu across the form? [5]
23. Is all the information users enter into the data forms validated and users informed if it is not in an acceptable format? [28]
24. Are all abbreviated words of the same length? [13]
25. Is the format of a data entry value for similar data types consistent from screen to screen of a given form? [13]
26. Is the design on the input type e.g. text box or drop down consistent across the form? [5]
27. Do data entry screens and dialog boxes indicate when fields are optional? [13]
28. Are the mandatory or required data entry fields clearly marked? [5, 28]
29. Is the length of the page controlled? E.g. by limiting the number of questions on the page [13, 28]
30. Has the skip logic been automated?
31. Are the help instructions visually distinct and accessible? [13, 28]
32. If menu items are ambiguous, does the tool provide additional explanatory information when an item is selected? [13]
33. Is the help function visible; for example, a key labelled HELP or a special menu? [13, 14]
34. Can users easily switch between help and their work? [13, 28]
35. Can users resume work where they left off after accessing help? [13, 28]

Table 3 The form layout

36. In instances where a form has many pages, is each page of the form labelled to show its relation to others? [13]
37. Is pagination shown at the bottom for those forms with several pages? [14]
38. Is there a link to each of the individual pages rather than just to the previous and next ones? [14]
39. For longer forms with multiple content sections, is there a short and clickable list of the sections at the top of the page? [13]
40. Are the buttons in the form e.g. the back button and the forward button mostly or always visible? [5]
41. Have the buttons on the form been designed in different sizes and colours to emphasize importance? [30]
42. Are users able to know where they are during navigation of the form? [28]
43. Is the main navigation menu placed in the left panel of the tablet or phone UI? [31]
44. Is the navigation regulated to ensure users do not have to navigate much? [14]
45. Can users move forward and backward between text fields or dialog box options? [13]
46. If the form has many pages, can users move backward and forward among all the pages in the set? [13]
47. If the tool uses a question and answer interface, can users go back to previous questions or skip forward to later questions? [13]
48. Are cancels/exits from pages or sections clearly marked? [14, 28]
49. Is it possible for users to undo their navigation in case they are not where they want to be? [14, 28]
50. Is there some level of personalization on the screen? [13, 28] e.g. on font sizes, viewing style
51. Is it possible to customize the error message in cases where users fail to understand the questions egg changing the language
52. Are users able to change the orientation of the form during data capture? [5, 14, 28, 32]
53. Is navigation i.e. horizontal or vertical consistent across orientations? [14, 32]
54. Is content consistent across orientations? [5, 14, 28, 32]
55. Are menu choice lists presented vertically? [13]
56. If "exit" is a menu choice, does it always appear at the bottom of the list? [13]
57. Are menu titles either centred or left-justified? [13]
58. Are inactive menu items greyed out or omitted? [13]
59. Are prompts, cues, and messages placed where the eye is likely to be looking on the screen? [13]
60. Do text areas have "breathing space" around them? [13]
61. Are size, boldface, underlining, colour, shading, or typography used to show relative quantity or importance of different screen items? [13]
62. Is there good colour and brightness contrast between image and background colours? [13]
63. Is the respondent able to add, remove or update their responses in the form as and when the respondent feels the need to?
64. Is the data the users enter into the form saved automatically such that they only have to save when necessary? [28]
65. Is it possible to get a summary of all the data users have entered at any given time?
66. Are there shortcuts in case one needs to back track?
67. Are users able to interact with the form by swiping or pinching (zooming in and out) instead of only touching? [5]
68. Is layout clearly designed avoiding visual noise? [14]
69. Are meaningful sections of questions separated by white space? [13]
70. Is it possible to see all the questions in one view without scrolling?
71. Does the mobile tool's UI keep the total number of touchable UI elements to less than 10 per view? [30]
72. Is the number of submissions and clicks minimized during the process of entering data into the form? [14, 32]
73. If users are working from hard copy, does the screen layout match the paper form? [13]
74. Authorization and authentication.

Table 3 The form layout *(Continued)*

75. If the tool does not store any information that is sensitive are users kept logged in but with an option of logging out when necessary? [14, 32]
76. When logging in must be done, is there an option that allows users to see the password clearly? [14, 32]
77. Does the tool provide the user an alternate method of authentication?
78. Does the tool help users to retrieve the login data in case they have forgotten? [33]

Table 4 The input process

79. Is it possible to see a single response that has been selected in the form when surrounded by unselected options? [13]
80. Is there visual feedback in menus or dialog boxes about which response choices are selectable? [13]
81. Is there visual feedback in menus or dialog boxes about which choice the cursor is on at any given time? [13]
82. If multiple options can be selected in a menu or dialog box, is there visual feedback about which options are already selected? [13]
83. Is there a visible clue that shows users that they can swipe across the user interface? [14]
84. Are the list pickers e.g. drop downs more frequently used during data capture than text fields? [28]
85. Are data entry or text fields large enough to show all the entered data without scrolling? [31]
86. Can users reduce data entry time by copying and modifying existing data? [13]
87. Are character edits allowed in data entry fields? [13]
88. If menu lists are long e.g. more than 7 items on the response choice menu, can users select an item, either by scrolling or by typing a mnemonic code (filtering)? [5, 13]
89. Are field labels close to fields, but separated by at least one space? [13]
90. Are multiword field labels placed horizontally and not stacked vertically? [13]
91. When users enter a screen or dialog box, is the cursor already positioned in the field users are most likely to need? [13]
92. Has auto-tabbing been avoided except when fields have fixed lengths or users are experienced? [13]
93. Users dislike typing, is information computed for them where applicable? [14, 32] e.g. Age
94. Does the tool make use of device information like data and time, geo-location, device number, etc. as input data? [5]
95. Does the tool automatically align format for numeric values e.g. entering currency symbol, entering commas in numeric in numeric values greater than 9999? [13]
96. Do field labels appear to the left of single fields and above list fields? [13]
97. Are field labels and fields distinguished typographically? [13]
98. Is there consistent design on input element (e.g., textbox, dropdown)? [5]
99. Is the input element style modified too much? Can users recognize how to interact with the element? [5]
100. If expandable menus are used, do the menu labels clearly indicate that they expand to a set of options? [5]

Table 5 Error handling

101. If pop-up windows are used to display error messages, do they allow users to see the field in error? [13]
102. Does the tool show error signals and marks on the actual field that has an error and needs to be changed? [5]
103. Are users prompted to confirm commands that have drastic, destructive consequences? [13, 34] e.g. deleting the form
104. Is there an "undo" or "redo" function during data entry in the form or after completing a task or group of tasks? [14, 28]
105. Are users able to leave an unwanted state without having to embark on an unwanted user interface interaction? [28]
106. Does the tool warn users if they are about to make a potentially serious error? [13]
107. Does the tool prevent users from making errors whenever possible? [13]
108. Do data entry fields and dialog boxes indicate the number of character spaces available in a field? [13]
109. Do fields in data entry screens and dialog boxes contain default values when appropriate? [13]
110. Is the data specific format or input type expected of the respondent indicated where applicable before they attempt to enter text in a given field?
111. Are the data format requirements put inside or outside of the text box?
112. On the form, is the location of positive button (e.g., OK button, next button) on the right and negative button (e.g., cancel button, back button) on the left? [5, 13]
113. Are touchable areas sufficiently big? [13, 32]
114. Are the touchable objects e.g. buttons in the screen placed too close? [5]
115. Is crowding targets avoided? For example when targets are placed too close to each other, users can easily hit the wrong one [13, 32]
116. Are the data input types appropriate for the type of information being entered in the field e.g. use number input type for numeric information [5]
117. Although the visible part of the target may be small, is there some invisible target space that if users hit that space, their tap will still count? [13, 32]
118. When signalling an input error in a form, is the field that needs to be changed specifically marked? [14, 32]
119. Does the tool preserve users' work in order to correct errors by just editing their original action instead of having to do everything over again? [35]
120. Does a back button simply return the form to a previous view without loss of data? [28]
121. Does the tool reduce the work of correcting the error? Does it guess the correct action and let users pick it from a small list of fixes? [21]
122. If an error is detected, does the tool tell the user what happened, why and how to fix it? [28]
123. Does the system provide an example input for format-specific or complex information? [5]

Table 6 Form submission

124. For data entry screens with many fields can users save a partially filled form? [13]
125. Is the submit button disabled as soon as it has been clicked during submission of the form?

Abbreviations
DHIS: District Health Information Software; GPS: Global Positioning System; MEDCFs: Mobile Electronic Data Capturing Forms; ODK: Open Data Kit; Open MRS: Open Medical Records System.; OSS: Open Source Software; SAD: Specific Application Domain

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These are available upon request from the corresponding author.

Authors' contributions
AM wrote the protocol and participated in the data collection and analysis. VN and TT participated in data collection. AB participated in data collection and analysis. All authors participated in the manuscript preparation and approval of its final copy.

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Not applicable.

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Paper V

Original Paper

High-Fidelity Prototyping for Mobile Electronic Data Collection Forms Through Design and User Evaluation

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Abstract

Background: Mobile data collection systems are often difficult to use for nontechnical or novice users. This can be attributed to the fact that developers of such tools do not adequately involve end users in the design and development of product features and functions, which often creates interaction challenges.

Objective: The main objective of this study was to assess the guidelines for form design using high-fidelity prototypes developed based on end-user preferences. We also sought to investigate the association between the results from the System Usability Scale (SUS) and those from the Study Tailored Evaluation Questionnaire (STEQ) after the evaluation. In addition, we sought to recommend some practical guidelines for the implementation of the group testing approach particularly in low-resource settings during mobile form design.

Methods: We developed a Web-based high-fidelity prototype using Axure RP 8. A total of 30 research assistants (RAs) evaluated this prototype in March 2018 by completing the given tasks during 1 common session. An STEQ comprising 13 affirmative statements and the commonly used and validated SUS were administered to evaluate the usability and user experience after interaction with the prototype. The STEQ evaluation was summarized using frequencies in an Excel sheet while the SUS scores were calculated based on whether the statement was positive (user selection minus 1) or negative (5 minus user selection). These were summed up and the score contributions multiplied by 2.5 to give the overall form usability from each participant.

Results: Of the RAs, 80% (24/30) appreciated the form progress indication, found the form navigation easy, and were satisfied with the error messages. The results gave a SUS average score of 70.4 (SD 11.7), which is above the recommended average SUS score of 68, meaning that the usability of the prototype was above average. The scores from the STEQ, on the other hand, indicated a 70% (21/30) level of agreement with the affirmative evaluation statements. The results from the 2 instruments indicated a fair level of user satisfaction and a strong positive association as shown by the Pearson correlation value of .623 (P<.01).

Conclusions: A high-fidelity prototype was used to give the users experience with a product they would likely use in their work. Group testing was done because of scarcity of resources such as costs and time involved especially in low-income countries. If embraced, this approach could help assess user needs of the diverse user groups. With proper preparation and the right infrastructure at an affordable cost, usability testing could lead to the development of highly usable forms. The study thus makes recommendations on the practical guidelines for the implementation of the group testing approach particularly in low-resource settings during mobile form design.

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KEYWORDS

high-fidelity prototype; group user testing; mobile electronic data collection forms; usability evaluation

Introduction

Background

Usability implementation in many design scenarios, even in user-centered designs (UCDs), is still unsatisfactory [1]. This leads to unusable interfaces especially for nontechnical users [2], and such interfaces contribute to the failure of most interactive systems [3]. Of the reasons for this failure, 1 is that developers of open-source software (OSS) such as the mobile electronic data collection forms (MEDCFs) are not prioritizing the use of the UCD approach in their software development projects. They instead develop software targeting particular features [4]. This approach often leaves out the end users in the design and evaluation of these systems, whose major role is to interact with the finished products. As a result, in low- and middle-income regions, several data collection systems exist, but these are often difficult to deploy, hard to use, complicated to scale, and rarely customizable [5], hence grossly decreasing their usability.

The mobile user interface designs are usually based on the desktop paradigm whose designs do not fully fit the mobile context [6], which in turn breeds usability challenges. Other challenges may also be hardware related, for example mobile phones have limited disk space, memory, processor speed, and battery life, among others. In addition, the mobile networks on which they depend are highly variable in performance and reliability [7]. Furthermore, the limited screen size makes efficient presentation of information and navigation to the users difficult [8,9]. In fact, some of the electronic forms have multiple questions, which may make presentation on the screen quite complicated. In some phones, the display resolution may not favor good presentation of tables and images on the screen. Additionally, the keyboard size or character setting is limited irrespective of the users' finger size [10,11] and the content. This leads to incorrect choice selection and wastage of time in additional scrolling activities, which is also common with smaller interfaces [10,12].

Literature Studies and Justification

Usability is mainly concerned with the exhibited design features of interactive products in relation to how easy the user interface is to use [13], as well as the user satisfaction as a result of such use [14]. Usability is, therefore, defined by characteristics such as the cognitive perception, the ability to interact with the system, and the perception of the response from the system [3], which may vary across individuals. Important to note is that the usability of MEDCFs relies on the capabilities of the software provided by the software developers [15]; however, a number of developers have a limited understanding of usability [1,2] and how it can be implemented. This is because despite the fact that the developers' goal is usability, they tend to follow engineering criteria, which results in products that seem obvious in their functioning for the developers but not for general users, and this often leads to negative results after evaluation [16,17]. Evaluation is one of the primary stages in the UCD and in design science research (DSR), which can be used to improve the quality of any system or prototype during and after its development. Evaluation is essential in conducting rigorous DSR as it provides evidence that a newly created artifact achieves the purpose for which it was designed [18]. However, evaluating usability alone may not be sufficient to improve the quality of the system, without considering the emotions and feelings of the users as they interact with the systems or applications [19]. This brings in the aspect of user experience (UX), which is concerned with getting a more comprehensive understanding of the users' interactive experiences with products or systems [20]. UX includes all the users' emotions, preferences, perceptions, behaviors, and accomplishments that occur before (preinteraction experience), during (actual interaction experience), and after use (postinteraction experience) of the product [19-21].

User testing is one of the usability evaluation methods where the assessment of the usability of a system is determined by observing the users working with that system [22]. Here, a representative number of end users perform a set of tasks using a prototype system, and the usability challenges are presumably identified by user observations during the exercise [23]. Group usability testing, on the other hand, also involves several participants individually but simultaneously performing the given tasks, with one or more testers observing and interacting with the participants [24]. The motivation for testing is based on the assumption that any system that is designed for people to use should be easy to learn and remember, contain the functions that people really need in their work, and also be easy and pleasant to use [25]. Evaluating user design preferences is not a common approach in the development of mobile data collection forms partly because of time and financial constraints. In fact, this is the first study in Uganda where this kind of testing has been conducted, and we do not have knowledge of any such study from the published literature.

Objectives

This study therefore assesses a set of design guidelines using the group testing approach and records the end users' experience after interacting with the high-fidelity prototype. It also recommends some practical ways of implementing group testing during mobile form design, particularly in low-resource settings. To achieve this, a high-fidelity prototype was developed based on the end users' design preferences and evaluated by the research assistants (RAs) for usability and UX after interaction using SUS and STEQ. We report the level of satisfaction and the features from the prototype the RAs are satisfied with.

Methods

Participants

The study participants were 30 RAs, and all of them were collecting data on a maternal and child health project (the Survival Pluss project) in northern Uganda, which is funded by the Norwegian Programme for Capacity Development in Higher

Education and Research for Development (NORHED) [26]. Of the RAs, 3 were certificate holders and 9 were diploma holders, whereas 18 were degree holders in various fields, which included accounting, agriculture, social work, laboratory services, and nursing. Of these, 23 RAs had been collecting data for a period of 2 years or less, whereas 7 had collected data for a period ranging from 4 to 6 years. All the RAs had used open data kit (ODK) [5,27] to collect data; however, 3 reported to have used tangerine, Survey Monkey, and OpenMRS, in addition to ODK [28].

Prototype

A Web-based high-fidelity prototype for MEDCFs was developed between January and February 2018. This prototype was meant to demonstrate the RAs' design preferences having collected them earlier using a mid-fidelity prototype [29,30]. It was also used as a basis for evaluating to what extent these design preferences contribute to the usability of the data collection forms. A high-fidelity prototype is a computer-based interactive representation of the product with a close resemblance to the final design in terms of details and functionality. The high-fidelity prototypes not only test the visuals and aesthetics of a product but also the UX aspects in relation to interaction with the product [31]. The prototype (see Multimedia Appendix 1) was created in Axure RP 8 without any backend functionality and was created to fit on Samsung Galaxy J1 Ace phones that were being used to collect data on the Survival Pluss project, and they had a view port size of 320 by 452.

The prototype had 3 main sections structured based on the project's content. These consisted of the demographic section where participants were required to fill the participant ID, interviewer name, and interviewer telephone number. Section I had list pickers and section II showed different table designs capturing a child's sickness record. We explained to the RAs the potential value of the user testing exercise before giving them access to the prototype and to the tasks they were supposed to do. A summary of the entered data on the child sickness was available for the users to crosscheck and *agree* or *disagree* to its correctness, after which they were prompted to submit. Before submission, the users were warned of the inability to edit the data once they have been submitted. At this point, the progress bar indicated 100%, meaning that the form had been filled to completion and submitted.

Group Testing Exercise

The group testing exercise was conducted in February 2018 in Lira, Uganda. The RAs were required to complete some tasks (Multimedia Appendix 2) during the group testing exercise. This was meant to create uniformity in the prototype evaluation and also to be able to measure the time it took for each of the RAs to complete the same tasks. In addition to carrying out the tasks, they were also meant to read the feedback given as a result of the actions carried out and to respond appropriately until they correctly submitted the form. It was a requirement to complete all the tasks before submission of the form, and the participants were expected to record their start time before and finish time after the testing exercise. A total of 2 observers were present to record the exercise and to attend to the questions when asked to. The start time and end time were recorded for each participant in each session.

Prototype Evaluation

The prototype evaluation happened immediately after the group testing exercise. This was an ex-post naturalistic evaluation because we were evaluating an instantiated artifact in its real environment, that is, with the actual users and in the real setting [18,32]. The artifact was a high-fidelity prototype, and the actual users were the RAs who were collecting data on mobile phones using ODK, an OSS software.

Instruments Used in the Prototype Evaluation

A total of 2 instruments were used to evaluate the prototype usability, one was the SUS, a standardized questionnaire, and the other was STEQ. By combining the two, we expected to gain more detailed insight and also to test our generated questionnaire against the standardized one. These 2 posttest questionnaires were administered after the participants had completed the tasks in a bid to show how users perceived the usability of the data collection forms [33].

The STEQ comprised 13 statements and was developed based on the literature with a purpose of making an alternative instrument, other than the SUS. The statements were based on features such as form progress, simplicity in use, error correction and recovery, and visual appeal, among others. The RAs were required to indicate their level of agreement with the evaluation statements by selecting options, which included *strongly disagree*, *disagree*, *somewhat agree*, *agree*, *strongly agree*, and *don't know* and were tallied to a score of 1, 2, 3, 4, 5, and 6, respectively. The evaluation statements were selected from 4 usability evaluation questionnaires, namely the Computer System Usability Questionnaire [34], Form Usability Scale [35], Questionnaire for User Interaction Satisfaction [36], and statements from the Usability Professional Association [37]. The selected statements were based on the fact that they could be used to assess usability in mobile data collection forms as defined by the design preferences of the RAs and were all affirmative statements with positive valence. It is alleged that participants are less likely to make mistakes by agreeing to negative statements [38] similar to the case of a balanced questionnaire consisting of positive and negative statements [39]. However, and for the sake of simplicity, we used only affirmative statements adopting the style of the 4 abovementioned usability evaluation questionnaires.

The SUS is a balanced questionnaire that is used to evaluate the usability of a system and comprises 10 alternating positive and negative statements [40]. The SUS acted as a complementary scale to the STEQ. The SUS has been experimentally proven to be reliable and valid [33] because of its ability to control against acquiescence bias and extreme response bias [38,39]. In acquiescence bias, respondents tend to agree with all or almost all statements in a questionnaire, whereas the extreme response bias is the tendency to mark the extremes of rating scales, rather than the points near the middle of the scale [38,39]. These biases greatly affect the true measure of an attitude. The word *system* was replaced with the word *form* for some of the statements in both questionnaires.

Table 1. The 13 statements in the tailormade evaluation questionnaire and the number of respondents (n=30) in each category from *strongly disagree* to *strongly agree*.

Evaluation statement	Strongly disagree, n (%)	Disagree, n (%)	Neutral, n (%)	Agree, n (%)	Somewhat agree, n (%)	Don't agree, n (%)	Total (N)[a]
The form informs about its progress during interaction	0 (0)	0 (0)	2 (6)	8 (27)	20 (67)	0 (0)	30
The information, for example, onscreen messages provided in this form were clear	1(3)	0 (0)	3 (11)	4 (14)	18 (64)	2 (7)	28
It was easy to move from one page to another	3 (10)	2 (6)	1 (3)	8 (27)	15 (50)	1 (3)	30
The overall organization of the form is easy to understand	1 (3)	0 (0)	2 (6)	13 (43)	12 (40)	1 (3)	30
I knew at every input what rule I had to stick to (possible answer length, date format, etc)	2 (6)	3 (10)	7 (23)	5 (17)	13 (43)	0 (0)	30
Reading of characters on the form screen is easy	1 (0)	3 (10)	9 (30)	17 (57)	0 (0)	0 (0)	30
The form gave error messages that clearly told me how to fix the problems	3 (10)	1 (3)	1 (3)	2 (6)	21 (70)	2 (6)	30
I was able to fill in the form quickly	2 (6)	4 (13)	3 (10)	8 (27)	13 (43)	1 (3)	30
It was simple to fill this form	1 (3)	1 (3)	5 (17)	10 (33)	13 (43)	0 (0)	30
Whenever I made a mistake when filling the form I could recover easily and quickly	0 (0)	1 (3)	2 (6)	5 (17)	21 (70)	1 (3)	30
This form is visually appealing	0 (0)	2 (6)	6 (20)	10 (33)	10 (33)	2 (6)	30
Overall, the form is easy to use	1 (3)	2 (6)	1 (3)	8 (27)	17 (57)	1 (3)	30
Overall, I am satisfied with this form	0 (0)	0 (0)	7 (21)	8 (27)	14 (41)	1 (3)	30

[a]Some respondents did not reply to all statements.

Results from the 2 instruments were compared. Previous studies have shown that irrespective of the questionnaires used being balanced or affirmative, the scores from the 2 questionnaires are likely to be similar [38]. This is because there is little evidence to show that the advantages of using balanced questionnaires outweigh the disadvantages, some of which include misinterpretation of the scales leading to mistakes by the users [38]. The STEQ was summarized using frequencies in an Excel sheet where the evaluation statement with majority *agreeing* to it was taken as the option which RAs were most satisfied with (Table 1). On the other hand, SUS scores are calculated based on the statement being scored [40], and we did the same in this study. For the positive statements 1, 3, 5, 7, and 9, the score contribution was what the user had selected minus 1. For the negative statements 2, 4, 6, 8, and 10, the score contribution was 5 minus what the user had selected. The total sum of the score contributions was obtained and multiplied by 2.5 [40]. This gave the overall result of the form usability from each participant.

Results

This section presents the results after evaluation of the high-fidelity prototype using the tailor-made evaluation questionnaire and the SUS.

End-User Experience in Relation to System Usability Scale and Study Tailored Evaluation Questionnaire Scores

Of the data RAs, 80% (24/30) *agreed* that the form progress was visible, form navigation and organization were easy, and that the error messages clearly indicated how to fix problems. The same number also *agreed* that the form was simple, that it was quick and easy to recover in case of a mistake, and that overall the form was easy to use. In addition, half of the participants also *agreed* that they knew the rules to stick to when inputting the data and also found reading characters on the form easy.

However, more than 23% (7/30) of the participants *disagreed* to the form being easy to navigate and to the ability to fill the form quickly. Still some of the participants were neutral to some of these evaluation statements, that is, they neither *agreed nor disagreed*. For example, 36% (11/30) of the participants were neutral about easy reading of characters on the screen and 27% (8/30) of the participants were neutral about knowledge of the rules to stick to when inputting data. In addition, 23% (7/30) were neutral about the form being visually appealing and with their satisfaction with the form. We calculated the quantities and the respective percentages of those who *agreed, disagreed,* and those who *did not know* or were *neutral* to the evaluation statements during the evaluation exercise (Figure 1). The figure shows that about 70% of the RAs were satisfied with the form prototypes.

The individual SUSs ranged from 50 to 90 (Figure 2), with an average score of 70.4 (SD 11.7). This value was above the recommended average SUS score of 68, which showed that the RAs were fairly satisfied with the usability of the prototype. However, over 20 of the RAs felt that the form was easy to use and would like to use it more frequently, there was proper integration of various functions in the form, and they felt very confident about using the form. The same number of participants did not find the form unnecessarily complex, and neither was there any inconsistency in the form. For some of the statements, the number of participants who were *agreeing* and *disagreeing* was almost equal. For example, 12 felt they would need a technical person to use the form, whereas 16 did not, 12 felt the form was cumbersome to use, 15 felt otherwise, and 18 participants felt they needed to learn a few things first before using the form whereas 15 *disagreed* to that. Finally, 9 of the participants would opt not to use the form more frequently.

We plotted a graph to compare the association between the time it took to complete the form and the SUS scores (Figure 3). The results indicate that the time the participants took to fill the form also varied ranging from 5 to 35 min across the participants, which gave an average of 19 min overall. The direction of the relationship between the SUS score and the time is negative as shown in Figure 3. Results from the bivariate Pearson correlation we conducted indicated that the SUS score and the time taken did not have a statistically significant linear relationship because *P*=.699 which is greater than .01 for a 2-tailed test.

Comparison of Results From the System Usability Scale and the Study Tailored Evaluation Questionnaire

Using these instruments concurrently turned out to be important because we were able to test for both usability and UX using the 2 instruments. In this study, the SUS is meant to measure usability, whereas the evaluation questionnaire is more detailed and meant to capture more of the UX after including the new design preferences.

Figure 4 indicates a positive relationship between the 2 variables, for example, the participants who were satisfied with the prototype (scored 4 or 5) according to the STEQ had high SUS scores and the ones who were not satisfied (scored 1 or 2) had relatively low SUS scores. The results from the bivariate Pearson correlation indicate that this relationship is significant at the .01 level for a 2-tailed test because the *P*-value is less than .01. The Pearson correlation value of .62 further signifies a strong association between the SUS score and the STEQ score.

The participants with the lowest SUS scores all found that the form was not simple to fill, easy to use, and were also not satisfied with it as depicted in the STEQ. These results could be attributed to the fact that there was a general comparison between the forms they had been using (ODK) and the high-fidelity prototype. It felt that the prototype was limiting their usage because due to missing functionality they could not freely do what they were used to doing with ODK. In general, the results from these 2 instruments are proof that the 2 evaluation methods or instruments are meant to complement each other and not to compete against each other [41].

Figure 1. The percentage of participants who agreed, disagreed or were neutral to the evaluation statements.

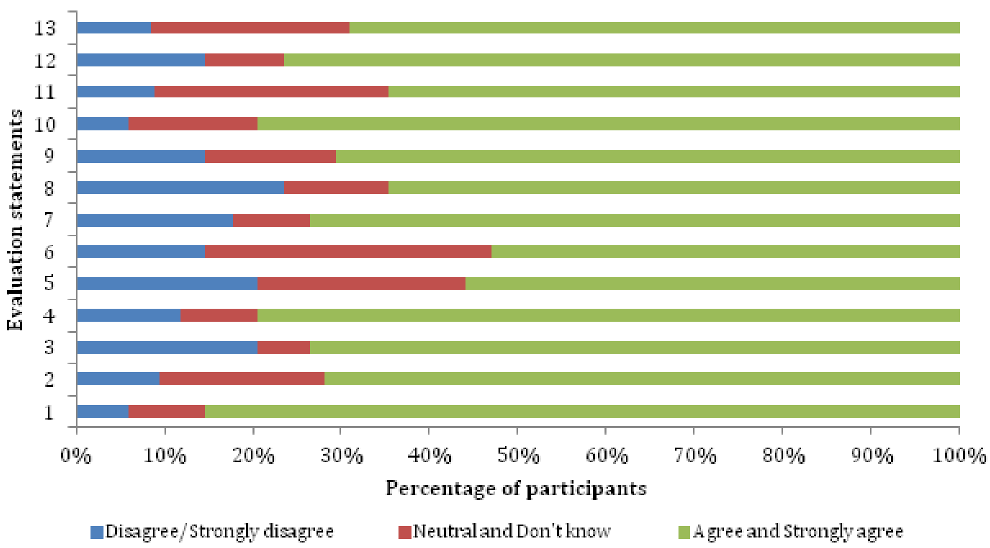


Figure 2. Results from the research assistants' (RAs) evaluation using the System Usability Scale (n=30).

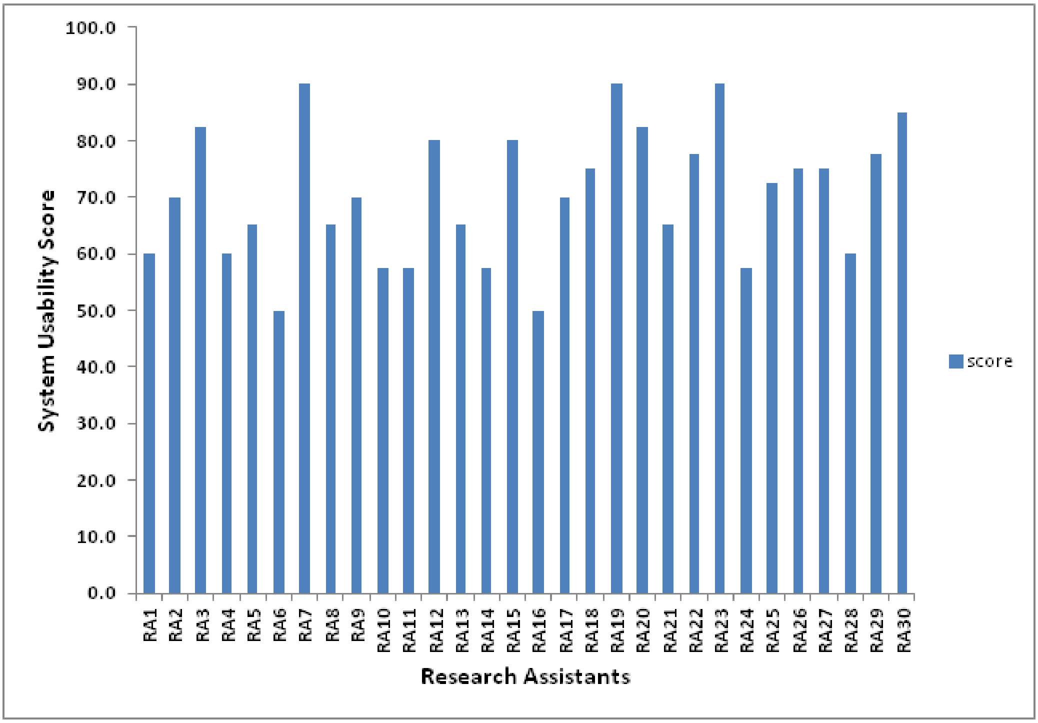


Figure 3. System Usability Scale compared with form completion time (minutes).

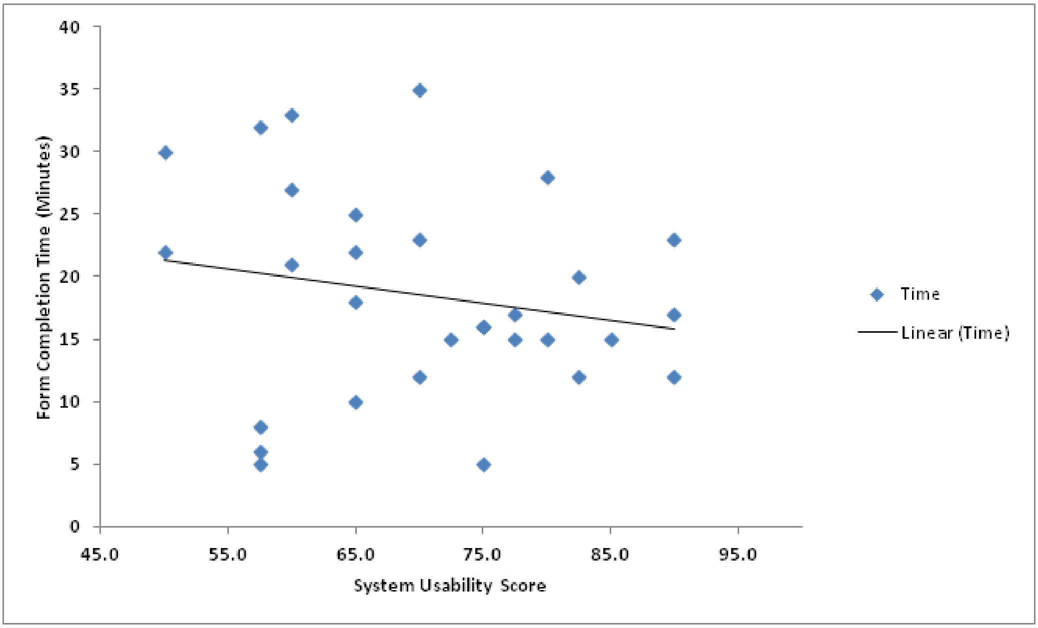
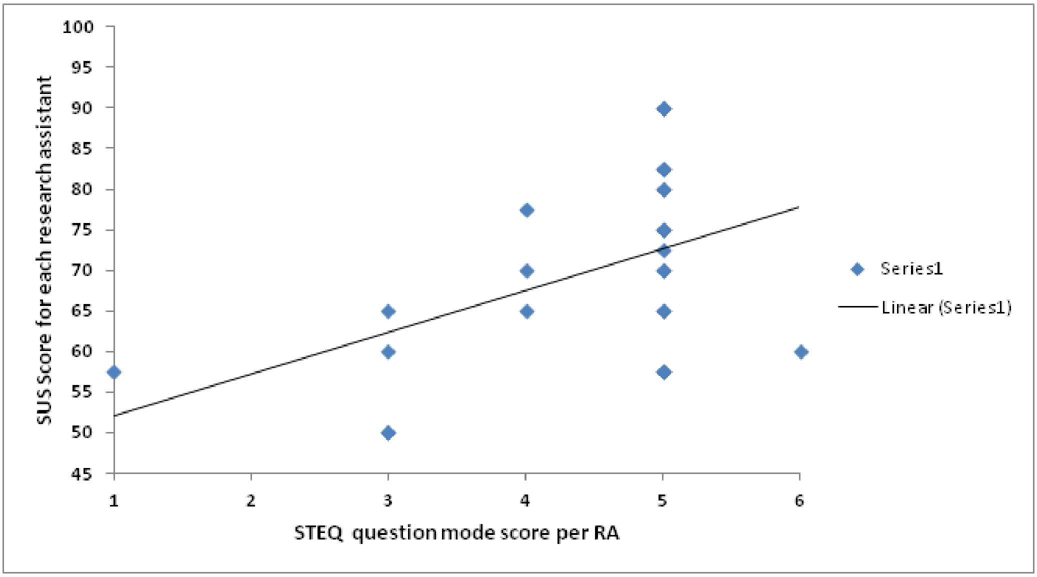


Figure 4. System Usability Scale (SUS) score compared with the Study Tailored Evaluation Questionnaire (STEQ) score. RA: research assistant.



We also note that the results for our generated affirmative STEQ do not depict any acquiescence bias because there were variations in the number of participants who *agreed* to a specific evaluation statement, meaning that not all the participants simply agreed to the evaluation statements. The percentage of participants with agreeable responses ranged from 60% (18/30), which was the lowest number, to 85% (29/30) the highest percentage (Figure 4). We also did not experience extreme response bias because the participants' responses did not only target the extreme options on the scale but also included neutral responses as shown in evaluation statements 5, 6, 11, and 13 where the percentage of respondents were 26% (8/30), 36% (11/30), 30% (9/30), and 76% (23/30) respectively. Thus, from this questionnaire, we were still able to get what the participants felt about the data collection form.

Discussion

Principal Findings

Our findings from the STEQ indicated that about 70% of the responses were *agreeable* to the affirmative statements, and the alternative average SUS score was 70.4, which showed that the participants were generally satisfied with the data collection forms. The results also indicated a strong positive association between the 2 evaluation questionnaires. Using 2 evaluation methods turned out to be important because it provided an opportunity to test for both the usability of the forms and the UX. This is based on the fact that a product with good usability can generate negative UXs, hence leading to dissatisfaction, whereas a product with bad usability can generate positive experiences or satisfaction [42]. In other words, good usability will not always lead to a good UX and the reverse is true.

We used 30 participants in this study, contrary to the recommended 5 by some researchers. The justification of the number of use testers varies and is usually linked to the benefit per cost ratio [43], whereas some researchers also intimate that 5 test users are enough to detect 80% of the usability problems [44]. However, Pablo [17] suggests selecting as many users as would be representative of the target audience provided it does not affect the usability data analysis.

Usability is not an absolute concept, but is relative, dependent on the task and the user [17]. In this study, the variations in the levels of agreement with the different design features and the time taken to complete the tasks by the participants support this. The time the users spent in the evaluation process ranged from 5 to 35 min. The participants had never been involved in such an activity before, and at times found it difficult to follow the tasks while filling the form, which affected their time specifically during consultation. Some of the vocabulary particularly in the SUS may have been a bit complex to the participants, considering that usability was a new discipline to the participants.

Prototype evaluation as a means of usability testing may not necessarily identify comprehensively all the design problems in the prototype [17] because it may be hard to observe the participants diligently, attend to all their queries, and at the same time record the sessions all in one go. Thus, using prototype evaluation can be a time-consuming and error-prone task that is dependent on subjective individual variability [17]. However, errors can be managed by ensuring that there are enough observers during the exercise to support the participants where necessary, and also the tasks chosen should cater for the variability of all the participants. Using a prototype that can be accessed in an offline state would also be useful especially in areas where internet access and speeds are a problem.

Study Limitations

Metrics from posttest evaluations do not indicate why users struggle with any design and also do not provide insight on how the design can be improved because their main focus is on tracking how users feel about using a given product [33]. Their main focus is on producing a usability score for the system rather than the identification and remediation of the specific usability issues [45]. This was true for this study as well because the RAs were not required to elaborate on why they had scored the way they did, which then leaves a gap on how best to improve the MEDCF design. There is therefore a need to identify these usability issues and remediation and give them the attention they deserve.

It is important to note that the SUS questionnaire was given after the first evaluation questionnaire, when some of the participants were probably tired and had lost their concentration, which may have had an influence on the SUS score. It was evident in some questionnaires that the users did not give much thought to what they were evaluating but ticked the same score across all the statements, for example, 1 participant who scored 50 selected *agreed* to 8 of the 10 SUS statements. This kind of evaluation certainly affects the results of the SUS score because of the alternating positive and negative statements that comprise this instrument. The SUS was deliberately designed to obtain reliable scores by alternating positive and negative statements on the same thing, that is, the UX dimension.

It was not possible to attach the users' experience to their individual scores, because we collected the demographics data during the evaluation of the mid-fidelity prototype [29] and we did not collect it again, and yet the participants did not have unique identifiers.

The results also indicate that the participants were not satisfied with the size of the screen characters and visual appeal. One would argue that the phone had a small screen size as in some cases, one had to scroll up and down several times on the same page to fill up the content on that screen. This could have had an impact on the scores from the RAs and the subsequent results.

A reasonable amount of time was spent trying to secure an internet connection, and on getting it, the internet speed was rather slow hence affecting the prototype loading time. As a result, the participants had to work in shifts because the internet could support 5 people at a go, meaning that some of the participants had to wait for longer hours before they could finally begin the exercise. Second, Survival Pluss project has a follow-up component of their recruited mothers, and some of these RAs had prior appointments to meet these mothers at the time when we were carrying out the evaluation. This also prolonged the time taken to carry out the evaluation because some of the RAs were not available on particular days or particular times.

Recommendations and Future Work

Tailoring OSS solutions to user-specific needs and preferences at reasonable costs is worth the effort. We thus recommend that data collectors worldwide are involved in form design and evaluation as early involvement could also help understand the potential of the group, their preferences, and the group's appropriate design solutions.

It is also important to consider the infrastructure and the user groups in such group testing activities, for example in this case, it would be advisable to have the prototype accessible in an offline state especially in areas where internet accessibility is a challenge.

It is not always feasible for software developers to include more resource-demanding features such as rich graphics, and perhaps some elements of gamification, but it is important to note that the RAs will always have some expectations that are worth exploring and considering.

Conclusions

Evaluating user design preferences to determine the UX using the group testing approach is not a common approach in the development of mobile data collection forms, and yet this could be one way of tailoring design to the user needs so as to cater for the diversity in context and user groups especially in rural Africa [46]. Using high-fidelity prototyping to demonstrate the design variations turned out to be a feasible and affordable form development option irrespective of the time it consumed during the evaluation process. The design features in the high-fidelity prototype that were evaluated can be a good basis when designing mobile data collection forms to improve usability and UX. In addition, adopting 2 evaluation instruments could be considered during user testing for purposes of comparing and complementing findings.

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Authors' Contributions

AM wrote the protocol and participated in data collection and analysis. TT participated in data collection. AB participated in data collection and analysis. All authors participated in the preparation of paper and approval of its final copy.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Screenshots showing the high-fidelity prototype.

[PDF File (Adobe PDF File), 1MB - humanfactors_v6i1e11852_app1.pdf]

Multimedia Appendix 2

Tasks carried out during interaction with the prototype.

[PDF File (Adobe PDF File), 251KB - humanfactors_v6i1e11852_app2.pdf]

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Abbreviations

DSR: design science research
MEDCF: mobile electronic data collection form
NORHED: Norwegian Programme for Capacity Development in Higher Education and Research for Development
ODK: Open Data Kit
OSS: open-source software
RA: research assistant
STEQ: Study Tailored Evaluation Questionnaire
SUS: System Usability Scale
UCD: user-centered design
UX: user experience

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