mHealth4Afrika - Co-designing an Integrated Solution for Resource Constrained Environments

Miriam Cunningham [a,*], Paul Cunningham [a,*], Darelle Van Greunen[b]

[a]IIMC, IST-Africa Institute, mHealth4Afrika, Dublin, Ireland
[b] School of ICT, Nelson Mandela University, Port Elizabeth, South Africa

Background: mHealth4Afrika is a collaborative research and innovation project, co-funded under Horizon 2020. It is focused on supporting Sustainable Development Goal 3 and Horizon 2020 Societal challenges by researching and evaluating the potential impact of co-designing and developing an open source, multilingual enabled mHealth platform to support quality community-based primary maternal healthcare delivery at semi-urban, rural and deep rural clinics, based on end-user requirements in Southern Africa (Malawi, South Africa), East Africa (Kenya) & Horn of Africa (Ethiopia).

Methods: A mixed methods strategy is applied. For technical development of the platform, design science research techniques are applied. The various platform iterations are implemented using an agile development process. Qualitative data collection and ethnographic observation was used during the needs requirements and base line study and validation of system iterations. These methods support regular interaction with policy makers, district and clinic managers and healthcare workers as part of the co-design process.

Results: This paper aims to share insights into the co-design process to develop a platform that integrates Electronic Medical Records, Electronic Health Records, medical sensors and visualisation tools, and automatically generates monthly program indicators.

Conclusions: mHealth4Afrika has developed a custom application to strengthen primary healthcare delivery in resource-constrained environments. It supports a range of interdependent programs defined in consultation with key stakeholders. This is achieved by interacting with a data model set up in DHIS2 via a WebAPI to facilitate holistic monitoring of a patient's wellbeing.

Keywords: Africa, Ethiopia, Kenya, Malawi, South Africa, Electronic Healthcare Records, Sensors, mHealth

1 Introduction

1.1 Background

In the context of Sustainable Development Goal 3 (SDG3) - "Ensure healthy lives and promote well-being for all at all ages", governments are working towards achieving Universal Health Coverage [1]. This requires a number of pillars to be put in place to support people-centred health services (eHealth strategies including a regulatory and data privacy environment, skills development programs and electronic health records). WHO highlights that eHealth is an "*integral part of delivering improvements in health*" care delivery and electronic health records enhance patient diagnosis and treatment through access to accurate and timely patient data [2]. An electronic health record (EHR) is defined as: "*real-time, patient-centred records that provide immediate and secure information to authorized users. EHRs typically contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, as well as radiology images and laboratory results*" [2]. [3] notes that "*mHealth in the high-income countries is driven*

by the imperative to cut healthcare costs, while in developing countries it is mainly boosted by the need for access to primary healthcare".

Despite the progress being made in introducing electronic patient records in larger hospitals in urban areas, paper-based registries are the default data capture method in resource constrained urban, rural and deep rural health centres in Ethiopia, Kenya, Malawi and South Africa (current mHealth4Afrika beneficiary countries). None of the participating health centres have access to a complete electronic patient record system [4, 6, 7]. Prior to engaging with mHealth4Afrika, intervention clinics in Ethiopia, Kenya and Malawi were not using electronic medical devices or an electronic system to record patient data at the point of care [5].

One of the driving forces in increasing the use of EHRs in Africa has been around addressing requirements for specific donors and programs including Human Immunodeficiency Virus (HIV) and Tuberculosis (TB) [9 - 10]. In South Africa clinic staff input specific data sets related to HIV and TB into separate health information systems. They do not currently use a single integrated electronic health information system to collect all patient medical data [8]. However, there is a growing awareness that using silo applications is not sustainable, for a variety of reasons including data fragmentation and duplication of effort.

As highlighted in [4], the importance of interventions taking account of information needs at different stages in the continuum of care is well documented in literature [11 - 12].

1.2   mHealth4Afrika Research Focus & Objectives

mHealth4Afrika is primarily focused on supporting SDG3 by co-designing a modular, multilingual, state-of-the-art health information system, aimed at strengthening primary healthcare delivery in resource constrained environments [4 - 7]. Since November 2015, the mHeath4Afrika platform has been co-designed with and validated by Ministries of Health, district health officers, clinic managers and health workers in primary healthcare facilities in resource constrained urban, rural and deep rural environments in Southern Africa (Malawi, South Africa), East Africa (Kenya) and Horn of Africa (Ethiopia). This input has informed an iterative development approach [4 - 8]. mHealth4Afrika integrates Electronic Medical Records and Electronic Health Record functionality with medical sensors and data visualisation tools to facilitate the interpretation and monitoring of the patient results [5].

The overall objectives [4 - 7] include to:
- research end-user requirements for rural and deep rural communities in developing country contexts;
- research and evaluate the challenges and potential benefits associated with co-designing a common multilingual patient record framework that integrates readings and clinical data from tablets and medical sensors used at the point of care;
- train healthcare workers in urban, rural and deep rural clinics on the coordinated, integrated use of medical sensors and electronic patient records to support more efficient, high quality healthcare delivery in resource constrained environments and
- pilot the integrated solution in semi-urban, rural and deep rural health clinics in Southern Africa (Malawi and South Africa), East Africa (Kenya) and Horn of Africa (Ethiopia) to assess usability and user acceptance and modifications required to facilitate wider adoption at national, regional and continental level.

mHealth4Afrika aims to provide both direct and indirect contributions to primary healthcare delivery at health centre level by supporting improvements in: (a) the quality and impact of primary healthcare delivery through timely capture of information, systematic storage of important data points in the patient electronic record, and improved follow up; (b) data quality (by reducing human error); (c) frequency of contact with a focus on prevention through adoption of state-of-the-art technologies at the point of care; (d) accuracy and quality of monthly aggregate program indicators; and (e) access to educational materials for clinic staff and patients to strengthen digital literacy and health skills [5, 7].

mHealth4Afrika has introduced the use of medical sensors at the point of care [5- 7]. The intervention clinics currently have access to an oximeter (SpO2, pulse), glucometer (sugar levels), blood pressure, contactless thermometer, weighing scales and the HemoCue Hb 201 (haemoglobin). Sensors can be used to identify non-communicable diseases (including hypertension, diabetes) at the point of care and facilitate triage through the use of a range of medical sensors (not currently practiced at health centre level) [8].

Through integrated use of state-of-the-art technologies in a platform co-designed with key stakeholders, mHealth4Afrika aims to strengthen building the status and skills of healthcare workers in the participating health centres. mHealth4Afrika has compiled a series of tools and multimedia training materials to improve

the digital literacy capacity and health skills of healthcare workers. This is complemented by face-to-face training provided to all staff nominated by clinic managers in intervention health centres [5].

This paper is focused on sharing insights into the co-design process followed to develop and validate the mHealth4Afrika platform. Section 2 outlines the methodology applied. Section 3 provides insights into the mHealth4Afrika platform, limitations of the study and ongoing research. Section 4 presents the conclusion.

2   Methodology

mHealth4Afrika is applying a mixed methods strategy [13]. For technical development of the platform, design science research techniques are applied whereby the problem is identified, artefact requirements defined, and the artefact is designed, developed, demonstrated and evaluated [14]. The various platform iterations are implemented using an agile development process. This supports regular interaction with policy makers, district and clinic managers and healthcare workers as part of the co-design process to validate the current iteration and prioritise functionality and data sets for subsequent iteration(s) [5, 7].

Qualitative data collection and ethnographic observation was used during the needs requirements and base line study (November 2015 - January 2016, 40 informants from 19 health centres in the four intervention countries), alpha validation (November - December 2016, 49 participants from 14 health clinics in the intervention countries) and validation of the first iteration of the beta platform (November - December 2017, 36 participants from 11 health clinics in the intervention countries). Based on the use of purposive sampling techniques, intensity sampling was the most appropriate approach [15, 16].

The needs assessment and baseline studies provided critical insights into national protocols, clinical workflow and reporting requirements, as well as the nature of the environments within which the platform would be used, to inform the alpha design. The baseline study provided valuable insights into relevant human resource capacity, practical and technical challenges, equipment and infrastructure related deficits [8].

The alpha and initial beta validations focused on validating user interfaces, functionality, workflow and initial data sets to be collected for Maternal Health and Child Under 5 Programs [4, 5]. These programs were selected based on their priority for each country. Each validation informed the specification of the next iteration of the platform.

mHealth4Afrika secured the necessary ethical approval required in each country [4 - 7]. There were no risks to participants based on their contribution to this study, which was voluntary. Participants were all adults and nursing school or university graduates. They were generally fluent in English, and no vulnerable people were targeted. The intervention clinics/health centres are identified by the Ministries of Health and district health offices. This study is taking place at a mix of semi-urban, rural and deep rural health centres in the Amhara Region, Northwest Ethiopia, Bungoma County, Western Kenya, Zomba and Machinga Districts, Southern Malawi and Eastern Cape, South Africa. None of these facilities have doctors. Clinic management signed an Informed Consent form during Quarter 4 2015 agreeing that data collected throughout the project duration could be used for the purposes of research, informing policy and associated publications. To ensure anonymity, each transcript per health facility was allocated a unique numerical code. With the consent of participants, interviews were audio recorded to facilitate creating transcripts to complement field notes taken during interviews. Following validation sessions, transcripts based on the audio recordings were created to provide raw data for analysis. Each participant or group of participants was allocated a code to ensure that data was sufficiently anonymised prior to data analysis, which leveraged Creswell's Data Analysis Spiral [15].

3   mHealth4Afrika Iterations

3.1   Technologies

One of the research objectives for mHealth4Afrika was to design a patient record framework leveraging some of the functionality of District Health Information System 2.0 (DHIS2). The rationale for this was based on a significant number of Ministries of Health in Africa including Kenya, Malawi and South Africa using DHIS2 as the back-end Health Management Information System (HMIS) for routine reporting of monthly aggregated program data. As a result of participation in mHealth4Afrika the Ministry of Health in Ethiopia is now transitioning to DHIS2 as the HMIS for aggregated data.

The DHIS2 has two main modules: a statistical processing module for routine reporting of numeric health data from health facilities and a single events module "Tracker" for individual patient information. The majority of DHIS2 installations are focused on statistical health data (aggregated data) from health facilities.

It was a conscious decision for mHealth4Afrika to research whether a patient focused application could be built on top of DHIS2 to support a consistent data model to store and retrieve patient data as well as support automatic generation of aggregate monthly indicators based on patient data.

The Tracker module is used in some countries for specific applications, e.g., tracking malaria patients in Zambia and maternal deaths in Uganda. The eRegistry module (adaptation of Tracker) has been used since 2017 in Palestine to capture reproductive and maternal health data based on WHO Essential Interventions. While Tracker supports a data model to be configured for programs, its user interface is not intuitive.

Having analysed both the user interface (UI) for Tracker and eRegistry during the preparation for the mHealth4Afrika alpha platform, two main challenges were identified. The current user interface of the DHIS2 Mobile Tracker Capture is not intuitive and is difficult for healthcare workers to navigate. The current architecture does not support easy adaptation of the user interface or necessary reconfiguration to support end user workflow. It is primarily used as a simple data entry form for a single program.

mHealth4Afrika reviewed the configuration of eRegistry and determined that the data set based on WHO Essential Interventions is not sufficiently comprehensive for mHealth4Afrika intervention clinics. The researchers also determined that the eRegistry use of Tracker was not appropriate for the clinical environments addressed by mHealth4Afrika. The findings and limitations identified from the extensive research undertaken by mHealth4Afrika continues to be fed back to University of Oslo to inform their roadmap for future iterations of Tracker.

As a result, it was necessary for mHealth4Afrika to develop a custom application and user interface using the Angular JS v1.6.9 programming tool that interacts with the mHealth4Afrika data model set up in DHIS2 via a WebAPI (Application programming interface). It was necessary to address a number of technical challenges interacting with the WebAPI based on the complexity and volume of data sets in each program.

The data model for each program (data elements, option sets, program sections and stages, program rules) is configured using the tools in DHIS2. The data model determines the program structure, with its stages, sections and rules. This allows a significant amount of data model related work to be implemented without programming. The mHealth4Afrika application has been programmed to dynamically render the data model for each program. This is very important in terms of maintenance and ease of modifying and adding programs going forward. It significantly reduces the requirement for access to scarce technical resources.

3.2   Functionality

The functionality and user interface of the mHealth4Afrika platform has evolved over time based on feedback received to the alpha prototype [4] and initial iterations of the beta platform [5 - 7] and user requirements.

The initial use case selected for the alpha and initial iteration of the beta was based on antenatal care. This was selected for two primary reasons. First, it is quite complex, thus providing demanding terms of reference for data collection requirements. Second, it is a free service in most African countries, and will impact many people due to the high level of demand. Detailed analysis was undertaken in terms of national protocols, clinical workflow and reporting requirements to prepare a common framework addressing the needs of the four intervention countries.

Based on the pre-beta validation in June 2017 and the Beta platform v1 validation during November - December 2017, it was very clear that health centres require a health information system that allows any patient to be registered once and then over a period of time enrolled in multiple programs depending on their health conditions [5]. This resulted in a re-architecture of the mHealth4Afrika Beta application and data model structure.

Functionality included in the mHealth4Afrika Beta v3 platform includes:
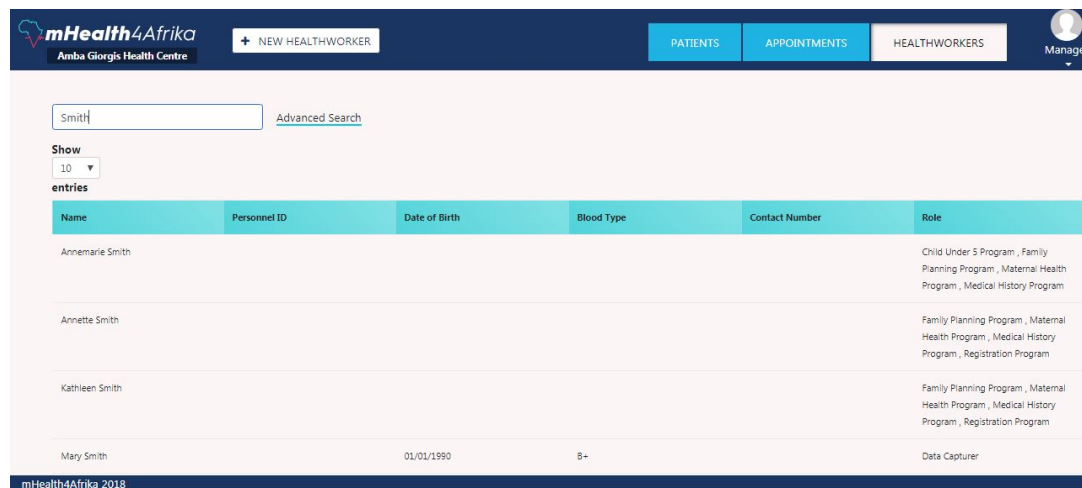
Clinic related functionality
- Set up, view and edit Healthcare workers as system users; Assign access rights based on specific program responsibilities
- Patients - Add, view and edit a new patient record, search the patient list
- Clinic Appointments - Add, view, edit patient appointments, search appointment list

Patient related Functionality

- Patient Profile - provides access to demographic information, programs, appointments, risk factors, and visualisation of program specific readings
- Programs - Add, view, edit data collected during visits related to:
  - Medical History
  - Maternal Health (Pregnancy Test, Antenatal, Delivery, PostNatal)
  - Family Planning
  - Cervical Cancer Screening
  - Child Under 5 (Growth & Nutrition, Childhood Illnesses, Immunisation, Vitamin A, Deworming)
  - Communicable Diseases: Tuberculosis, Antiretroviral therapy (ART)
  - General Out Patient Department (OPD)
- Patient Reports by Program

3.3   Use Cases & User Interface

Use cases were developed around different roles and actions taken to support program specific workflow. The data elements, workflow and associated logic were set up to provide a common back end data storage and reporting framework.

Figure 1. Clinic Manager searching Health Worker List to update access rights

The clinic manager assigns access rights to each nurse / healthcare professional based on the programs for which they have operational responsibility. For example, the registration clerk can be assigned responsibility to the Registration program while a nurse can be assigned responsibility to Maternal Health, Child Under 5, TB and ART programs.

When a patient comes to the clinic, they first visit the reception desk or records office. The registration / records clerk logs into the system, searches for the patient and checks pending appointments. If the patient has not already been registered, the clerk will set up an electronic patient record and assign a medical record number based on the normal health facility protocols. The patient will then queue for a consultation for the relevant program.

Figure 2. Clinic Manager searching Patient List by Program

Figure 3. Nurse viewing Patient Overview for Maternal Client

A nurse / healthcare professional undertakes a consultation for each program. They log into the mHealth4Afrika platform, search the patient list and retrieve the patient profile page. Depending on the access rights that the nurse has, they can see the patient profile page related to a number of programs as tabs at the top of the page.

The Patient Overview page has a common structure across all programs providing access to patient demographics, risk factors, program specific information including program stages and reports, appointments and visualisation of relevant data sets.

Figure 4. Clinic Manager viewing Patient Overview for a Tuberculosis Client

Figure 5. Clinic Manager viewing Patient Overview for a Child Under 5 Patient

The healthcare professional can then review data collected during previous visits and add data for the current consultation. The visualisation tools on the patient overview page are dynamically updated to reflect the latest data collected. Tool Tips are included within the data collection forms as an online learning /support tool. Program specific data can be viewed and downloaded as a series of patient reports.

Figure 6. Clinic Manager viewing Immunisation Details input for a Child Under 5 Patient

3.4   Limitations

There are a number of limitations of this research. A deliberate limitation has been to engage with policy makers and professional healthcare participants in rural, deep rural and semi-urban clinics in Northern Ethiopia, Western Kenya, Southern Malawi and Eastern Cape in South Africa, to gather intelligence from clinical staff responsible for local healthcare delivery. While this provides geographic representation from Southern and East Africa and ensures that the programs available through the platform are based on national requirements in these four countries, the study findings may not be representative of other Southern and East African Member States, let alone all African Member States. The sample size is also relatively small due to costs associated with equipping clinics in some countries.

3.5   Ongoing Research

The current version of the beta platform is being piloted in the intervention clinics while additional functionality is being added to the next iteration. Functionality prioritised for inclusion in Beta v4 includes automatic counting of aggregated monthly program indicators and SMS notifications for patient appointments. Literature indicates that SMS appointment reminders can be effective in increasing engagement with health service delivery [17]. Based on consultation with clinic managers, automated generation of monthly program indicators will save on average three to five person days' effort per month per clinic. These time savings can strengthen primary healthcare delivery by facilitating access to continuous professional medical education and provide more time for difficult consultations.

mHealth4Afrika is continuing research on integration of additional readings from medical sensors. The process for selecting the medical sensors and transferring data using the secure data communication standard Health Level 7 Fast Healthcare Interoperability Resources (FHIR)® to the electronic patient record is addressed in a separate paper.

4   Conclusions

This paper provides insight into the objectives and co-design process followed to develop, validate and inform the design of the mHealth4Afrika platform iterations, Beta v3 functionality and ongoing research activities.

mHealth4Afrika has developed a custom application to strengthen primary healthcare delivery in resource constrained environments. It supports a range of interdependent programs (Medical History, Maternal Health, Family Planning, Cervical Cancer Screening, Child Under 5, TB and ART) defined in consultation with key stakeholders. This is achieved by interacting with a data model set up in DHIS2 via a WebAPI to facilitate holistic monitoring of a patient's well being. The Patient Profile Page provides the healthcare professional with insight into the current records and risk factors for a specific patient, based on data collected during previous visits and visualisation of vital signs. This is limited to those programs for which the healthcare worker has access rights.

mHealth4Afrika aims to assist primary healthcare facilities to increase the quality and impact of care through timely and accurate capture of information, systemic storage of important data points in the electronic patient record and improved follow up. It aims to support preventative care by providing a state-of-the-art platform designed to encourage patients to attend relevant free services such as antenatal care as well as other services.

Acknowledgements

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