Design and Usability Testing of an mHealth Application for Midwives in Rural Ghana

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Submitted in partial fulfillment of the requirements for the Doctor of Philosophy under the Executive Committee of the Graduate School of Arts and Sciences

COLUMBIA UNIVERSITY

2011
ABSTRACT

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Midwives in Ghana provide the majority of rural primary and maternal healthcare services, but have limited access to data for decision making and knowledge work. Few mobile health (mHealth) applications have been designed for midwives. The study purpose was to design and test an mHealth application (mClinic) that can improve data access and reduce the reporting burden for midwives at the Millennium Villages Project site in Ghana.

From the design science field, the Information Systems Research Framework guided this study through two research cycles: 1) Relevance, and 2) Design. The first phase of the Relevance Cycle took a user-centered approach to assess the people, organizations, and technology of the midwives’ environment through participant observation, contextual inquiry, and interviews. In the second phase, structured requirements specification was used to categorize the data into goals, system qualities, and constraints. From the categorized data, use cases were developed for patient registration, antenatal care, malaria, family planning, and referrals. Use cases then informed the development of functional requirements. In the Design Cycle, we first used functional requirements for patient registration and malaria to develop the mClinic prototype as part of a coded-in-country initiative. Next, we examined usability of the mClinic prototype by conducting field testing, heuristic evaluation, and usability surveys. Additionally, low-fidelity prototyping was used to determine applicability of the other use cases to the midwives’ environment.

Midwives reported inability to access critical data, high patient loads, and extensive reporting requirements. Low technical self-efficacy and inadequate infrastructure were
identified as barriers to implementation. Heuristic evaluation noted issues related to hardware selection, workflow, and security. Midwives ranked the tool as useful in the usability survey; however, ease-of-use rankings were neutral. Interviews indicated this was related to low technical self-efficacy. Applicability checks found support for touch-entry prototypes over those that included lengthy forms or text-entry.

The study supported the utility of design science and user-centered methods in rural Ghana for understanding the midwives’ environment, developing functional requirements, and guiding evaluation. Midwives reported mClinic would facilitate data access and reduce reporting burdens. Improving midwives data access is essential for clinical decision making and promoting their knowledge work.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE OF CONTENTS</td>
<td>i</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>v</td>
</tr>
<tr>
<td>ABBREVIATIONS</td>
<td>vi</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>vii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>ix</td>
</tr>
<tr>
<td>CHAPTER 1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Problem Statement</td>
<td>4</td>
</tr>
<tr>
<td>Purpose of Study</td>
<td>4</td>
</tr>
<tr>
<td>Theoretical Framework</td>
<td>5</td>
</tr>
<tr>
<td> Relevance cycle</td>
<td>6</td>
</tr>
<tr>
<td> Rigor cycle</td>
<td>8</td>
</tr>
<tr>
<td> Design cycle</td>
<td>8</td>
</tr>
<tr>
<td>Significance of the Study</td>
<td>10</td>
</tr>
<tr>
<td>Definition of Concepts</td>
<td>11</td>
</tr>
<tr>
<td>Research Questions</td>
<td>12</td>
</tr>
<tr>
<td>Conclusion</td>
<td>14</td>
</tr>
<tr>
<td>CHAPTER 2. LITERATURE REVIEW</td>
<td>16</td>
</tr>
<tr>
<td>Ghana and Health</td>
<td>16</td>
</tr>
<tr>
<td> Maternal Health &amp; Family Planning</td>
<td>17</td>
</tr>
<tr>
<td> Infectious Disease</td>
<td>17</td>
</tr>
<tr>
<td> Non-Communicable Diseases</td>
<td>18</td>
</tr>
<tr>
<td> Healthcare Workers in Ghana</td>
<td>19</td>
</tr>
<tr>
<td> Data management and quality</td>
<td>19</td>
</tr>
<tr>
<td> Training of Rural Midwives</td>
<td>20</td>
</tr>
<tr>
<td>Information Needs and Practices of Healthcare Workers in Developing Countries</td>
<td>21</td>
</tr>
<tr>
<td>Midwives and Nurses as Knowledge Workers Using HIS</td>
<td>23</td>
</tr>
<tr>
<td>Health Information Systems in Developing Countries</td>
<td>24</td>
</tr>
<tr>
<td>mHealth in Developing Countries</td>
<td>25</td>
</tr>
</tbody>
</table>
Emergency services ................................................................. 27
Data collection and disease surveillance .................................................. 27
Information resources, diagnostic, and decision support .................................. 27
Human-Computer Interaction for Developing Countries (HCI4D) ....................... 29
Design Science in a Developing Country Context ............................................. 30
Conclusion ..................................................................................... 32
CHAPTER III. METHODOLOGY ................................................................. 34
Project Context ............................................................................. 34
Setting .......................................................................................... 38
Cycle I. The Relevance Cycle ................................................................. 41
  Sample ......................................................................................... 42
  Design ......................................................................................... 42
  Requirements Analysis ...................................................................... 42
  Development of Functional Requirements ............................................ 44
Cycle II. The Design Cycle ..................................................................... 46
  Build Phase ................................................................................ 46
  Evaluation Phase .......................................................................... 47
Summary .......................................................................................... 50
CHAPTER IV. RESULTS ........................................................................ 51
Cycle 1. Relevance Cycle ...................................................................... 51
  People ......................................................................................... 52
  Organizations .............................................................................. 61
  Technology .................................................................................. 63
  Problems and Opportunities ............................................................ 64
Cycle 2. Design Cycle ......................................................................... 72
  Build Phase ................................................................................ 72
  Evaluation Phase .......................................................................... 73
Summary .......................................................................................... 76
CHAPTER 5. DISCUSSION ..................................................................... 78
Summary of Study ............................................................................... 78
Discussion of Results ........................................................................... 78
LIST OF TABLES

Table 1.1 Summary of Concepts and Definitions 11
Table 1.2 Aims, Research Questions, and ISR Framework Cycle 14
Table 3.1 Outline of Study 40
Table 3.2 Data sources of structured requirements specification 45
Table 3.3 Mobile Usability Heuristics 50
Table 4.1 Classification of Midwives Interviewed 52
Table 4.2 Visit Times and Interruptions 54
Table 4.3 Monthly Reports 56
Table 4.4 Information Sources Used by Midwives 58
Table 4.5 Network and Internet Outages 63
Table 4.6 Use Case for Fever Registration 65
Table 4.7 Use Cases for Patient Registration 66
Table 4.8 List of System Qualities with Rationale 67
Table 4.9 Overview of Planned Forms 69
Table 4.10 Functional Specification and Uses Cases for Patient Registration 70
Table 4.11 Functional Specifications for Fever Registration 71
Table 4.12 Summary of Health I-TUES Survey 74
Table 4.13 Usability Issues and Severity Rankings 75
## LIST OF FIGURES

| Figure 1.1 | Design Science Research Cycles | 6 |
| Figure 1.2 | Temporal System Model | 7 |
| Figure 1.3 | Study Concepts and Outputs | 10 |
| Figure 2.2 | General Methodology of Design Science Research | 32 |
| Figure 3.1 | Typical Road in Rural Ghana | 36 |
| Figure 3.2 | Data Flow Chart for MGV-Net | 37 |
| Figure 3.3 | Map of Health Clinic Locations | 39 |
| Figure 3.4 | Structured Requirements Specification | 44 |
| Figure 3.5 | Overview of Design Cycle Evaluation Phase | 47 |
| Figure 3.6 | Sample of Low-Fidelity Prototype | 49 |
| Figure 4.1 | Typical Clinical Workflow | 53 |
| Figure 4.2 | Notifiable Disease Report | 57 |
| Figure 4.3 | Fever Register | 62 |
| Figure 4.4 | Sample Screen Shots of mClinic Interface | 73 |
| Figure 5.1 | Paper Medical Records | 84 |
ABBREVIATIONS

ACT  Artemisinin Combination Therapy
ANC  Antenatal care
CHN  Community Health Nurse
CHW  Community Health Worker
CPG  Clinical Practice Guideline
GHS  Ghana Health Service
GPRS General Packet Radio Service
HCI4D Human-Computer Interaction for Development
HEW  Health Extension Worker
Health I-TUEM Health Information Technology Usability Evaluation Model
Health I-TUES Health Information Technology Usability Evaluation Scale
HIS  Health Information Systems
ICT  Information and Communication Technology
IFA  Iron Folate (tablets)
ISO  International Standards Organization
ITN  Insecticide Treated (bed)Nets
ISR Framework Information Systems Research Framework
mHealth Mobile Health
MDGs Millennium Development Goals
MGV-Net Millennium Global Village Network
MVP Millennium Villages Project
NGO  Non-Governmental Organization
NHIS  National Health Insurance Scheme
ODK  Open Data Kit
PDA  Personal Digital Assistant
PHR  Personal Health Record
PMTCT Prevention of Mother-to-Child Transmission of HIV
RDT  Rapid Diagnostic Test
SP  Sulfadoxine-Pyrimethamine
TAM  Technology Acceptance Model
TBA  Traditional Birth Attendant
UN United Nations
UNDP United Nation Development Programme
USAID United States Agency for International Development
USD United States Dollars
WHO World Health Organization
XML eXtensible Markup Language
ACKNOWLEDGEMENTS

Many people touched and influenced this work and I wish to thank them all with my deepest, heartfelt gratitude. First and foremost, I would like to thank my adviser, Dr. Suzanne Bakken, who has been a mentor, role model, and friend throughout this process. This work would never have been accomplished without her belief, support, and encouragement in me.

Second, I would like to thank Dr. Patricia Mechael and Dr. Andrew Kanter for giving me an opportunity to work on the MGV-Net project; introducing me to the mHealth for development community; for their encouragement, advice, and support; and, for their inspiring dedication to improving global health.

I would also like to thank my committee members: Dr. Richard Garfield, Dr. Sarah Cook, and Dr. Jaqueline Merrill. Their feedback and encouragement was invaluable in tying all the different pieces of my work together.

I also want to thank all the people who contributed to this project. First, to the midwives and staff at the MVP site in Bonsaaso, Ghana, for taking time out of their day to talk with me in length about their work, struggles, and hopes for improving rural health in Ghana. I especially thank Portia Boakye Okyere for all her help. I would also like to thank the members of the MVP mHealth team for their work on this project. Finally, thank you to Yaw Anokwa for his advice on using Open Data Kit (ODK) and all those who have contributed to the development of ODK, especially the staff at Mindflow for their past and continued work on the development of mClinic.

Many of the faculty, staff, and students at both the School of Nursing and the Department of Biomedical Informatics supported me through this project. I would like to give thanks to many proof readers/editors/advisers: Dr. Yalini Senathirajah and Nicole Gellar, who both read multiple
iterations of my dissertation without bribery; Dr. Robert Lucero, Dr. Sunmoo Yoon, and Dr. Barbara Sheehan who provided critical advice and support throughout the process; Dr. David Kaufman who provided advice on HCI and use-case development; my cohort support group, Shanelle Nelson and Annie Rohan; and many other students and staff who attended my defense practice and provided last minute editing and feedback.

Many people touched my career along this path. Dr. Sheila Browne, who’s Research Explorations program started me on this path. Teena Johnson-Smith, who first taught me about computers. Laurie Wojtusik, who gave me my first clinical informatics job, through neither of us knew it at the time. Everyone at Hudson River HealthCare, my experiences there, from summer intern to EHR project manager and strategic planning facilitator, to staff nurse, will forever influence my career. Dr. Leanne Currie, who introduced me to nursing informatics research.

My dissertation was supported by a number of different grants and I would like to thank all the people and organizations who contribute to making funding for this type of research possible: P30NR010677, 1D11 HP07346, IDRC, Rockefeller Foundation, Novartis Fund for Sustainable Development, and the OpenROSA Consortium. I would especially like to thank Donald and Barbara Jonas and everyone at the Jonas Center for Nursing Excellence for their continuing generosity and recognition of the importance of nursing.

Finally, I would like to thank my family: my parents for their never-ending support; my mother-in-law for providing me with a quiet place to work in the last few months of writing; my husband, Sergio, for always having coffee ready, for giving me the opportunity to follow my dreams while raising a child, and for helping me stay balanced.
DEDICATION

To my daughter Amaya, who was lulled to sleep by journal articles instead of fairy tales, it is my deepest wish that this work will make the world a little bit better for you.
CHAPTER 1. INTRODUCTION

Midwives provide the majority of primary care, maternal care, and emergency obstetric care in rural Ghana (Prosser, Sonneveldt, Hamilton, Menottie, & Davis, 2006). Though 70% of Ghana’s population is located in rural areas, the majority of physicians are found in urban areas, primarily working in tertiary care centers (Prosser, et al., 2006; Taylor, 1992). Evidence has shown that inadequate distribution of healthcare workers has a negative impact on health outcomes (Anand & Bärnighausen, 2007; Speybroeck, Kinfu, Dal Poz, & Evans, 2006).

Midwives are considered an essential part of the healthcare workforce in sub-Saharan Africa, particularly for improving health outcomes in rural settings (Fullerton, Johnson, Thompson, & Vivio, 2011).

Ghana has made significant strides in reducing its maternal mortality ratio, from 731 per 100,000 live births in 1980 down to 409 per 100,000 live births in 2008 (Hogan et al., 2010). Improving access to skilled birth attendants, such as formally trained nurse-midwives, has been a key to this reduction in maternal mortality rates across sub-Saharan Africa (Alvarez, Gil, Hernandez, & Gil, 2009). Evidence from a recent USAID report indicates that the population of midwives in Ghana is aging towards retirement; newly graduated midwives have little incentive to work in rural areas and may be immigrating to other countries for employment; and, midwives are inadequately distributed throughout the country to meet the healthcare needs of rural populations (Prosser, et al., 2006). An insufficient midwifery workforce will likely stall or reverse the reductions that Ghana has made in maternal mortality as well having a negative impact on other health outcomes (Gerein, Green, & Pearson, 2006; Prosser, et al., 2006).

There are many factors that contribute job dissatisfaction and high turnover rates among midwives in rural Ghana. Addressing health workforce issues will require a multifaceted
intervention (WHO, 2006b). Poor work environment, high administrative burdens, and work overload have been identified as key contributing factors (Gerein, et al., 2006; Prosser, et al., 2006; Snow et al., 2011).

Health information systems (HIS) may be useful in addressing some of the issues and challenges faced by midwives in rural Ghana. HIS have been shown to improve the quality and efficiency of healthcare provision (Chaudhry et al., 2006; Tomasi, Facchini, & Santos Maia, 2004). Additionally, effective HIS allow nurses and midwives to function as knowledge workers, a role in which they gather, use, and build new knowledge (Snyder-Halpern, Corcoran-Perry, & Narayan, 2001). The knowledge worker role has been found to increase nurses’ feelings of autonomy and accountability, which has a positive effect on job satisfaction (Finn, 2001; Pierce, Hazel, & Mion, 1996; Ward & Kozakowski, 1987). However, implementation of HIS in developing countries has been challenging with many projects failing (Heeks, 2002). Selection of the appropriate technology and thoughtful design is critical to the success of any implementation (Braa, Hanseth, Heywood, Woinseth, & Shaw, 2007; Gerber, Olazabal, Brown, & Pablos-Mendez, 2010; Mechael, 2009a).

An emerging area of HIS is mobile health, or mHealth, which is defined as the use of mobile technology, such as cellular phones, wireless devices, or radio frequency identification tags, for healthcare or health services (mHealth Alliance, 2010). Early applications of mHealth was provided through the use of handheld devices known as personal digital assistants (PDAs) that provided various information resources such as medication dictionaries or point-of-care decision support (Istepanian, Laxminarayan, & Pattichis, 2006). The ability to develop applications on PDAs was limited due to lack of memory, screen space, poor graphical display, and inability to transfer data wirelessly to and from the device. Over time, however, PDAs have
become more powerful, allowing for more memory and data storage, full color graphical interfaces with video capability, integration of wireless access and integration with cellular devices into what we now know as smartphones, with the most popular being iPhones, Blackberry, and Android devices. Designing usable systems on mobile devices faces unique challenges due to limited screen space, limited processing power, ergonomic considerations, and security issues (Bertini, Gabrielli, & Kimani, 2006; Jones & Marsden, 2006).

Despite the wide variety of HIS and mHealth applications designed for developing countries, outcomes related to use of these tools have been mixed and studies assessing the design and evaluating their outcomes have been limited (Mechael, 2009a; Mechael & Sloninsky, 2008; Tamrat & Kachnowski, 2011; Tomasi, et al., 2004). Challenges of HIS deployments in developing countries include unstable or unavailable power sources; limited or nonexistent internet connectivity; largely computer and technology naïve workforces; varying and rapidly changing legal and governmental regulations; and the need for culturally and locally relevant information that is not generally found in existing information resources (Braa, et al., 2007; Gerber, et al., 2010; Heeks, 2006; Mechael & Sloninsky, 2008).

The need to understand the environment for which an application is being designed cannot be overemphasized. The consequence of poor HIS design can lead to end-user frustration, decreased productivity, project failure, and medical errors. An analysis of an HIS deployment in South Africa found that its failure could be attributed to inadequate infrastructure assessment, insufficient training and support of end-users, and lack of understanding of end-user needs and the intricacy of healthcare tasks; with an associated monetary loss of $22 million USD (Littlejohns, Wyatt, & Garvican, 2003). Berg suggests that these failures may occur when HIS implementations are viewed as a technical project rather than a process of sociotechnical change.
that requires continual adaptation and development of both the end users and the software
(2001). This begins with a grounded understanding of the end users, their tasks, and the
environment in which the application will be deployed and is cycled through simulations and
prototyping to understand how the application will work in and alter the end users environment
(Gould & Lewis, 1985).

**Problem Statement**

Midwives in rural Ghana report high levels of job dissatisfaction that results inability of
Ghana Health Services (GHS) to retain and recruit an adequate number of midwives to meet the
populations health needs. The shortage of midwives in rural Ghana will likely stall or reverse
the progress Ghana has made in reducing maternal mortality, providing adequate treatment for
malaria, and other GHS health goals. Key factors contributing to job dissatisfaction have been
poor working environment, professional isolation, and high administrative burden.

Health information system (HIS) technologies, such as mHealth, can provide a
mechanism for streamlining administrative work and decreasing professional isolation while also
giving opportunities for improving point-of-care decision support and knowledge development.
However, implementing such technologies in a developing country is challenging, as
demonstrated by the high failure rates and lack of sustainability of various HIS implementations
attempted in developing settings in the last decade. Appropriately designing systems for
developing countries is especially critical given the limited resources available for improving
healthcare infrastructure in such low resource settings.

**Purpose of Study**

The purpose of this study was to design and test an mHealth application for use by
midwives working in rural health facilities in Ghana. This study uses the Information Systems
Research (ISR) framework to guide our understanding of the environmental context, which includes people, organization, and technology, for which the artifact is being developed as well as to gain an understanding of the distinctive problems and opportunities that implementing in such a setting present.

This study used an action research approach by including active participation and design input of stakeholders at the study site in Bonsaaso, Ghana. The Millennium Villages Project is a model community under charter by the United Nations for eliminating extreme poverty, defined as those who make less than $1.25USD/day, through science-based and sustainable strategies for addressing healthcare, education, environment, and human rights (Kanter et al., 2009).

**Theoretical Framework**

The theoretical framework for this study is the ISR Framework in which various design processes are employed in order to build a product or a design artifact (Hevner, March, Park, & Ram, 2004). The design and development cycle is repeated iteratively until a desired final product is achieved. Hevner’s approach proposes that design science research projects using the ISR framework should consist of three research cycles, shown in Figure 1.1: the relevance cycle in which we seek to understand the environment of the research project by determining requirements and conducting field testing; the design cycle in which artifacts are produced and evaluated; and, the rigor cycle in which evaluation of artifacts and processes can contribute to the design science and application domain knowledge base (Hevner, 2007).
The purpose of any design science research is to solve problems or improve upon existing processes within a specified environment (Hevner & Chatterjee, 2010; Patel & Kaufman, 1998; Simon, 1996). To do this, we must understand the problems and opportunities to be addressed within the application domain, consisting of the people, technology, and organizational systems that will interact with the artifact to be developed (Hevner, et al., 2004). Any HIS implementation initiates a process of organizational change through the introduction of the artifact (B. Kaplan, 1997). The Design-Actuality gap is a model representing the current system versus the future system after the implementation of a HIS.

**Figure 1.1. Design Science Research Cycles** (Hevner, 2007)

*Relevance cycle*

The purpose of any design science research is to solve problems or improve upon existing processes within a specified environment (Hevner & Chatterjee, 2010; Patel & Kaufman, 1998; Simon, 1996). To do this, we must understand the problems and opportunities to be addressed within the application domain, consisting of the people, technology, and organizational systems that will interact with the artifact to be developed (Hevner, et al., 2004). Any HIS implementation initiates a process of organizational change through the introduction of the artifact (B. Kaplan, 1997). The Design-Actuality gap is a model representing the current system versus the future system after the implementation of a HIS.
Figure 1.2. Temporal system model of design-actuality gaps. Assessment of the current actuality and the system design (Heeks, 2002).

For example, the people or end-users, in the current system may have a low-level of technical self-efficacy. For the system to be successful, the end-users must reach a certain threshold of technical self-efficacy. This usually requires training unrelated to the actual system, such as word processing or internet search skills, in addition to training on the software being implemented. The designer may make an assumption that the end-users will be given the time and/or have the desire to reach the technical self-efficacy threshold. Failure can occur when the gap in the design and actuality is not met.

Design-actuality gaps must be considered in seven key areas: data and information sources and flow; hardware and software; workflow and processes of people using the system and those affected by it; stakeholder objectives and values; staffing and competencies; management systems and structures; and resources such as time and money (Heeks, 2002). Using these key areas to guide our research questions we can identify problems and opportunities in the current system that can be addressed with the development of a new artifact as well as those that need to be addressed to make the implementation successful. Analysis of design-actuality gaps is particularly important in a developing country context as the designers are often
from industrialized countries, as is the case in the study, and may make assumptions about the actuality that are incorrect (Heeks, 2002). The design-actuality gap model has been used in case-studies for understanding why HIS projects have failed (Best & Kumar, 2008; Gerhan & Mutula, 2007; Hawari & Heeks, 2010). These case studies can highlight common mistakes that can be avoided during the design of and HIS project to prevent failure.

**Rigor cycle**

The rigor cycle guided our selection of theories and methods for constructing and evaluating the artifact (Hevner & Chatterjee, 2010). Our selection of methods came from the literature review in Chapter 2 as well as the expertise of the research team. Within the literature review, methods were appraised for potential modification appropriate for use in a developing country context. Additionally, a search of both peer-reviewed and grey literature was conducted for existing artifacts that could meet the functional specifications and systems qualities drawn from the relevance cycle.

**Design cycle**

The design cycle is sub-divided into two phases: Develop/Build and Evaluate. In the Develop/Build phase the focus is on the creation of a highly usable artifact. Usability is defined as the user’s ability to perform the desired task using the artifact in the intended environment (Bennett, 1984). Usability has been shown to be a predictor of technology acceptance in HIS implementations (Carayon et al., 2011). The relevance cycle informs the functional requirements and system qualities of the artifact while the rigor cycle informs the design of the artifact (Hevner, 2007).

In the build phase, we contracted with a software company in sub-Saharan Africa as part of a coded-in-country initiative. The coded-in-country initiative supports information and
communication technology (ICT) capacity building in Africa by giving project opportunities to local programmers and entrepreneurs rather than outsourcing the work to ICT teams from highly developed countries (Dimagi, 2011).

In the evaluation phase of the design cycle, we apply the Health Information Technology Usability Evaluation Model (Health-ITUEM). Health-ITUEM is a model of usability evaluation that integrates subjective measures of usability through the technology acceptance model (TAM) and objective measures of usability through ISO 9241-11 (Yen, 2010). The TAM model posits that perceived usefulness and perceived ease-of-use predicts a clinician’s intention to use a particular HIS (Venkatesh, 2003). ISO 9241-11 provides guidelines for objectively evaluating usability in relation to system effectiveness, user and system performance, and user satisfaction (UsabilityNet, 1998). Health-ITUEM provides a comprehensive model for assessing usability using both subjective and objective measures (Yen, 2010).

The research questions for this dissertation fall within the relevance cycle and the evaluation phase of the design cycle. Figure 1.3 presents the concepts and the expected outputs.
Significance of the Study

The significance of this study is three fold. First, our application will establish the usefulness of applying the ISR framework in low-resource settings as a means of understanding the environmental context. Second, we will produce an artifact that has the potential for reducing data collection and sharing inefficiencies in the application setting, improving the quality of data collected, to serve as a professional resource, and provide a means for collecting data for patient management and public health surveillance. This will allow midwives to move from mere data gathers to true knowledge workers. Third, we will to establish a set of best practices in assessing

Figure 1.3. Study concepts and outputs.
environmental context in low-resource settings and contribute to the design knowledge base in a development context.

**Definition of Concepts**

Table 1.1 displays the concepts used in this study and their definitions.

<table>
<thead>
<tr>
<th>Concept</th>
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<tr>
<td>Android ODK</td>
<td>An open-source set of tools for development and management of mobile data applications on Android operating system mobile devices</td>
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<tr>
<td>Artifact</td>
<td>Something that is artificially produced or constructed that solves a problem or improves upon an existing solution to a problem.</td>
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<tr>
<td>Design-Actuality gaps</td>
<td>Congruence between the current system (actuality) and the designer’s vision of the system/needed system state.</td>
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<tr>
<td>Developing country</td>
<td>Countries with limited industrialization, underdeveloped economy, and a low-to-medium standard of living.</td>
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<tr>
<td>Environmental context</td>
<td>Includes the physical space where the application will be used, the end-users and other stakeholders, the organization using the application (either directly or indirectly), and the technological infrastructure.</td>
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<tr>
<td>E-readiness</td>
<td>The capacity to use information technology within an organization or country.</td>
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<tr>
<td>Functional requirements</td>
<td>Data inputs and outputs, manipulation, and processing that must be done by the system to satisfy the use cases.</td>
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<tr>
<td>Health I-TUEM</td>
<td>A usability model that integrates TAM and ISO 9241-11.</td>
</tr>
<tr>
<td>Highly developed country</td>
<td>A country with a developed industry and economy and high standard of living.</td>
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<tr>
<td>Information systems research framework</td>
<td>A framework for incorporating behavioral science with design science in the development of information systems.</td>
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<tr>
<td>ISO 9241-11</td>
<td>A model of objective usability.</td>
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<tr>
<td>Midwife</td>
<td>A skilled birth attendant who has received some type of formalized training in Midwifery and primary healthcare.</td>
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<tr>
<td>Knowledge Worker</td>
<td>A person who uses, analyzes, and creates knowledge.</td>
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<tr>
<td>Millennium Villages Project (MVP)</td>
<td>A model for ending extreme poverty in rural African communities using science based strategies to achieve the Millennium development goals.</td>
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<tr>
<td>Mobile Information and communication technology (ICT)</td>
<td>Information and communication technology that can be used while mobile, i.e. cellular phones.</td>
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<tr>
<td>OpenMRS</td>
<td>An open-source software platform for development of electronic health records.</td>
</tr>
<tr>
<td>Open source software</td>
<td>Software that is developed in a collaboratively with free access to source code allowing for non-licensed study, modification, and use of the code.</td>
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</table>
Perceived ease-of-use | The end users perception of learnability and memorability of the application.
---|---
Perceived usefulness | The end users perception of how the device will assist with the completion of work-related tasks.
PMTCT | Prevention of mother-to-child transmission of HIV
Technical Self-Efficacy | Confidence in learning and using new technology
Technology acceptance model (TAM) | A model by with the perception of the ease-of-use and usefulness of a system impacts the intention to use and ultimately actual use.
Usability | How easy the application is to use taking into account 5 factors: learnability, efficiency, memorability, error recovery, and satisfaction (Nielsen, 2003).
System Qualities | Attributes of the system in regard to usability, security, scalability, extensibility, and other quality characteristics.
Use cases | Expected interactions between the system and the end-user or other systems based on requirements gathering.
User interface | The component of the computer application where the end-user interacts with the application.
X-Forms | Specification model for data processing of extensible markup language (XML) data

*Table 1.1. Summary of concepts and definitions*

**Research Questions**

Our research questions are divided into the relevance cycle and the design cycle. The relevance questions address gathering the information needed in order to understand the environmental context in which our application will be deployed. The design questions involve the effectiveness of our translation of those needs into a design artifact through testing and evaluation.

- **Relevance Cycle**
  - People
    - What is the current workflow of MVP midwives?
    - What are the roles and responsibilities of midwives at MVP facilities?
What is the current experience of the midwives with technology and their comfort level in learning new technology?

What are the information needs and information seeking behaviors of midwives working in MVP facilities in Ghana?

Organizations

What are the issues in collecting data from the health facilities?

What is the support capacity for and HIS implementation at MVP Ghana?

Technology

What is the current technology infrastructure at MVP Ghana?

Problems & Opportunities

What are the functionality requirements for the application based on the needs and constraints of the application environment?

Design Cycle

Justify/Evaluate

What usability issues exist with the artifact?

What are the deficiencies in functionality or qualities of the artifact that need to be addressed to improve acceptance?

How does the artifact meet heuristic standards?

Table 1.2 organizes the research questions by study aims and ISR cycle.
### Table 1.2. Aims, Research Questions, and ISR Framework Cycle

<table>
<thead>
<tr>
<th>Aims</th>
<th>Research Questions</th>
<th>ISR Framework Cycle</th>
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| Determine the functional requirements, system qualities (non-functional requirements), and constraints of the artifact to be developed through assessment of the application domain | • What is the current workflow of MVP midwives?  
• What are the roles and responsibilities of midwives at MVP facilities?  
• What is the current experience of the midwives with technology and their comfort level in learning new technology?  
• What are the issues in collecting data from the health facilities?  
• What is the support capacity for an HIS implementation at MVP Ghana?  
• What is the current technology infrastructure at MVP Ghana?  
• What is the required functionality needed for the application based on the need and constraints of the application environment?  
• What are the information needs and information seeking behaviors of midwives working in MVP facilities in Ghana? | Relevance |
| Testing and evaluation of the developed artifact                      | • What is the usability of the artifact?  
• What are the deficiencies in functionality or qualities of the artifact that need to be addressed to improve acceptance?  
• How does the artifact meet heuristic standards? | Design cycle |

#### Conclusion

mHealth presents a unique and promising method for delivering health information in developing countries. Challenges exist in understanding the environmental context and constraints of implementing HIS in low-resource settings. The use of the ISR Framework as
proposed in this study will provide a guideline for an action research approach to application design and evaluation in a developing country. Midwives in rural Ghana need reliable, accessible, and accurate data to fully apply their domain knowledge to both patient and population care. Furthermore, this work will result in the development of an artifact that can be customized for use in similar settings for addressing healthcare workers information needs while improving clinical decision making with the potential to improve patient outcomes and support healthcare systems infrastructure.
CHAPTER 2. LITERATURE REVIEW

This literature review will first provide a brief profile of Ghana with information on the country’s key health issues. This is followed by the literature on the information needs of healthcare workers in developing countries with a focus on the role of midwives in meeting rural healthcare needs, the use of health information systems in developing countries with a focus on mHealth, and methods in design science.

Ghana and Health

Ghana, located in Western Africa, was the first sub-Saharan African nation to gain independence from its colonial rulers in 1957 and has had a stable democracy for the past few decades. Ghana is a tropical country roughly the size of Oregon with a population of 25 million (CIA, 2011). It is an ethnically, religiously, and linguistically diverse country. Though English is the national language and is used in educational settings, less than 36% of the population speaks it, especially in rural areas, and the adult literacy is approximately 66% (Trudell, 2009; UNICEF, 2010). Ghana has a gross domestic product per capita of $306 USD (Nguyen, Rajkotia, & Wang, 2011). The recent discovery of oil deposits in Ghana have brought economic growth and expansion to the country; the number of Ghanaians living in extreme poverty is rapidly declining and the country is expected to reach middle income status by 2020 (Ede, Sousa, Dhaliwal, & Munait, 2011).

The life expectancy at birth for males is 56 years and females is 58 years (WHO, 2011a). Though the incidence of HIV/AIDS, at 1.8%, is lower than the average incidence of 5.0% in other sub-Saharan African nations, the lack of available treatment and the high mortality rate still make it a pressing issue (HIV InSite, 2011). Other leading causes of death include: malaria, lower respiratory infections, perinatal conditions, stroke and heart disease, diarrheal diseases and
tuberculosis (WHO, 2006a). The WHO estimates the under-five mortality rate for 2005 to be 112 per 1000 live births with malaria (33%), neonatal complications (28%), pneumonia (15%), diarrheal diseases (12%), and HIV/AIDS (6%) as leading causes (2006a).

**Maternal Health & Family Planning**

Estimates for maternal mortality rates in Ghana for 2005 range from 378 to 560 per 100,000 live births, and despite discrepancies, remain higher than WHO and government goals (Asamoah, Moussa, Stafstrom, & Musinguzi, 2011). Maternal mortality is the second leading cause of death, after infectious disease, among Ghanaian women 12-49 years old, with the most common cause of maternal death being from post-partum hemorrhage (Andreatta, Gans-Larty, Debpuur, Ofosu, & Perosky; Ghana Statistical Services, Ghana Health Service, & Macro International, 2009). In rural areas, lack of skilled attendants, financial resources, and accessible emergency obstetric care lead to an increased risk of maternal death (Fofie & Baffoe, 2010). The fertility rate in Ghana is 3.9 births per woman (The World Bank, 2011) with 0.7 births per woman reported as unintended. Unmet family planning needs are reported by 34% of Ghanaian women, with a higher rate in rural areas (Johnson & Madise, 2011).

**Infectious Disease**

Ghana has made great progress towards reducing the transmission of HIV. The prevalence of HIV decreased from 3.6% in 2003 to 1.8% in 2009 (Ede, et al., 2011). However, disparities remain between socio-economic groups on access to antiretroviral therapies with only 24% of those needing treatment actually receive it (UNAIDS, 2010). Additionally, condom use in rural areas and HIV testing in married couples is not widely accepted (Aheto & Gbesemete, 2005).
Malaria remains a significant cause of morbidity and mortality in Ghana, particularly among children under five, and has been associated with an increased risk of stillbirths (Yatich et al., 2010). Despite the number of malaria prevention initiatives in Ghana, one study found that less than 40% of pharmacy staff had adequate knowledge about current malaria control initiatives and only 21% were aware of current malaria treatment guidelines (Buabeng, Matowe, Smith, Duwiejua, & Enlund, 2010). Even with the introduction of rapid diagnostic tests for malaria, misdiagnosis and over-diagnosis of malaria remain common, resulting in misallocation of resources and contributing to medication resistance (Chandler, Whitty, & Ansah, 2010; Whitty, Chandler, Ansah, Leslie, & Staedke, 2008). This evidence suggests that the information needs regarding the prevention and management of malaria remain high, even among healthcare workers.

**Non-Communicable Diseases**

The prevalence of non-communicable diseases in developing countries has increased greatly with increasing average lifespans, lifestyle changes, continuing poverty, and urbanization (de-Graft Aikins et al., 2010). A recent survey found an increasing morbidity for women in Ghana for diseases more commonly thought of as problems of industrialized nations: hypertension, diabetes, chronic pain, arthritis, deteriorating visual acuity, and dental problems (Duda et al., 2011). The WHO describes in the increase in non-communicable disease in developing countries as a “double burden” for health systems with limited capacity to treat present problems with infectious disease and a scarcity of healthcare workers with training and/or experience with chronic disease management (Marshall, 2004). Clinical management of non-communicable disease often requires long-term data sets and patient histories which are not currently adequately managed in existing paper records. Increased chronic disease in Ghana has
resulted in high rates of disability and premature deaths which have been associated with inadequate knowledge of health workers of chronic disease management (de-Graft Aikins, 2005; de-Graft Aikins, Boynton, & Atanga, 2010).

**Healthcare Workers in Ghana**

Ghana, like many other developing countries, faces a shortage of healthcare workers. The majority of physicians work in the metropolitan areas of Accra and Kumasi, while rural areas retention and recruitment to rural areas remains a challenge due to perceived professional isolation, decreased income, and lack of mentoring and distance learning opportunities (Snow, et al., 2011).

Nurses, like physicians, are not adequately distributed between rural and urban settings in Ghana (Donkor & Andrews, 2011). Significant job dissatisfaction and high-turnover rates among nursing and midwifery staff are common, with considerable “brain drain” to the US and Great Britain (Talley, 2006). Working conditions and compensation for nurses/midwives are poor, with job assignments dictated by the government, and virtually no opportunity for advancement (Donkor & Andrews, 2011). Ghana, like many countries in Sub-Saharan Africa, is made up of a large number of ethnic groups, sharing their own language, customs, and practices. Midwives and nurses, who may be serving in an area outside of their own cultural group would need further information and support about local socio-cultural factors that may affect treatment seeking behaviors or health risks of patients in the community that they are serving (Apalayine & Ehikhamenor, 1996).

**Data management and quality**

Another challenge faced by Ghana’s healthcare system is the management and collection of data. In many developing countries, cause of death is usually determined through reports
from relatives rather than on pathology or autopsy data, as is commonly done in industrialized countries. These verbal autopsies are often inconsistent in assigning accurate causes to maternal death making it difficult to determine where and what resources and training should be allocated (Chandramohan, Rodrigues, Maude, & Hayes, 1998). Certain conditions, such as hypertensive disorders, tend to be over-diagnosed while death related to malaria and other infectious disease is underreported (Asamoah, et al., 2011; Ordi et al., 2009). Ghana’s government is in the process of a rollout of national health insurance (NHIS). Having quality data on use of services and resources is a key element for appropriate spending, allocation of resources, and ensuring that NHIS serves in reducing the costs of out-of-pockets expenses and catastrophic health expenditure for Ghana’s citizens (Debpuur, Welaga, Wak, & Hodgson, 2010; Nguyen, et al., 2011).

**Training of Rural Midwives**

For the purpose of this study, we define a midwife as a skilled birth attendant who has received some type of formalized training in midwifery versus a traditional birth attendant (TBA) who is primarily trained through apprenticeship. As in the developed world, the pre-service training of midwives in Ghana vary widely, with technical, baccalaureate and graduate training available as pathways to entry-to-practice (Fullerton, et al., 2011). This variation means that midwives may enter practice with three years of previous training as a nurse plus work experience or with no previous nursing training or clinical work experience (Prosser, et al., 2006). Furthermore, studies of rural healthcare workers in developing countries have found most workers to be young and/or inexperienced, with little computer skills and high turnover rates (Martinez, Villarroel, Seoane, & del Pozo, 2005).
Poor road access to rural health facilities may limit opportunities for continuing education. In Ghana, rural facilities may be several hours away from the nearest population center due to the lack of paved roads. Additionally, since midwives work independently, leaving the facility for continuing education means that no or limited services will be provided until she returns (Martinez, et al., 2005; Prosser, et al., 2006). Evidence suggests that recertification practices and license maintenance requirements are not consistently applied or monitored in Ghana. In general, a midwife is licensed to practice for life after completing and passing pre-service training and certification exams (Fullerton, et al., 2011). Inconsistencies in training and continuing education practices highlight the need for insuring rural midwives have access to appropriate information for supplementing their training and clinical knowledge and the need for a mechanism for continuing training and recertification.

**Information Needs and Practices of Healthcare Workers in Developing Countries**

Appropriate and timely health information is necessary for providers to give proper care to their patients, whether this information is lab results, medications, patient history, or information on the latest standards of care. In developing countries health care providers, particularly those working in rural areas, often lack access to health information due to a lack of communication infrastructure as well as lower levels of computer literacy (Pakenham-Walsh, Priestly, & Smith, 1997).

Providers in developing countries may rely on heavily on colleagues or printed materials when making health decisions (Kapiriri & Bondy, 2006). This presents challenges as the information may not be up-to-date or represent current best practices. Furthermore, one study found that donated textbooks were not appropriate because they did not include culturally or locally relevant information, such as information about tropical diseases or local health practices.
or inclusion of treatment modalities that are not locally available (Musoke, 2000). While several studies found electronic resources useful in developing countries, these studies only looked at doctors working in urban, tertiary care settings (Aronson, 2004; Burton, Howard, & Beveridge, 2005).

Studies have noted that many midwives feel unprepared to meet the most pressing needs of the current health crisis in Sub-Saharan Africa, such as treating resistant strains of malaria and prevention of mother-to-child transmission of HIV (Leshabari, Blystad, de Paoli, & Moland, 2007; Mechaël, 2009b; Prosser, et al., 2006). One nurse, with 20 years’ experience in public health was quoted as saying: "I have only attended one workshop for one week on promoting exclusive breastfeeding. I'm still using the same knowledge to educate mothers on how to feed their babies. I feel like I'm not knowledgeable enough to give my clients updates, especially in this time of AIDS." (Leshabari, et al., 2007, p. 7). This lack of knowledge is exacerbated by the limited opportunities for continuing education noted in the previous section.

Paper record keeping systems in developing countries may be insufficient for monitoring of interventions and serve as poor information resources to providers. An analysis of paper records in Kumasi, Ghana on obstetric complications found deficiencies that made root-cause analysis of obstetric complications impossible (Danquah et al., 1997). In Ghana, new records are created based on visit type and patients may use different names based on the type of visit making record linkage difficult if not impossible (Allotey & Redipath, 2000). Inconsistencies in record keeping practices present a challenge, particularly in tracking high-risk patients and in ensuring continuity of care, especially for patients with chronic conditions. While health information systems (HIS) may assist in record linking, the proper identification and tracking of patients requires collaboration from local, regional, and governmental health officials.
Midwives and Nurses as Knowledge Workers Using HIS

A knowledge worker is defined as “those who are able to critically reflect upon the explicit knowledge of the organization by adding personal, theoretical, and tacit knowledge” (Brooks & Scott, 2006, p. 84). Knowledge workers in their role acquire, transmit, and apply knowledge as well as creating new knowledge (Kelloway & Barling, 2000). Transforming nurses and midwives into knowledge workers is important for several reasons. First, it promotes autonomy that may lead to improved job satisfaction (Finn, 2001; Pierce, et al., 1996; Ward & Kozakowski, 1987). Additionally, nurses and midwives who can effectively use and produce knowledge can help identify patient needs, affect policy, and play a great role in their healthcare system (Antrobus, 1997; J Sorrells-Jones & D Weaver, 1999). Nurses and midwives need access to accurate and complete data regarding their patients in order to function as knowledge workers (Snyder-Halpern, et al., 2001). Transforming nurses and midwives into effective knowledge workers may require organizational changes that ensure nurses and midwives have access to critical information and an organizational culture that allows for diffusion of knowledge to affect change in individual practice as well as the organization (Brooks & Scott, 2006).

HIS can be useful in promoting knowledge worker role amongst nurses and midwives. Snyder-Halpern and colleagues (2001) outline the how HIS can aid in knowledge work and the four roles for nursing and midwifery knowledge workers: data gatherer; information user; knowledge user; and knowledge builder. In the data gather role, the knowledge worker collects clinical data (Snyder-Halpern, et al., 2001). HIS can be used to facilitate data collection at the point-of-care and improve the accuracy of the data collected (Montoya & Carlson, 1996). In the information user role, the knowledge worker interprets and organizes data for clinical decision making (Snyder-Halpern, et al., 2001). HIS can support this role by helping to organize relevant
data needed for clinical decision making and simplifying access to patient data, providing data in a timely manner, and fitting into workflow (Bates et al., 2003). The knowledge user role occurs when domain knowledge is applied to patient information (Snyder-Halpern, et al., 2001). HIS can facilitate this role with context specific information resources and access to and evidenced-based clinical knowledge bases (Bates, et al., 2003; Snyder-Halpern, et al., 2001). The knowledge builder role occurs when domain knowledge is used to interpret and understand aggregated patient data (Snyder-Halpern, et al., 2001). HIS can support this role by giving nurses and midwives access to aggregate patient data that allow the nurse or midwife to evaluate their work and recognize and interpret practice patterns (Ozbolt & Graves, 1993; J. Sorrells-Jones & D Weaver, 1999).

As frontline workers, the knowledge gathered by midwives and nurses in rural facilities is critical for identify patterns among patients and identifying need areas for targeted interventions. HIS implementations that support knowledge work in developing countries have been limited (W. A. Kaplan, 2006; Mechael & Sloninsky, 2008; United Nations Foundation, 2010).

**Health Information Systems in Developing Countries**

Several reviews have found that most HIS implementations in developing countries lack published reports on patient outcomes and/or quality improvements (Blaya, Fraser, & Holt, 2010). This is partially due to complexity in establishing baseline data using paper-records as well as the rapidly evolving healthcare systems in the developing world due to various, concurrently occurring local government initiatives in conjunction with the World Health Organization, the United Nations Development Programme (UNDP), and other non-governmental organizations (NGOs) (Braa, et al., 2007). Most HIS projects have faced challenges in establishing long-term sustainability (Gerber, et al., 2010). Projects often require
data collection standards to meet the needs of national or international donors that often fail to address local needs (Gordon & Hinson, 2007). These projects are further challenged by short-term funding mechanisms and failure to provide adequate training and support once foreign experts leave (Heeks, 2002).

Sharing of resources and expertise, such as the use of open-source software and nationally and internationally shared technical expertise have helped to alleviate the costs associated with HIS implementation while providing a model for sustainable success (Blaya, et al., 2010; Were et al., 2010). In addition, local human resource capacity building is recommended for long-term success of any implementation (Heeks, 2002). A key factor to success of HIS implementations in developing countries is user acceptance (Fraser & Blaya, 2010; United Nations Foundation, 2010; Williamson, Stoops, & Heywood, 2001). Methods for increasing user acceptance include providing adequate support and training for learning the new system, encouraging local ownership and data use, cultivating local leadership and project champions, and sensitivity to local culture (Fraser & Blaya, 2010; Rotich et al., 2003; Waters et al., 2010). Additional studies have shown that alignment of the HIS intervention with user needs and provider technical self-efficacy are also significant factors in technology acceptance (Wu, Wang, & Lin, 2005).

**mHealth in Developing Countries**

Mobile health technologies are being increasingly used to meet the information needs of health care workers in sub-Saharan Africa (Fraser & Blaya, 2010). Recent advances in the mobile telephony technology, as well as significant infrastructure improvements in sub-Saharan Africa, the low start-up development costs, end-user familiarity, and increased research funding from both private foundations and industry sources make mobile phones a strong candidate as
the tool for health information delivery in developing countries (W. A. Kaplan, 2006; Mechael, 2009a; Mechael & Sloninsky, 2008). The mobile phone market in Africa is the fastest growing in the world, having increased 58% from 1999 to 2004 (LaFraniere, 2005). Africa was the first continent where mobile phone use exceeded landline use and the current mobile phone penetration rate in Africa is 30% and growing (International Telecommunication Union, 2009). There is growing interest in using the existing and growing mobile phone infrastructure in Africa as a means of delivering health information solutions, however, systematic reviews on the topic have found that most published studies have been brief pilot and feasibility studies with limited evaluation and little mention of project scalability and long-term feasibility (W. A. Kaplan, 2006; Mechael & Sloninsky, 2008; Tamrat & Kachnowski, 2011). However, mobile technology has rapidly become faster, smarter, and cheaper; rapidly changing the technological and financial barriers of studies that are even just a few years old (W. A. Kaplan, 2006).

To date, most mHealth projects in Sub-Saharan Africa have targeted community health workers (CHWs), who play a vital role in accessing hard-to-reach patients (W. A. Kaplan, 2006; Tamrat & Kachnowski, 2011). Most CHWs are lay-people with limited education and/or training to meet the demands of patients burdened with chronic disease or other serious afflictions (Kober & Van Damme, 2004). Projects targeting other types of providers have been extremely limited (James & Versteeg, 2007; W. A. Kaplan, 2006; Mechael & Sloninsky, 2008). Applications using mHealth for healthcare workers have generally been in the following categories: emergency services, health promotion, data collection and management, monitoring, information resources for healthcare workers, disease surveillance, and point-of-care decision support (Mechael, Douglas, Lesh, & Kwan, 2009; Tamrat & Kachnowski, 2011; United Nations Foundation, 2010).
Emergency services

Applications targeted at emergency service support include: Rural Extended Services and Care for Ultimate Emergency Relief (RESCUER) (Tamrat & Kachnowski, 2011; United Nations Foundation, 2010). RESCUER combined the use of two-way radios with bicycles and ambulances in order to respond to obstetric emergencies and resulted in a 50% reduction in maternal mortality (Musoke, 2002). Similar projects in Bangladesh, the Gambia, and India have been reported but no published data on the effect of the interventions are available (Cole-Ceesay et al., 2010; Tamrat & Kachnowski, 2011).

Data collection and disease surveillance

A wide range of tools are available for data collection purposes and disease surveillance. OpenXData and EpiSurveyor are both used for remote data collection. OpenXData is an open-source software for data collection that works on inexpensive java based phones and has be used in several countries in Africa and South East Asia (OpenXData, 2011). EpiSurveyor is similar to OpenXData though it is available on a wider range of phones and has a cost associated with its use, though a free version with limited functionality is available (DataDyne, 2011). These tools, and others like it, allow for faster and higher quality survey data collection (Lang, 2011). A number of survey tools have also been created for disease surveillance, the most well-known being FrontlineSMS which was used to monitor water quality in Haiti following the most recent cholera outbreak (Greenemeier, 2011).

Information resources, diagnostic, and decision support

Several programs have been designed as an information resource for healthcare workers including: Enhancing nurses access for care quality and knowledge through technology (ENACQKT); HealthLine; Mobile HIV/AIDS Support; Primary Healthcare Nursing Promotion.
Program; and, The Uganda Health Information Network (UHIN); diagnostic and decision support tools such as phone based dosage calculators, medical sensors, and remote diagnostic support (United Nations Foundation, 2010). The ENACQKT project provided clinical information resources to nurses and student nurses to nurses in the Caribbean resulting in an 27% average reduction in time to access clinical information (International Development Research Center, 2009). HealthLine uses speech recognition to give community health workers with low literacy levels access to information resources, it is currently in pilot testing (Sherwani et al., 2007). UHIN allows for sending and receiving data in remote clinics, was developed by AED-Satellite, who report that the project resulted in quicker and more cost-effective data collection with improved data quality (Kinkade & Verclas, 2008). AMREF’s Only summary information was available for Mobile HIV/AIDS support and the Primary Healthcare nursing promotion program (United Nations Foundation, 2010).

A more advanced example of decision and diagnostic support is e-IMCI. A treatment algorithm developed by UNICEF known as Integrated Management of Childhood Illness (IMCI) was integrated in to a PDA (e-IMCI) for use by clinicians in Tanzania. The use of the PDA based tool found increased adherence to investigation guidelines and a reduction of time spent documenting care (DeRenzi et al., 2008). Another application, the Aceh Besar midwives mobile-phone project, supplied midwives with mobile phones to transmit health data and provides diagnostic support through communication with health coordinators and other midwives. The study results showed increased confidence in the midwives self-reported ability to solve difficult clinical problems, though results on medical knowledge scores were mixed (Chib, 2010).
Evaluation of the impact of these applications is still limited. Much of the project data reported here come from online reports rather than peer-reviewed journals. Most of the reports were short-term evaluations of pilot testing. Many of these pilots faced common challenges such as: equipment not being available (Sherwani, et al., 2007); lack of healthcare infrastructure to support the goals of the project (Cole-Ceesay, et al., 2010; Musoke, 2002); staff morale and project buy-in (Cole-Ceesay, et al., 2010); and difficulty in distinguishing between borderline cases in clinical decision making and limiting the development of clinical reasoning (DeRenzi, et al., 2008).

**Human-Computer Interaction for Developing Countries (HCI4D)**

In the developing world, it is common for most web users to have only experienced accessing the internet through a mobile device. Mobile web sites often assume that users have access to or previous experience with a personal computer and such instructions had a negative impact on users ability to appropriately navigate a site (Gitau, Mardsen, & Donner, 2010). Researchers have noted that current participatory design methods rely on users having a base understanding and knowledge of technology that is often inappropriate in developing settings (Smith & Dunckley, 2007). Other considerations for HCI4D include inadequate power infrastructure, low literacy levels or inability to translate technology specific concepts to the local language, and cultural variations in mental models (Ho, Smyth, Kam, & Dearden, 2009). Participatory design methods, which often seek design proposal from users, may not be feasible amongst users whose understanding of technology is limited (Gitau, et al., 2010; Heukleman, 2006; Maunder, Marsden, Gruijters, & Blake, 2007)

Various alterations to user centered design methods for use in developing countries have been proposed though there is limited data available on the effectiveness of such methods.
(Maunder, et al., 2007). Ramachandran et al. (2007) suggests establishing a “technology baseline”, by exhibiting examples of software with similar functionality to the one to be implemented. This can also be done through computer literacy and training prior to the design sessions (Kimaro & Titlestad, 2008). However, these methods may be limited in the case of time or human resource constraints. The use of low-fidelity prototyping in this context may be challenging if such prototypes contain concepts that are unfamiliar to the user (Lalji & Good, 2008; Maunder, et al., 2007).

**Design Science in a Developing Country Context**

As previously noted, many HIS implementations in developing countries have resulted in failures (Braa, 2004; Heeks, 2002). Heeks (Heeks, 2006) categorizes failures as either total, when the system is never implemented or is implemented, then abandoned; or partial, when key goals are not attained or unwanted outcomes occur. Success is defined as most stakeholder groups attaining key goals without significant unwanted outcomes. Success of an HIS is a dynamic concept and can be defined in terms of effectiveness, improved efficiency, organizational acceptance, end-user satisfaction, and patient satisfaction (Berg, 2001).

Design science is the development, implementation, evaluation, and adaptation of artificial artifacts for problem solving (Hevner, 2007; Simon, 1996). When discussing the objectives of design science, Patel and Kaufman (1998) have stated:

One of the goals…is to discover what works and then determine why some things work and others don’t. A working system is an outcome not merely of technology but of the social and cognitive processes of integrating such a system into the daily workflow (p. 490).
Best practices exist for applying what is known to work in HIS implementations. However, most pre-design and pre-implementation assessment tools have been developed for use in industrialized countries. A search of four databases, PubMed, Google Scholar, Google, and ProQuest, using the search terms “Informatics”, “Information Systems”, “Information technology”, “*readiness”, “assessment”, “implementation”, “developing countr*”, “low resource”, and “Africa”, was only able to identify one tool for implementation e-readiness assessment at the organizational level, the NGO ICT and e-Readiness Self-Assessment Tool (NGO Connect Africa Network, 2011). This dearth of tools and methods has been noted by other authors (Dorflinger & Gross, 2010; Toyama & Muneeb, 2009). The lack of existing tools for assessing needs in developing countries stresses the importance of careful design and planning in order to close the design-actuality gap.

Design science methods can be useful in closing these gaps. Prescriptive theories on design will help us determine how to create a system (Gregor & Jones, 2007). Design research should result in four general outputs: constructs, or concepts and language of the problem; a model, the proposed problem solutions or representations; methods, which are guidelines, algorithms, or practices for performing tasks; and, instantiation, or the actual developed artifact (Hevner & Chatterjee, 2010; March & Smith, 1995).
Figure 2.2. General Methodology of Design Science Research. This figure shows the steps in the design research process and the expected outputs at each step (Vaishnavi & Kuechler, 2004).

It should be noted that this method is always iterative. Even with a successful implementation re-evaluation would be required as technology, organizations, policies, etc. that affect the use of the artifact change, so would the artifact need to be adapted (Gregg, Kulkarni, & Vinze, 2001; Hevner, et al., 2004; Purao, 2002). Frequent interactions between developers and end-users have been noted to result in positive project outcomes (Lim et al., 2009).

Conclusion

Ghana, like many other sub-Saharan nations, faces a public health crisis of communicable diseases, high maternal and infant mortality rates, and a growing burden of non-communicable diseases. Large health disparities exist between Ghana and the developed world, as well as within Ghana itself between the more affluent urban populations and the poorer rural ones.
These challenges are exacerbated by a lack of trained healthcare workers to meet the needs of the population.

In rural areas, primary care is provided primarily by midwives. These midwives are responsible for a wide scope of practice, from neonates up to the elderly. They have little opportunity for continuing education and rely heavily on pre-service training as their knowledge-base. This is concerning due to the inconsistency in pre-service training as well as the inability of midwives to keep abreast of best evidence and current clinical practice guidelines (Prosser, et al., 2006). Pre-service training programs may not prepare novice midwives for the challenges of rural health care as many students have reported having limited access to current textbooks or scholarly journals (Khalil, 2006). These gaps in training and continuing education should be taken into consideration in the design of an information support tool.

An HIS implementation must be designed for the midwives’ current actuality in order to be successful. It has been noted that up to 25% of HIS implementations in developing countries have failed, and those that persist often proves to be unsustainable or unscalable (Heeks, 2002, 2008; Walsham & Sahay, 2006; Were, et al., 2010). Friedman (1995) noted:

Installing an information system in a functioning health care setting requires in-depth understanding of the organization and ecology of the workplace: how the system affects the structure of work and how, in return, some unchangeable features of the work create constraints on a system (p. 66).

Design science provides a structure for understanding the ecology of the application environment. By using the Information Systems Research Framework to guide our system design and testing we can improve our understanding of the current system actuality in order to close the design-actuality gap.
CHAPTER III. METHODOLOGY

This study was composed of two research cycles as guided by the ISR framework (Table 3.1). The first, the relevance cycle, was intended to increase our understanding of the application domain to determine the functional requirements of the artifact. This was done through characterizing the information seeking behavior and information needs of nurses and midwives currently working at Millennium Village Project (MVP) facilities in Ghana. Second, we did an analysis of current workflow, documentation procedures, and documentation practices in regard to quality and completeness needed for proper follow-up and reporting. Additionally, we looked at barriers to the implementation of a mobile-phone based application. In the second cycle, the design cycle, we evaluated the usability of our artifact using field testing and post-testing interviews and surveys.

Project Context

In September of 2000, world leaders gathered and adopted the United Nations (UN) Millennium Declaration which was a commitment to a global partnership for ending extreme poverty (defined as people earning less than $1.25 USD/day) by 2015. The goals of this partnership, known collectively as the Millennium Development goals (MDGs) are the following: eradicate extreme hunger and poverty; achieve universal primary education; promote gender equality and empower women; reduce child mortality; improve maternal health; combat HIV/AIDS, Malaria and other diseases; ensure environmental sustainability; and develop a global partnership for development (United Nations, 2000).

In 2002, the UN Millennium project was commissioned by the UN Secretary General to develop a concrete plan of action for meeting the MDGs. MVP is based on those findings and instituted in collaboration with the Earth Institute at Columbia University, The Millennium
Promise Organization, and the United Nations Development Program. MVP sites are located throughout sub-Saharan Africa and work in collaboration with local governments to achieve a sustainable end to extreme poverty by targeting the MDGs (Kanter, et al., 2009). The MVP Bonsaaso Ghana Cluster consists of six villages encompassing a population of 30,000. The villagers are primarily employed in small-scale, open-pit mining operations or through family and cooperative farms.

To meet the healthcare needs of this community, MVP has built or enhanced seven rural clinics, increased collaboration with the local district hospital, and provided two emergency transport vehicles. Three of the MDGs specifically target healthcare issues: reduce child mortality (MDG4); improve maternal health (MDG5); and combat HIV/AIDS, Malaria, and other diseases (MDG6). Strategies for MDG4 have included improving immunization coverage for children under five and increasing screening rates for malnutrition and childhood illnesses. For MDG5, MVP has responded by constructing new health facilities or improving existing clinics, ensuring clinics are adequately equipped with medical supplies, and training community health workers to recognize the need for emergency obstetrics, and increasing access to family planning (Kanter, et al., 2009). MDG6 has been addressed through teaching prevention methods, supplying of prophylactics (bed nets for malaria; condoms for HIV) and supplying medicine and strategies for the treatment of HIV, Malaria and TB.

The villages are primarily connected by a network of unpaved roads, shown in Figure 3.1, and transportation to each village can take over an hour, though most of the villagers do not have access to transportation. Villages are serviced by seven community health facilities spread throughout the region as well as a district hospital. However, many villagers may have to walk a considerable distance to reach the facility.
During the harvest season, patient visits are sharply decreased because of the requirements of farming. Patient visits tend to peak in the winter after farmers have been paid for their harvest and have more money for the co-payments required by the national health insurance scheme. Visits also peak in June/July at the height of malaria season. Patients may come between 9am to 3pm Monday through Friday and 9am to 11am on Saturdays for services. In addition, the staff is on-call 24-7 for emergencies and to perform deliveries. In recent years, there has been an increase of deliveries done in the facilities as the result of community outreach efforts. Traditionally, deliveries have been done at home with traditional birth attendants rather midwives at the facilities or obstetricians at the district hospital.

*Figure 3.1. Typical road in rural Ghana.* Clinics are connected by a series of primarily unpaved roads.
MVP is currently implementing the Millennium Global Village-Network (MGV-Net). The goals of this network are to facilitate the coordination of care between the CHWs and the facility, improve the continuity of care of patients, and increase the efficiency of data collection and reporting, and contribute to the evaluation of MVP’s progress towards the MDGs. MGV-Net is an open-source electronic health delivery platform that captures data for managing patient care, program evaluation and monitoring, decision-making and management. It will enable: the facility-based data capture of individual-level information; community-based data capture of individual-level information; data storage of individual patient health records; and, an automated mechanism for aggregating data and generating reports and feedback to healthcare providers and managers (Mechael, Nemser, & Kanter, 2010).

Figure 3.2 shows the data flow of the overall MGV-Net project.

*Figure 3.2. Data Flow Chart for MGV-Net* (Mechael, et al., 2010)
The artifact being designed for this dissertation, known as mClinic, will serve as the interface between midwives, shown as clinicians in Figure 3.2, and the rest of the MGV-Net platform. Additional components of MGV-net are ChildCount+ and OpenMRS. OpenMRS is an open-source electronic health record platform that serves as the primary data backbone of MGV-Net. Child Count+ allows community health workers to use SMS text messaging via mobile phones to register children under five living in their catchment area to determine and track the need for immunizations and provide decision support for malnutrition and malaria screening as well as insuring proper follow-up.

MGV-Net has already been IRB approved for human subjects review including the midwives and other staff members involved in this study. This study has been designed to minimize dependency on completion of the other aspects of MGV-Net being implemented in order to proceed. The design, methodology, data collection, and interpretation of findings in regard to mClinic will be the primary responsibility of this author.

**Setting**

All studies took place one-on-one with each midwife at their individual facility of employment. Facilities are one floor structures generally consisting of a waiting area, a record room, a computer room, a lying-in ward, a labor room, a post-partum room, a dispensary, and an exam room. Facilities are generally staffed by one midwife, one community health nurse, and two health extension workers.
Figure 3.3. Map of Health Clinic Locations in Bonsaaso, Ghana.
<table>
<thead>
<tr>
<th>ISR Framework</th>
<th>Relevance Cycle</th>
<th>Design Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Descriptive</td>
<td>Descriptive</td>
</tr>
<tr>
<td>Sample &amp; Setting</td>
<td>On-site with MVP-Ghana Staff</td>
<td>On-site with MVP-Ghana Staff</td>
</tr>
</tbody>
</table>

| Model          | Design-actuality    | Health I-TUEM              |
|                |                     |                            |

| Concepts       | Functional requirements | Usability               |

| Procedures     | Participant observation, contextual inquiry, in-context interviews, and generalized interviews | Three use-cases were given for participants to complete while being audio recorded. Health-ITUES survey. Post-test interviews. Mobile usability heuristic evaluation. |
|                |                     |                            |

| Expected Outputs | Functional requirements and system quality specifications | Refined specifications |

*Table 3.1. Outline of Study*
Cycle I. The Relevance Cycle

In this cycle, we seek to understand the people, organizations, and technology that make up the application domain. The purpose is to identify the problems and opportunities that can be addressed with HIS. The goal of this cycle was to create a functional and non-functional requirements specification and to develop use cases for building our prototype. The research questions for this cycle as guided by the ISR framework are as follows:

- **People**
  - What is the current workflow of MVP midwives?
  - What are the roles and responsibilities of midwives at MVP facilities?
  - What is the current experience of the midwives with technology and their comfort level in learning new technology?
  - What are the information needs and information seeking behaviors of midwives working in MVP facilities in Ghana?

- **Organizations**
  - What are the issues in collecting data from the health facilities?
  - What is the support capacity for an HIS implementation at MVP Ghana?

- **Technology**
  - What is the current technology infrastructure at MVP Ghana?

- **Problems & Opportunities**
  - What is the required functionality needed for the application based on the need and constraints of the application environment?
Sample

Six out of seven midwives that had been working at MVP-Ghana were interviewed in their facility in September 2010. Other staff members were interviewed at the MVP-Ghana administrative site included: the data manager, a data analyst, the information systems (IS) manager, and the health team manager.

Design

This was a descriptive study using participant observation and user-centered design techniques. This part of the study was done in two phases; first, we did a requirements analysis followed by development of functional requirements based on the results of the first phase.

Requirements Analysis

Procedures

This study used a combination of participant observation, contextual inquiry, in-context interviews, and generalized interviews to establish a rich data set with iterative, descriptive coding for analysis. Contextual inquiry is a user-centered method for design that involves participation observation during which the participant describes the tasks they are performing or the researcher asks for further clarification (Coble, Maffitt, Orland, & Kahn, 1995). Each midwife was observed for one morning of clinic hours (approximately 9am to 2pm). Community health nurses were observed for the duration of specialty clinic hours (either antenatal care or child well care) for the same time period. Field notes and memoing were used to record participant observation. Contextual inquiry conducted with midwives after observations for 30-60 minutes (Coble, et al., 1995). Part of the contextual inquiry process was spent review the paper tools that the midwives used to document care and for reporting to GHS and MVP. Additional open-ended interviews were conducted using the design-actuality gaps
model to guide questions to refine our understanding of midwives and other staff members’ roles, understand midwives perceptions of organization goals, and discover existing barriers to an mHealth implementation.

Interviews of other staff were also conducted at the MVP-Ghana administrative site using Non-Governmental Organization (NGO) ICT eReadiness Self-Assessment Readiness Tool as a guide. This tool was developed for NGOs to assess their eReadiness and is specifically targeted toward the assessment of African organizations that may be limited in terms of infrastructure, resources and technical skills (Van Belle, 2009). The tool goes through a series of questions on technical infrastructure resources to assess current technology use and readiness for the introduction of additional technology (NGO Connect Africa Network, 2011).

The paper tools collected during interviews were reviewed by the research team and a US-based midwife to assess for completeness of needed elements. Brainstorming with MVP leadership, a US-based midwife with expertise on global health practices and midwifery training, software developers and an HCI expert were used to refine the functional requirements and use cases.

**Data Analysis**

Analysis of current documentation tools was done by comparing data captured by existing tools to national and international standards of care. Midwives’ statements were captured using memoing and then sorted into the following categories of interest derived from the ISR Framework: midwife characteristics, roles, and capabilities. Additional data analysis was done using descriptive methods. Open coding was used to develop initial data categories from both field notes, analysis of current paper tools, and contextual inquiry. Codes were then categorized into goals, functional requirements, constraints, and system qualities and used to develop use cases.
Development of Functional Requirements

Procedures

Functional requirements were developed using the data collected in the first phase using a structured requirements specification. This method is strongly focused on end-user’s needs (Orr, 1981). Figure 3.4 illustrates how we use our data to create functional requirements and ultimately a prototype design.

Figure 3.4 Structured Requirements Specification (Sehlhorst, 2006)

The MVP mHealth project team members involved with the functional requirements specification consisted of one doctoral candidate in nursing informatics (the project lead), one faculty member in biomedical informatics, the mHealth program coordinator, and the director of mHealth strategy. All of the team members assisted with verifying the results of the functional requirements.
Table 3.2 describes each element of the structured requirements specification with the data sources used to inform the element. The phase of the study took place from October 2010 through March 2011.

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal</td>
<td>Organizational goals; What we want to achieve</td>
<td>Midwife and staff interviews; contextual inquiry; document analysis; comparison with national international standards and policies</td>
</tr>
<tr>
<td>Use Cases</td>
<td>Description of user and system interaction to complete a task</td>
<td>Goals; Participant observation; Midwife interviews; contextual inquiry; document analysis; comparison with international standards</td>
</tr>
<tr>
<td>System Qualities</td>
<td>Non-functional requirements such as availability, security, etc.</td>
<td>Interviews</td>
</tr>
<tr>
<td>Functional Requirements</td>
<td>What are the system inputs, how does the system behave, how are the inputs processed, what are the outputs</td>
<td>Use cases; interviews; contextual inquiry and document analysis; national and international standards and policies</td>
</tr>
<tr>
<td>Constraints</td>
<td>Restrictions on how functional requirements can be implemented</td>
<td>Interviews; participant observation</td>
</tr>
</tbody>
</table>

*Table 3.2 Data sources of structured requirements specification*

Goals were prioritized by determining the needs most mentioned by the midwives. This was compared to organizational goals, and national and international goals. The top goals were determined by agreement of the project team and then used to develop use cases.

Use-cases were then developed by the project lead based on goals and data from contextual inquiry and other sources. Workflow observations form the clinic guided how and when data would be entered into mClinic. Uses cases were verified by the project team and refined as needed.

System qualities and constraints were primarily determined from staff interviews and observations. Interview notes were compared to the International Standards Organization (ISO) software quality requirements and evaluation standards (ISO, 2011). The developed system
qualities and constraints were then reviewed and refined by the project team. Use cases and system qualities were used to inform the functional specification while the constraints placed restriction on the software selected for the project.

**Cycle II. The Design Cycle**

The purpose of this cycle was to have targeted end-users identify issues related to the usability of the artifact and to verify the applicability of proposed functional specifications and use cases. The goal is to evaluate the proposed artifact, to obtain data to improve the design, and to increase the likelihood of technology acceptance. The research questions for this cycle are the following:

- What usability issues exist with the artifact?
- What are the deficiencies in functionality or qualities of the artifact that need to be addressed to improve acceptance?
- How does the artifact meet heuristic standards?

This cycle is divided into two phases, the build phase and the evaluation phase.

**Build Phase**

Various mHealth applications were reviewed by the project lead and the mHealth coordinator and Open Data Kit (ODK) was selected for the development of mClinic. ODK allows forms based data to be sent and received by OpenMRS on Android phones. A development team was selected based on previous experience ODK and OpenMRS and regional location in Sub-Saharan Africa.

Software was selected based on the constraints determined during the relevance cycle and approved by the project team. We contracted with the development team in January 2011 and development took place from January through May. Use cases and functional specifications
were shared with the developers via Google© Docs. Bi-monthly calls with the mHealth project team, the developers, and the ODK project lead via Skype©. Bi-monthly calls were used to clarify functional specifications. Code updates and software documentation were sent using a shared DropBox© folder. The result of this phase was the project artifact, the mClinic prototype.

**Evaluation Phase**

**Design**

This study took a user-centered approach and was conducted in three steps. First, we conducted hybrid lab-live testing, as suggested by the HCI4D literature (Ho, et al., 2009; Maunder, et al., 2007). Second, we gave the midwives a post-test survey based on Health-ITUEM (Yen, 2010). Third we conducted post-test interviews which included low-fidelity prototyping of planned or requested forms and applicability checks. Figure 3.5 shows the steps of the evaluation phase and how we expected the data to contribute to our understanding of usability.

**Figure 3.5.** Overview of Design Cycle Evaluation Phase procedures and analysis.
Sample

All seven midwives currently working at MVP-Ghana were interviewed in their individual facilities in May of 2011. Additional interviews were conducted with the data analyst and the IS manager at the MVP administrative site.

 Procedures

Testing of mClinic was conducted outside of regular clinic hours, however, in some instances there were patients being seen in the facilities at the same time. Participants were given three scenarios based on goals and developed use cases. The first was to register a new patient into the mClinic, the second and third were to record patients who had come into the clinic with a fever and were suspected of having malaria. Real data collected in the clinic was used for the testing and deleted afterwards. The participants were asked to provide feedback while using mClinic. This testing was voice recorded as well as the researcher recording field notes.

Post-testing, participants completed a survey using a modified version of the Health-ITUES scale (Appendix A), which assesses perceived usability. Exploratory factor analysis extracted a four factor solution with Cronbach’s alphas ranged from .81 to .95 for subscales in a sample of registered nurses rating a shift scheduling system (Yen, Wantland, & Bakken, 2010). A confirmatory factor analysis showed that the explained variances were: 78.1% for quality of work life, 93.4% for perceived usefulness, 51.0% for perceived ease-of-use, and 39.9% for user control (Yen, 2010).

Finally, we conducted post-testing interviews. Midwives were asked their thoughts about the usability and usefulness of mClinic. Applicability checks on functional requirements and use cases were conducted with the MVP midwives and MVP staff. Midwives were shown low-
fidelity prototypes of either planned forms or forms they suggested might be useful (Figure 3.6). Prototypes were drawn on paper while reviewing use case elements and paper data collection tools from the clinic. Each box represented a new screen on the mobile device while arrows represented swiping to next screen. Applicability checks help identify the importance and suitability of the research findings by serving as a member check with the expected end-user of the system in development (Rosemann & Vessey, 2008).

Figure 3.6 Sample low-fidelity prototype. An example of a low fidelity prototype for collecting ANC data with decision support for malaria treatment.

Data analysis

Usability problems were evaluated using Mobile usability heuristics, outlined in Table 3.3, which is a modification of Nielsen’s for mobile devices (Bertini, et al., 2006). Descriptive
statistics were used to analyze the post-test surveys and applicability checks with supplemental data from the midwife and staff interviews to qualify the results.

| Heuristic 1 | Visibility of system status and losability/findability of the mobile device |
| Heuristic 2 | Match between system and the real world |
| Heuristic 3 | Consistency and mapping |
| Heuristic 4 | Good ergonomics and minimalist design |
| Heuristic 5 | Ease of input, screen readability and glancability |
| Heuristic 6 | Flexibility, efficiency of use and personalization |
| Heuristic 7 | Aesthetic, privacy and social conventions |
| Heuristic 8 | Realistic error management |

Table 3.3. Mobile Usability Heuristics. From Bertini, et. al. (2006).

Summary

This chapter outlined the procedures for the two cycles of our study. In the Relevance cycle, participant observation, contextual inquiry, and interviews were used to inform the development of the functional requirements of mClinic. The subsequent Design cycle was divided into two phases, build and evaluate. In the build phase, functional requirements were used to design the application as a part of a coded-in-country initiative. In the evaluation phase, multiple methods were used to assess the usability mClinic. The use of multiple methods in both the Relevance and Design cycles increases the credibility and validity of the results.
CHAPTER IV. RESULTS

The results presented in this chapter describe the findings of each of the research cycles. In the first cycle, the relevance cycle, we studied the people, organizations, and technology that make up MVP-Ghana. In this cycle we identified the problems and opportunities that exist in the current system. Finally, we developed functional requirements based on the goals, use cases, and system qualities to inform the design of an artifact, known as mClinic. In the second cycle, the design cycle, we tested the usability of our mClinic prototype. We also validated the functional specifications created in the first cycle.

Cycle 1. Relevance Cycle

The first phase of the relevance cycle involves requirements gathering, which can be broadly categorized into three topics: people, organizations, and technology. This was done through participant observation and interviewing midwives using the design-actuality gaps model to guide our questions. A total of eight midwives were interviewed for this study representing all the midwives currently working in the Bonsaaso, Ghana cluster of the MVP. Five of the midwives were interviewed twice, once in September 2010 and again in May of 2011. One midwife was unavailable for the first round of interviews and interviewed only in May 2011. Another midwife who had been interviewed in September 2010 had quit and her replacement was interviewed in May of 2011. Table 4.1 is a list of the midwives interviewed indicating whether they were interviewed in the first, second, or both rounds; the number of years of experience they have as a practicing midwife; and, their classification as an experienced or inexperienced using five years as a cutoff.
Table 4.1. Classification of Midwives Interviewed.

<table>
<thead>
<tr>
<th>Midwife</th>
<th>Interview 1</th>
<th>Interview 2</th>
<th>Years Exp.</th>
<th>Classification</th>
<th>Previous Nursing Exp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>20</td>
<td>Experienced</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X</td>
<td>26</td>
<td>Experienced</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>X</td>
<td>3</td>
<td>Inexperienced</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>X</td>
<td>43</td>
<td>Experienced</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>X</td>
<td>4</td>
<td>Inexperienced</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>X</td>
<td>42</td>
<td>Experienced</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td></td>
<td>8</td>
<td>Experienced</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td></td>
<td>2</td>
<td>Inexperienced</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Other key staff members at the MVP-Ghana administrative site were also interviewed for supplemental information.

**People**

For this phase of the relevance cycle, we sought to answer the following questions:

- What is the current workflow of MVP midwives?
- What are the roles and responsibilities of midwives at MVP facilities?
- What is the current experience of the midwives with technology and their comfort level in learning new technology?
- What are the information needs and information seeking behaviors of midwives working in MVP facilities in Ghana?

**Workflow**

Each MVP clinic is staffed by one midwife, one community health nurse, and one to two health extension workers (HEW). Clinics are small one floor houses that contain a reception area, a medical record office, a pharmacy room, a “lying-in” ward for sick patients, a labor ward, a post labor recovery ward, a bathroom, and an exam room. At many of the clinics there was also a living area where the staff resided. Clinic hours were generally from 9am to 3pm, though midwives are on call 24/7 for laboring patients and emergencies with every other weekend off, during which time patients were referred to a neighboring clinic. Community Health Nurses
(CHNs) and Community Health workers (CHWs) would generally travel to the town a day or two before to remind patients that a particular day was for antenatal visits or well-child visits. The clinics did not schedule appointments, and all non-emergent patients were given a number so that they could be seen in the order in which they arrived. After receiving their number a patient is then triaged by either the community health nurse or the HEW and their vital signs taken. Vital signs and any other pertinent data are then recorded in the patients PHR for the midwife to review. The patient then waits to see the midwife.

**Figure 4.1. Typical Clinical Workflow.** Typical flow of low-risk antenatal care patient.

Antenatal care visits for established patients generally had a total face time of less than ten minutes. The typical workflow was as follows:

1. Patient enters room and hands PHR to midwife. Midwife reviews patient data. Data documented in PHR through visit. Data may also be transcribed into antenatal care log during the visit or at the end.
2. Midwife conducts physical assessment of patient. This involves measuring the fundal height, presentation, descent, and fetal heart rate.

3. Patient complaints, such as swelling or nausea are then addressed. Depending on the gestation patients are also given prophylactic treatment for malaria and tested for HIV.

4. Patient teaching is done.

Interruptions during a patient visit were common. During nine observed visits there was an average of 1.3 interruptions per visit with an average duration of 14.5 minutes. Interruptions often required the midwife to leave the exam room for several minutes.

<table>
<thead>
<tr>
<th>Observation Number</th>
<th>Total Time (minutes)</th>
<th># of interruptions</th>
<th>Reason for interruptions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>1</td>
<td>Needed in dispensary</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>3</td>
<td>Another patient in lying-in ward was being referred to hospital for severe malaria</td>
<td>This patient was referred to hospital for severe edema. Patient stated she had gone to the hospital but no results were documented</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>1</td>
<td>Ambulance could not be located. Clinic midwives are part of phone tree in this instance.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>2</td>
<td>HEW needed help reinforcing discharge instructions with non-English speaking Chinese miners.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>1</td>
<td>Follow-up with previous patient</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>17</td>
<td>2</td>
<td>Laboring patient</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>13</td>
<td>3</td>
<td>Consulting with CHWs</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>0</td>
<td></td>
<td>Patient tested positive for malaria.</td>
</tr>
</tbody>
</table>

*Table 4.2. Visit times and interruptions*
Interruptions may disrupt clinical reasoning thus compromising patient safety and/or cause patient dissatisfaction (Potter et al., 2005). A high frequency of interruptions may impact patient safety as well as being an important aspect of clinical workflow, as the artifact will have to allow for easy movement between patients (Martikainen, Ikavalko, & Korpela, 2010).

Roles and Responsibilities

Midwives were responsible for documenting nearly all of the patient care. The majority of documentation took place in the patient’s PHR with an abbreviated note written on the paper chart. Additional patient data were logged into one of the following registers: antenatal care, well child, fever, cash, delivery, and/or outpatient. Registers serve as the primary data source for monthly reporting.

There was a high burden of monthly reporting. There were over a dozen monthly (or more frequent) reports, listed in Table 4.3, required to be submitted to GHS and/or MVP administration.
<table>
<thead>
<tr>
<th>Report Name</th>
<th>Key data elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addendum Antenatal/Maternity Monthly Data Returns</td>
<td>ANC visit information; Malaria prophylaxis; Delivery information</td>
</tr>
<tr>
<td>Communicable disease surveillance report</td>
<td>Malaria cases; Pneumonia cases, Diarrhea, AIDS, STDs</td>
</tr>
<tr>
<td>Facility report of HIV test kit usage</td>
<td>HIV test kits used</td>
</tr>
<tr>
<td>Family planning returns</td>
<td>Contraceptives administered</td>
</tr>
<tr>
<td>Immunization and vaccine monthly returns</td>
<td>Vaccines used and immunizations given by age and dose</td>
</tr>
<tr>
<td>Institution monthly returns</td>
<td>Malaria medication used</td>
</tr>
<tr>
<td>Malaria reports of outpatient cases</td>
<td>Malaria cases (by age and pregnancy)</td>
</tr>
<tr>
<td>Malaria reports ITN/SP Stock</td>
<td>Malaria medication used and stock holdings</td>
</tr>
<tr>
<td>Midwives return</td>
<td>ANC visit information; Delivery information; Postnatal data; Abortion data; PMTCT data</td>
</tr>
<tr>
<td>Monthly data returns on Artesunate-Amodiaquine</td>
<td>Malaria medication used; Children and pregnant women receiving treatment</td>
</tr>
<tr>
<td>Medication and testing stock</td>
<td>Malaria medication use; RDTs used</td>
</tr>
<tr>
<td>National AIDS/STI control programme monthly returns</td>
<td>HIV testing and treatment; STD testing and treatment; PMTCT data</td>
</tr>
<tr>
<td>Outpatients Morbidity</td>
<td>Causes of morbidity</td>
</tr>
<tr>
<td>PMTCT monthly returns</td>
<td>PMTCT data</td>
</tr>
<tr>
<td>Returns on deliveries</td>
<td>Delivery data</td>
</tr>
<tr>
<td>Statement of Outpatients</td>
<td>Patient age and insurance status</td>
</tr>
<tr>
<td>Weekly notifiable diseases report</td>
<td>Cholera, meningitis, measles, H1N1, Guinea worm, yellow fever, polio</td>
</tr>
</tbody>
</table>

**Table 4.3. Monthly Reports**

Several of these forms had been re-copied several times and were illegible. Most of the reports contained duplicate information or were the same report requested in multiple formats. Nearly half the reports required data about malaria diagnosis and/or use of anti-malarial drugs. All reports were filled out by hand by the midwives and they reported doing all the calculations themselves. Knowledge about what reports were required was knowledge held institutionally by the midwives as there seemed to be no documentation or written protocols regarding reporting requirements. Furthermore, in some instances it seemed the facilities were using different versions of the same communicable disease report. None of the midwives knew where to receive the most current form. Midwife 4 stated in regards to the weekly notifiable diseases report,
shown in Figure 4.2, “Look at this, you can’t even read it, but it is required. Every month I spend all my time filling this out, then someone picks it up, no one gives me a new one, no one tells me how I am doing”.

<table>
<thead>
<tr>
<th>Technical Self-efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Of the midwives interviewed, only one had previous experience using a computer in school for writing papers. There was no day-to-day computer use for either business or personal reasons. All expressed apprehension about learning to use computers and felt they would need extensive assistance. All felt comfortable using mobile phones, but only one owned a smartphone. All expressed a willingness to learn new technology but many expressed concerns</td>
</tr>
</tbody>
</table>

Figure 4.2. Notifiable disease report. Repeated copying has made this report unreadable.
about added workload. Midwife 8 stated in regards to the opportunity to learn the new technology, “Thank you for making me a modern woman”.

**Information Practices**

When asked what they did when they had questions about the diagnosis or management of a patient, Midwives stated that they relied on either textbooks or phone calls to colleagues to meet information needs. Table 4.4 lists the information sources that midwives indicated they use.

<table>
<thead>
<tr>
<th>Information Sources</th>
<th># of Midwives Reported Using</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textbook</td>
<td>5</td>
</tr>
<tr>
<td>Drug reference</td>
<td>6</td>
</tr>
<tr>
<td>Journals</td>
<td>0</td>
</tr>
<tr>
<td>Consult with hospital physician</td>
<td>6</td>
</tr>
<tr>
<td>Consult with other midwife/nurse</td>
<td>3</td>
</tr>
<tr>
<td>GHS practice guidelines</td>
<td>2</td>
</tr>
<tr>
<td>Computer Search</td>
<td>0</td>
</tr>
</tbody>
</table>

*Table 4.4. Information Sources Used By Midwives (n=6)*

None of the midwives could readily identify resources for obtaining up-to-date evidence-based practice guidelines and there seemed to be some confusion about which guidelines should be followed. For example, when asked how many prenatal visits a patient should have, each of the midwives answered 12. However, current WHO practice guidelines as well as GHS guidelines for an uncomplicated pregnancy is four visits, though WHO is in the process of re-evaluating this guideline (WHO, 2011c). Midwives reported that changes in clinical practice guidelines were usually received through offsite trainings, though these did not seem to occur very often, or by visit from a trainer (usually from MVP or GHS) who would update them on a particular practice.
Patient information came primarily from the patient’s paper-based personal health records (PHRs) and patient self-report. These are paper booklets given to the patient at the time of their first visit for a particular condition that are produced by Ghana Health Services. There are booklets for maternal health, family planning, child health, and adult health. It is uncommon for patients to come to the clinic without the PHRs. Paper-based medical records are also kept at the clinic but the records are 8.5 by 5.5 inch index cards that hold sparse information. New medical records are created every year with the previous year’s record number contained on the new card for reference. The record numbers are created by the order in which the patient is seen throughout the year, for example, the fifth patient seen in 2011 would have a record number of 5/2011. Midwives reported that these records are rarely useful for patient history since more pertinent and up-to-date information would be in the patient’s PHR.

Midwives reported a number of barriers to accessing information. First, while all the midwives had both personal and MVP supplied cellular phones, many felt they did not receive adequate credit (air time) for placing calls to follow-up on referrals or for collaborating with colleagues. Several of the midwives reported feeling isolated and disconnected from the administrative offices and that their needs were often unaddressed. Midwife 1 stated: “They [the administrators] come here and they don’t even tell us they are coming. We need things they can bring us but they don’t call. I don’t have a car; I don’t even have a bicycle. We need food, we need supplies, but they don’t let us know.”

While all the clinics had computers installed, only five of the seven clinics were able to access the internet. The midwives all reported having little-to-no experience using computers and no experience searching for clinical practice resources online. Midwife 3 stated: “They have
to come and train us so we are more confident with the computer. We don’t know what we are doing with the computer. None of us.”

Experienced midwives were less likely to report consequences of not having access to information. Midwife 4 stated: “I have all the information I need”, though this same midwife later complained about not receiving follow-up information from both referrals and from reports sent to the MOH. Inexperienced midwives were more likely to vocalize having unmet information needs resulting in unnecessary patient referrals and a lack of confidence in clinical practice. Midwife 5, who later quit stated: “Sometimes I don’t know what to do, and I refer a patient to the hospital. I probably don’t need to do it, but no one tells me, and I never know what the results were.”

The midwives reported a number of unmet information needs. All reported difficulty in receiving follow-up information on patients referred to the local district hospital. Patients were most often referred for HIV and other lab testing, severe malaria, complications of pregnancy, or for complex diagnoses. Inexperienced midwives in particular were concerned that they were referring patients unnecessarily but since no feedback was available there was no opportunity for learning how to manage a particular case.

**Preparation for Knowledge Work**

Nurses and midwives are unable to function as knowledge workers when clinical data is “fragmented, incomplete, and unreliable” (Snyder-Halpern, et al., 2001, p. 19). In the MVP-Ghana clinics, clinic data is fragmented across multiple sources. The most complete records, the patient’s PHR is not kept in the clinic. Additional data elements are spread across multiple registries and incomplete paper records. The quality of the data is questionable as evidence
shows documentation was occasionally inaccurate or incomplete. Currently, there is no efficient mechanism in place for extracting knowledge from the various fragmented data sources.

**Organizations**

- What are the issues for collecting data from the health facilities?
- What is the support capacity for an HIS implementation at MVP Ghana?

**Data Collection**

Most of the data collection is done on paper and collected monthly by motor cycle. Data is collected primarily in registers, with separate registers for antenatal care, child care, fevers, STD testing, etc. A few of the data elements needed by MVP for reporting is now entered by HEWs into OpenMRS at each of the facilities and then extracted and collated by data analysts at the MVP sites. The data currently being collected in OpenMRS includes a household survey, HIV data, malaria testing data, verbal autopsies, outpatient diagnosis, and birth registration. This data is obtained from paper registers before being entered into the computer.

Problems were noted to exist with the quality of the paper record data collected. For example, reports on fevers were collected on a paper fever register by midwives and then entered into OpenMRS by the HEWs. A number of data integrity issues were noted with this report. The purpose of the fever register is to capture data on any patient suspected of having malaria. The midwives record the patient’s temperature, the duration of the fever, the results of the rapid diagnostic test (RDT) for malaria, they record whether or not the patient has danger signs of severe malaria. Patients should be treated with Artemisinin combination therapy (ACT) if either the RDT is positive or if they are exhibiting extreme danger signs of malaria. An example of a fever register is shown in Figure 4.3. In the last column, labeled as action taken, it states enter 1 for “ACT and home” and 2 for “ACT and referred”.
**Figure 4.3. Fever register.** This form is indicative of data quality issues with existing paper documentation.

In the last column all the patients have 1, indicating that they were treated with ACT and sent home. However, none of the patients had danger signs of malaria and only eight of 17 had a positive RDT. This problem was found in three of four clinics where we checked for the issue.

To further complicate this matter, the data analyst reported that this format was not consistent with what was required by GHS. That report lists the following options for the “Action Taken” column: “1. ACT and Home”, “2. Treated for Severe malaria”, “3. ACT and antibiotics”; “4. Antibiotics”; “5. Referral to hospital”, “6. Observed and sent home”, and “7. Other”. Additional, another data element for post-48 hour follow-up is needed but not captured in the current form.
**Technical Support**

There are currently two full-time IT staff members employed at the main administrative site. This site is located one to two hours’ drive from any of the clinics, limiting the availability of on-site technical support. There is likely to be limited resources for providing on-site support for the phones.

**Technology**

- What is the current technology infrastructure at MVP Ghana?

**Infrastructure and resources.** Internet access at the health clinics is delivered via cellular service. Only five of the seven sites had a reliable cellphone signal due the location of cell towers. An additional tower is expected to be constructed in the next year to resolve signal issues at the remaining two sites. Both network outages and slowdowns were reported as occurring occasionally. The clinics are supplied electricity using solar panels. Black outs and brown outs occur occasionally.

<table>
<thead>
<tr>
<th>Outage Type</th>
<th>Time 1</th>
<th>Time 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Outages</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Internet Outages</td>
<td>N/A</td>
<td>2</td>
</tr>
</tbody>
</table>

*Table 4.5. Network and Internet Outages*

While 3G is supposed to be widely available, the most commonly picked up signal was general packet radio service (GPRS) Edge (2.9G).

Each facility maintained one charging station for cell phones which was also where computers were connected to a power supply. All of the sites had computers in place but facility staff reported that they had not received adequate training on their use. At the sites with internet access, the HEWs were doing some data entry into OpenMRS, otherwise the computers were unused. The IS manager reported one computer had become unusable when a community member had inserted a USB drive with a virus into it. Additionally, another computer was
observed to have been moved under a window into direct sunlight, potentially causing damage. The IS manager reported limited resources for adequately maintaining and keeping the computers on site up-to-date. Remote desktop management software is not currently in use at MVP. He also reported there is no plan in place for training users on computer competence and basic maintenance. Additionally, he stated security of computers in the facilities as inadequate.

Problems and Opportunities

In this second phase of the relevance cycle, we used the data from the first phase to develop functional specifications for an artifact, known as mClinic, for use at MVP-Ghana. The research question for this phase was:

- What are the functionality requirements for the application based on the needs and constraints of the application environment?

Goals

Functional requirements were specified for mClinic over an eight month period from July 2010 – March 2011. Initial goals were gathered from senior staff at MVP and it was determined there was a need for a mobile interface to interact with OpenMRS within the facilities. The initial focus of the application would be on patient registration, Antenatal care (ANC) patients, and malaria treatment, but with the flexibility to incorporate other types of patients in the future, such as family planning, referral tracking, and child health. The results of the initial six interviews with MVP midwives in September 2010, analysis of current paper based reporting and record tools, and comparison with the WHO’s clinical practice guidelines were used to answer the following questions regarding functional requirements. The results of the interviews validated the need for better documentation practices regarding ANC and malaria treatment.
**Use Cases**

Uses cases were developed from the goals. The initial use cases created for development purposes were patient registration and patient with a fever (suspected malaria). Tables 4.6 and 4.7 show the use cases developed for patient with a fever and patient registration. Additional use cases created for the low-fidelity prototype testing were monitoring of an ANC patient, family planning, and referral tracking. Samples of the low-fidelity prototypes may be seen in Figure 3.6 and Appendix C.

<table>
<thead>
<tr>
<th>Use Case FR1. Enter new fever encounter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Actor:</strong> MW</td>
</tr>
<tr>
<td><strong>Preconditions:</strong> User was found or entered in patient registration/Look-up form and added to patient list</td>
</tr>
<tr>
<td><strong>Success end condition:</strong> Patient data is entered.</td>
</tr>
<tr>
<td><strong>System:</strong> Fever Register</td>
</tr>
<tr>
<td>1. MW selects patient from list</td>
</tr>
<tr>
<td>2. MW verifies patient demographic items</td>
</tr>
<tr>
<td>3. MW completes the following items</td>
</tr>
<tr>
<td>• Encounter date</td>
</tr>
<tr>
<td>• Duration of fever</td>
</tr>
<tr>
<td>• RDT results</td>
</tr>
<tr>
<td>• Danger signs of malaria</td>
</tr>
<tr>
<td>• Treatment given</td>
</tr>
<tr>
<td>• If yes, which medication</td>
</tr>
<tr>
<td>• Referral</td>
</tr>
<tr>
<td>4. MW uploads data to OpenMRS</td>
</tr>
<tr>
<td><strong>Extensions:</strong></td>
</tr>
<tr>
<td>2a. Data needs to be updated, changes recorded to patient registration</td>
</tr>
<tr>
<td>4a. No network connection is available</td>
</tr>
</tbody>
</table>

*Table 4.6. Use Case for Fever Register (FR)*
### Actors

<table>
<thead>
<tr>
<th>Name</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midwife</td>
<td>MW</td>
</tr>
<tr>
<td>Community Health Nurse</td>
<td>CHN</td>
</tr>
<tr>
<td>Community Health Worker</td>
<td>CHW</td>
</tr>
<tr>
<td>Health Extension Worker</td>
<td>HEW</td>
</tr>
</tbody>
</table>

### Use Case PRM1. Enter new maternal health Patient

**Primary Actor:** MW  
**System:** Patient Registration/Look-up Form  
1. MW verifies patient’s information  
2. MW creates a new patient record which stores the following information: Surname, Other Names, Gender, DOB, Age (calculated from DOB), NHIS # (optional), Hospital Record# (optional), Name of insurance scheme (optional), 1st OP #, Unit #, Home address, Employer address (optional), Mobile Phone # (optional), Unique identifier.  
3. Patient record is uploaded to server  
4. Patient is added to Maternal Health Patient List  
5. Barcode labels are generated for patient documents  

**Success end condition:** New patient is registered in OpenMRS and patient record is available in ODK-Clinic and ODK-Collect  

**Extensions:**  
1a. CHN, CHW, or HEW registers patient  
   1a1. Transfer data to MW device if network is not available  
3a. No network connection is available  
3b. Duplicate record is found  
5a. Barcode printer not available  
   5a1. Notation on paper records that user has been entered into the system

### Use Case PRM2. Look-up existing maternal health record

**Primary Actor:** MW  
**System:** Patient Registration/Look-up Form  
1. MW searches for patient  
2. MW verifies data  
3. Patient is added to Maternal Health Patient List  
4. Barcode labels are generated for patient documents if needed  

**Success end condition:** Patient data is updated in OpenMRS if needed and patient record is available in ODK-Clinic and ODK-Collect  

**Extensions:**  
1a. CHN, CHW, or HEW searches for patient  
   1a1. Transfer data to MW device if network is not available  
1b. No network connection is available  
2a. Data needs to be updated  
2b. Data needs to be updated but network connection is lost  
4a. Barcode printer not available  
   5a1. Notation on paper records that user has been entered into the system

*Table 4.7. Use cases for patient registration form (PRF).*
**System Qualities**

The key system qualities desired were coded into six categories, shown in table 4.8, with supporting rationale. System qualities came from multiple sources, as well as the expertise of the mHealth team. This list is exclusive to mClinic and excludes information related to the OpenMRS backend (such as database backup and redundancy). These categories were derived from relevant sub-characteristics in the International Standards Organization (ISO) software quality requirements and evaluation (SQuaRE) standards (ISO, 2011).

<table>
<thead>
<tr>
<th>System Quality Category</th>
<th>Rationale from data</th>
<th>Data Source</th>
</tr>
</thead>
</table>
| **Accuracy**            | A primary goal of this system is to improve the accuracy of data collection from the facilities. Data validation should be a key component of the interface. | • Document analysis  
• Contextual inquiry  
• Interviews with data analyst and data manager |
| **Documentation**       | Easy-to-use, picture based manuals should be made available at the clinic due to the lack to technical support available to midwives | • Interviews with midwives/nurses  
• Interviews with IT staff |
| **Learnability**        | Due to the low technical self-efficacy of the end-users and the limited availability of technical support ease of learnability should take precedence over advanced functionality. | • Interviews with midwives/nurses  
• Interviews with IT staff |
| **Resource Utilization**| Midwives see about 30 patients in the morning. Hardware selection should support allow for this level of use without needing recharging | • Participant observation |
| **Security**            | The system will be used to collect patient data. The phones and the software itself should be secure. Remote deleting of data should be implemented in case the phone is lost. Data should be encrypted when sent over wireless network. | • Participant observation  
• Interviews with IT staff  
• Interviews with midwives/nurses  
• Literature review |

*Table 4.8 System Qualities and Data Sources*

**Constraints**

As a part of the greater MGV-Net project, compatibility with OpenMRS was a key constraint on our system. We also had to consider the potential for long-term sustainability, scalability and cost. We selected Open Data Kit (ODK) to build our mClinic application. ODK is a freely available set of open-source software tools designed for mobile data collection (ODK Team, 2011). ODK-Collect allows data to be sent to OpenMRS via XForms while a second tool,
ODK-Clinic, allows for viewing of data from OpenMRS. We contracted with a Kenyan-based software company, Mindflow, to modify the tools so that patient data can be viewed, added, and updated seamlessly with ODK-Clinic. We chose this software because it worked on Android-based cellphones which are widely available in Africa and becoming increasingly less expensive. Furthermore, forms for ANC patients, malaria, and our other use cases could easily be created and added to ODK-Clinic by non-programmers thus keeping the cost of development low. We wanted to use smartphones over java-based phones because of the desire to offer decision support, such as for malaria treatment or PMTCT, and to display and increased amount of clinical data that would not be viewable on a smaller phone. Secondly, the modularity of ODK meant we could start with one or two data collection tools, such as antenatal progress notes, and it expand it by simply adding more forms as the midwives become comfortable using the system. It was also our desire that by using XForms that non-programmers could design and create additional forms using the XForms builder in OpenMRS, thus increasing the ease of scalability of the system.

**Functional Specification**

Table 4.9 is a list of an initial set of forms we planned to develop based on the first phase of the relevance cycle and the use cases. Due to time constraints, only the patient lookup and registration form and the fever registry form were ready in time for testing. However, these form sets were useful for the applicability checks that were conducted with the midwives, the results of which will be discussed later.
<table>
<thead>
<tr>
<th>Forms</th>
<th>Purpose</th>
<th>Inputs</th>
<th>Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient lookup and registration Form</td>
<td>Lookup existing patients and add new patients. Update patient registration information</td>
<td>Patient identification information (Name, DOB, insurance ID, barcode ID), patient contact information</td>
<td>Patient data can be searched by identification information, ideally by scanning the barcode on the patient’s PHR or from the patient’s paper record if PHR is not available</td>
</tr>
<tr>
<td>Maternal Health Form Set</td>
<td>Per pregnancy tracking of maternal health data</td>
<td>Obstetric history, lactation history, STDs, physical exam data, laboratory tests, antenatal progress record, labor and delivery outcomes, post-natal progress report, patient teaching done</td>
<td>When opening the form, alert midwife if patient due for malaria prophylaxis or PMTCT</td>
</tr>
<tr>
<td>Family planning Form Set</td>
<td>Track family planning methods and medication needs</td>
<td>Current and previous method use, obstetric history, social history, patient history, STDs, physical exam, cervical screening, lab tests, etc.</td>
<td>Patients on oral contraceptives or IUDs who need follow-up can be alerted to CHW or CHN for outreach.</td>
</tr>
<tr>
<td>Child health Form Set</td>
<td>Tracking child well care and immunization needs</td>
<td>Immunizations given, prophylaxis given, patient teaching, developmental data and screenings, malaria treatment</td>
<td>Alert midwife if immunizations or screenings are due</td>
</tr>
<tr>
<td>Referral tracking Form</td>
<td>Tracking and reporting of referral data between health facilities and district hospital</td>
<td>Patient information, referral reason, follow-up results, referring midwife</td>
<td>Alert midwife when referral report is available</td>
</tr>
<tr>
<td>Registry Form Sets</td>
<td>Quick entry of registry data required for monthly reporting</td>
<td>Fever, PMTCT, ANC, Deliveries, etc.</td>
<td>Transfer of data to other forms as appropriate</td>
</tr>
</tbody>
</table>

**Table 4.9. Overview of Planned Forms.**

The functional requirements and use cases for the patient registration form and the fever register are shown in Tables 4.10 and 4.11. The barcoding functionality specification was later removed after brainstorming sessions with the mHealth team when it was determined that maintenance of printers at health facilities would be cumbersome and unsustainable due to limited availability of IT staff and printer supplies.
1. Purpose and scope
The goal of this form is to register new patients into OpenMRS and make them accessible from the various forms of the handheld system. It should also generate unique identifiers for printing barcode labels.

2. Requirements

a. Data elements

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Possible Values</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surname</td>
<td>Text</td>
<td>Required</td>
<td></td>
</tr>
<tr>
<td>Other Names</td>
<td>Text</td>
<td>Required</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Text</td>
<td>M/F</td>
<td>Must match OMRS dictionary</td>
</tr>
<tr>
<td>DOB</td>
<td>Date</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>Number</td>
<td>Calculated from DOB</td>
<td>Or estimated</td>
</tr>
<tr>
<td>NHIS #</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospital Record#</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name of insurance scheme</td>
<td>Text</td>
<td>DDL</td>
<td></td>
</tr>
<tr>
<td>1st OP #</td>
<td>alphanumeric</td>
<td>XXXX/XXXX</td>
<td></td>
</tr>
<tr>
<td>2nd OP #</td>
<td>alphanumeric</td>
<td>XXXX/XXXX</td>
<td></td>
</tr>
<tr>
<td>Unit #</td>
<td>Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home address</td>
<td>Text</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employer address</td>
<td>Text</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile Phone #</td>
<td>Text</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unique identifier</td>
<td>alphanumeric</td>
<td>Randomly generated</td>
<td>Not sure if we need this, may just want to use NHIS#. However, might need this for other countries.</td>
</tr>
</tbody>
</table>

b. Functional Requirements:

- Search existing patient list to determine patient does not already exist in list
- Search for patient by any of the following items: Surname, Other Names, DOB, NHIS #, Hospital Record#, 1st OP #, 2nd OP #, Mobile Phone #, Unique identifier, Barcode
- Add a new patient with ability to store locally and upload to server
- Upload should check for duplicate patients
- Generate and print barcode label based on unique identifier
- Exit to next form

Table 4.10. Functional Specification for Patient Registration
1. **Purpose and scope**
The goal of this form is to collect data from patients who present in the clinic with a fever and transfer it to OpenMRS for reporting purposes.

2. **Requirements**

   a. **Data elements**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Possible Values</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surname</td>
<td>Text</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Other Names</td>
<td>Text</td>
<td></td>
<td>Required</td>
</tr>
<tr>
<td>Gender</td>
<td>Text</td>
<td>M/F</td>
<td>Must match OMRS dictionary</td>
</tr>
<tr>
<td>DOB</td>
<td>Date</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>Number</td>
<td>Calculated from DOB</td>
<td>Or estimated</td>
</tr>
<tr>
<td>NHIS #</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encounter date</td>
<td>Date</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of fever</td>
<td>Number</td>
<td>Number of days</td>
<td></td>
</tr>
<tr>
<td>RDT results</td>
<td>Boolean</td>
<td>Yes/No</td>
<td>This concept already existed in OpenMRS. Indeterminate was additionally available as a choice</td>
</tr>
<tr>
<td>Danger signs, Malaria</td>
<td>Boolean</td>
<td>Yes/No</td>
<td></td>
</tr>
<tr>
<td>Treatment given</td>
<td>Boolean</td>
<td>Yes/No</td>
<td></td>
</tr>
<tr>
<td>If yes, which medication</td>
<td>Text</td>
<td>ACT, SP, other</td>
<td></td>
</tr>
<tr>
<td>Referral</td>
<td>Text</td>
<td>Hospital, none, other</td>
<td></td>
</tr>
</tbody>
</table>

   b. **Functional Requirements:**
   
   - Capture data elements listed above
   - Provide decision support for malaria treatment (if RDT results or danger signs = Yes then treat, otherwise don't treat)

*Table 4.11. Functional Specifications for Fever Register*
Cycle 2. Design Cycle

This cycle also consisted of two phases. In the first phase, mClinic was developed as part of a coded-in-country initiative. In the second phase, we tested and evaluated the patient registration and fever register forms of mClinic. We evaluated the usability of mClinic using the H-ITUES survey and mobile usability heuristics. Our goal was to identify usability issues with mClinic and refine the functional specifications for further iterative development. The research questions for this cycle were as follows:

- What usability issues exist with the artifact?
- What are the deficiencies in functionality or qualities of the artifact that need to be addressed to improve acceptance?
- How does the artifact meet heuristic standards?

Build Phase

Development took place for January through May of 2011. The focus of the development was on modification of ODK-Clinic so that data could be both sent and retrieved via XForms. Additionally, a module was developed for OpenMRS to allow for XForms developed within OpenMRS to be easily incorporated in ODK-Clinic. The OpenMRS XForms helper module and the modified version of ODK-Clinic are collectively what we refer to as mClinic.

It has been suggested that coded-in-country development will help support sustainability of ICT projects in Sub-Saharan Africa by building technology workforce capacity (Dimagi, 2011). However, such an undertaking is not without challenges. Lack of face time and cultural differences between the Kenyan software team and the mHealth team based in New York likely contributed to communication errors that slowed the development of the project. Additionally, it
was unclear what the roles of different team members were making it difficult to know who the appropriate contact was for various issues. The different time zones also made coordinating conference call meeting times a challenge. Because of the limited bandwidth in Kenya, communicating with the team during peak hours was a challenge. The recognition for the need to build capacity through coded-in-country development is a relatively new phenomenon, therefore best practices and guidelines for such projects are limited. Two forms were created for usability testing; a patient registration form and a fever register form (see Figure 4.4)

![Figure 4.4 Sample screen shots of mClinic Interface. Sample screen shots showing directions and data overview for the patient registration form.](image)

**Evaluation Phase**

The average time to complete the fever register form on the first attempt was 3.5 minutes and 2 minutes on the second attempt. Only one of the midwives preferred the QWERTY keyboard phone to the touchscreen phone, though all expressed first preference in a Samsung© Galaxy Tablet (Appendix B).
**Heuristic evaluation**

The version of mClinic used for testing was a prototype and not intended to be implementation ready. The usability testing provided an opportunity to evaluate the software heuristics using the mobile heuristic guidelines and identified issues that need to be addressed prior to implementation, shown in Table 4.12.

<table>
<thead>
<tr>
<th>Heuristic Category</th>
<th>Issue</th>
<th>Severity Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match between system and the real world</td>
<td>Adding patients required uploading, then re-downloading patient list to add new encounters</td>
<td>4 – Usability catastrophe</td>
</tr>
<tr>
<td>Good ergonomics and minimalist design</td>
<td>Small keyboard made buttons difficult to press</td>
<td>3 – Major usability problem</td>
</tr>
<tr>
<td>Ease of input, screen readability and glancability</td>
<td>Radio buttons were occasionally difficult to select</td>
<td>2 – Minor usability problem</td>
</tr>
<tr>
<td>Aesthetic, privacy and social conventions</td>
<td>Data privacy and security</td>
<td>3 – Major usability problem</td>
</tr>
</tbody>
</table>

*Table 4.12. Usability issues and severity rankings*

Key usability issues were categorized under the following heuristic categories: match between the system and the real world; good ergonomics and minimalist design; ease of input, screen readability, and glancability; and, aesthetic, privacy, and social conventions. With regards to the match between the system and the real world, mClinic worked well with existing patients and adding new patients. However, once a new patient was added, he or she would have to be appended to the patient list in the OpenMRS and that list would need to be downloaded to the phone again before encounter data could be added. This would be given the highest ranking on Nielsen’s severity ranking scale since it would be disruptive to workflow.

Good ergonomics and minimalist design applied primarily to the QWERTY phone selected for testing. The keyboard was small and the midwives had difficulty pressing one button at a time, reading the keyboard, and using the function key to select number. There was greater success with the touch-screen phone. A minor ease of input flaw was noted in that radio
buttons were occasionally difficult to select, though this occurred more often on the smaller phone.

Finally, in regard to aesthetic, privacy and social conventions, interviews revealed we must consider application level password protection since it is common for cellular phones to be shared among staff and family members and therefore phone level locking would be inadequate.

**Health I-TUES Survey**

Following usability testing, midwives were given the Health I-TUES survey, results of which are in Table 4.13.

<table>
<thead>
<tr>
<th>Question</th>
<th>Average Score (SD) (1=Strongly Agree – 5=Strongly Disagree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I think mClinic will make it easier to find information about my patient</td>
<td>1.5 (0.55)</td>
</tr>
<tr>
<td>2. I think mClinic will save time spent on monthly reports</td>
<td>1 (0)</td>
</tr>
<tr>
<td>3. mClinic will be an important part of documenting patient care</td>
<td>1.2 (0.41)</td>
</tr>
<tr>
<td>4. I am comfortable with my ability to use mClinic</td>
<td>2.2 (0.98)</td>
</tr>
<tr>
<td>5. Learning to operate mClinic is easy for me</td>
<td>2.3 (0.82)</td>
</tr>
<tr>
<td>6. It is easy for me to become skillful at using mClinic</td>
<td>1.7 (0.52)</td>
</tr>
<tr>
<td>7. I find mClinic easy to use</td>
<td>1.8 (1.17)</td>
</tr>
<tr>
<td>8. mClinic gives error messages that clearly tell me how to fix problems</td>
<td>2.8 (0.96)*</td>
</tr>
<tr>
<td>9. Whenever I make a mistake using mClinic, I recover easily and quickly</td>
<td>1.8 (0.41)</td>
</tr>
<tr>
<td>10. The information (on-screen messages) provided in mClinic is clear</td>
<td>1.3 (0.52)</td>
</tr>
</tbody>
</table>

*Two midwives skipped this question because they did not receive error messages during the testing.

Results of the Health I-TUES surveys indicated that the midwives strongly agreed that mClinic was useful and were in agreement-to-neutral about ease-of-use.
Applicability Checks

Post-testing interviews were consistent with the results of the Health I-TUES survey in that the midwives indicated that they believed that mClinic will be helpful to them and reduce time they spend creating monthly reports. Midwife 4 stated: “Look at the number of reporting formats we have to complete. The end of the month is so hectic for us. If this will help, I will use it.”

After being shown the low fidelity prototypes, several midwives expressed concern that the maternal health form set would be too time intensive and cumbersome to use. Midwife 1 stated, “Last week I was up for 48 hours delivering babies, seeing patients, and then more deliveries. This will be too much. Someone else should do it”.

More positive interest was generated for expanding the register-type forms and expanding it to capture more monthly reporting data. Midwife 5 stated, “We really need that for PMTCT, Morbidity and the Midwife Monthly. That would help. I would like to use that.”

Summary

This chapter has provided the results of the two research cycles, Relevance and Design. The requirements analysis phase of the Relevance cycle found that midwives had heavy patient burdens, high reporting requirements, and poor access to patient and aggregate data. In the functional requirements phase we developed a number of use-cases while focusing on the initial areas of patient registration and prevention and treatment of malaria.

In the design cycle, functional requirements were used to develop the prototype of mClinic as part of a coded-in-country initiative in the build phase. Results from this process provide valuable insight to the continuation of this, and other coded-in-country initiatives. In the
usability phase we found that the overall usability was high but issues about how to address ease-of-use remain.
CHAPTER 5. DISCUSSION

This chapter summarizes the results of the study and contains a discussion of those results including addressing the contributions, implications, strengths, limitations, recommendations for future research, and conclusion.

Summary of Study

The purpose of this study was to design an mHealth application for Midwives in rural Ghana using the Information Systems Research (ISR) Framework to guide the design science research process. The first cycle, the relevance cycle, was divided into two phases, requirements analysis and functional specifications. In the requirements gathering phase we used the design-actuality gaps model to assess the current system actuality to determine functional requirements and system qualities. Important gaps were noted between the current system and the desired future system. In the second phase of the relevance cycle, we developed functional specifications based on the findings of the first phase and the development of use cases.

In the second research cycle, the design cycle, we developed a prototype of mClinic through a coded-in-country initiative and then tested its usability. Overall, the midwives rated mClinic as usable and easy-to-use, though improving midwives technical self-efficacy will be necessary for implementation success. The applicability checks noted key issues in the perceived priorities of the designers versus the midwives that should drive future refinement of the prototype.

Discussion of Results

Numerous policy makers and academics have called for an expanded use of mHealth in developing countries for facilitating health-related data collection, decision-making, and health promotion (Gerber, et al., 2010; Mechael, 2009a; Mechael & Sloninsky, 2008; United Nations
This case study demonstrated that there remains considerable work to be done closing the design-actuality gaps for achieving success in mHealth deployments. The Information Systems Research Framework applies both behavioral and design science to our understanding, testing, and evaluation of informatics research (Hevner & March, 2003). We will revisit the research cycles of this study to guide the discussion of our results.

Relevance Cycle

Requirements analysis for this research were done by interviewing and observing midwives and other clinical staff, interviewing key administrative staff, and analyzing current documentation tools. The results of the requirements analysis can be divided into three categories which make up the application domain: people, organization, and technology.

People

Through observation and interview, we gained an understanding of the clinical workflow of the midwives, their roles and responsibilities within the organization, their technical self-efficacy, their current information practices, and their potential to act as knowledge workers.

The workflow of the midwives presents challenges to the application design. There is no easy way to share data collected by nurses and midwives during the course of a single visit in real-time because a continual server connection is not possible for syncing data between mobile devices. As noted in other work, matching technology to workflow is a key component of HIS implementation success (Williamson, et al., 2001). Unlike highly structured applications designed for community health works, mClinic should allow midwives to change seamlessly between patients and limit forced or controlled data entry (DeRenzi, et al., 2008). The design of forms will have to be considered carefully as this flexibility can also increase the potential for inaccurate or incomplete data (Strong, Lee, & Wang, 1997). Midwives may see 30 or more
patients in a day, the application should be responsive to the need to quickly add key elements of data during the visit, move between simultaneous patient visits, providing appropriate decision support and feedback to relieve cognitive burden, and limit the need to enter long, text-based narratives.

The midwives had a heavy burden of administrative reporting, as was found in other studies reviewed in the literature (Mechael, 2009b; Prosser, et al., 2006). Many of the tools used for reporting contained duplicate data and information particularly those regarding malaria. The bulk of data entry went into patient’s personal health records (PHR) which remained in possession of the patient, with the same data duplicated into the various registers. Improving the quality, accuracy, and accessibility of data collected at the clinics should be a priority.

Data accessibility refers to the ability to access data in a timely manner (Strong, et al., 1997). The data collected for reporting is inaccessible to midwives. They receive little to no feedback on the reports that they generate. They are unaware of their quality or productivity in comparison to their colleagues and they report that they are not given feedback about the overall health status of the patient population that they are serving. Providing access to aggregated data on the midwives patient population has the potential to provide them with knowledge to better serve their communities (Chaudhry, et al., 2006). The Aceh Besar mobile phones for midwives project found that access to information and resources improves midwives’ self-reported confidence to solve clinical problems (Chib, 2010). However, just providing information is not sufficient for evidence-based decision support, it must be integrated into clinical workflow in order to be effective (Bakken et al., 2008). Furthermore, community health nurses and midwives should be able to create lists of patients that need follow-up care so that community outreach efforts can be improved.
Overall, the midwives were enthusiastic about learning a new technology and the potential for mClinic to cut down on their burden of reporting. However, many of the midwives expressed concern about the additional burden of learning and entering data into the system would place on them. As noted in the literature review, buy-in from end-users is essential for project success (Cole-Ceesay, et al., 2010). Previous studies on HIS implementations showed that requiring system use by withholding pay or other punitive measures is ineffective as a means of ensuring use and is generally detrimental to project success (Joos, Chen, Jirjis, & Johnson, 2006; Scott, Rundall, Vogt, & Hsu, 2005; van der Meijden, Tange, Troost, & Hasman, 2003). Proving the value of the mClinic to the midwives will be an essential component of successful implementation, particularly in the early stages when double documentation is high and return data value for reporting and measuring outcomes is low.

**Information Practices.** In this research, we identified a number of information resources that are needed by the midwives that are not readily available to them. This includes referral and laboratory data from the district hospital and current guidelines on care practices. A separate laboratory information system is currently being developed at MVP-Ghana though it remains to be seen if integrating these separate systems will be successful. Additionally, a telemedicine center is under implementation at the district hospital site that may aid in obtaining referral data. Standardization of data formats across these systems is necessary to ensure that data exchange between them will be possible. For example mClinic and OpenMRS use a common concept dictionary to facilitate data exchange between the two systems (Kanter, et al., 2009).

Another key issue with information access relates to inadequate knowledge of clinical practice guidelines and reporting expectations. This was consistent with findings from the literature on the need for improving knowledge dissemination and continuing education.
opportunities for midwives in rural Ghana (Dohrn, Miller, & Bakken, 2006; Prosser, et al., 2006). Furthermore, midwives rely primarily on books for clinical information which have the potential to be out of date or inappropriate (Musoke, 2000). For the system be successful, more attention will be needed to ensure the flow of knowledge management between the midwives, administrative staff at MVP, and the system designers. When the study was initiated, it was identified that midwives were unaware of current World Health Organization (WHO) practice guidelines regarding the number of antenatal care visits for a low risk patients. Midwives verbalized that patients should have twelve visits, while WHO guidelines recommend a minimum of four visits and GHS only reimburses four visits. To further complicate this matter, a Cochrane review published after the initiation of this study found that the recommended reduced visit model was associated with an increase in perinatal mortality, and as a result the guidelines are currently under reevaluation by WHO (Dowswell et al., 2010; WHO, 2011c). This emphasizes the importance of the modularity of the system in allowing rapid development and deployment of new forms congruent with evolving practice guidelines. Previous work has integrated clinical practice guideline (CPG)-based decision support into documentation tools that assisted users through screening reminders, diagnosis generation, a tailored care plans (Bakken, et al., 2008). The tool was found to increase diagnoses related to obesity and decrease missed diagnoses (Lee et al., 2009). CPG-Based decision support could be applied similarly in our work.

User centered methods, such as participant observation and contextual inquiry, proved very useful in understanding the information uses and needs of the midwives. These methods have been widely used in developed countries as a means for assessing functional requirements for tools and software for the elderly because decrease technical knowledge makes participatory design methods impractical (Lundell & Morris, 2005). Further refinement of user centered
methods for determining functional specifications in developing countries may lead to the creation of more relevant and usable artifacts.

*Midwives as Knowledge Workers.* The current system of data management and data flow does not permit midwives to function as knowledge workers. The ability to act as knowledge workers will allow midwives to recognize patterns amongst patients and communicate knowledge across the organization to improve clinic care processes and patient outcomes (Snyder-Halpern, et al., 2001). An important component of mClinic is that it matches the mental model of the midwives documentation practices. This is important for midwives in that it will allow them access data that they use in clinical decision making in a format that is familiar to them. A top goal of mClinic has been to not merely function as a data collection tool, but as an information resource that allows midwives to apply their domain knowledge to both individual patient and population data.

*Organisation*

*Data Collection.* Currently, the key source of patient data is stored in the patient’s PHR. This will make adding patient historical data into the MGV-Net system nearly impossible as this data is in ownership of the patient. Paper records kept on site are limited and not easy to search, as shown in Figure 5.1. The midwives stated that they only search the paper record for information when the patient comes in without their PHR and that the information there is not necessarily valuable for their day-to-day practice.
Midwives relied heavily on patient PHRs, which were condition-specific, such as current pregnancy, and contained little historical data; very little patient data is actually kept and recorded at the clinic beyond data required for registry logs.

This emphasis on registers and PHRs is different from how clinical data is documented in the United States. In a recent studies of an electronic health record implementation in a low-resource and/or small practice settings in the United States, core functionality was identified as: billing; clinical reminders; clinical notes; radiology, medication, and lab order entry; immunization tracking; problem list; and medication list with the core of the system revolving around the clinical encounter (Rao et al., 2011; Sequist et al., 2007). Reporting needs were not mentioned as a part of core functionality nor was integration with patient’s PHRs. This reflects an important difference in clinical documentation practices in Ghana versus United States where...
the burden of reporting falls on administrative staff rather than clinicians and PHRs are not widely used. If we design the system centering on registry data rather than clinical notes it will likely be more consistent with the midwives practice while still capturing essential data for reporting and clinical decision making.

The registry logs contain important information for reporting requirements and could prove useful as a source of historical data and demographic data if staff could be identified with adequate skill and time to do the data entry. Registries may also prove an important source of data for baseline and post-intervention results. While we can add essential data at each visit, it will be impossible from a staffing and resource perspective to retroactively include past data at the time of the visit. This means that considerable time will pass before there is enough patient data in the system to make it useful for evaluating patient outcomes and effectiveness of the system itself or as a resource for other interventions. This is particularly true because only a few thousands patients are seen at each facility throughout the year. It is important to keep this knowledge in mind as there will likely be considerable pressure for outcomes and evaluation data.

Our goal, at this point, will not be to create a completely paperless system since widespread adoption of HIS in Ghana is unlikely, paper will still be needed to communicate with other organizations (Dykstra et al., 2009). Determining the key data elements of data to digitize should focus on data that is needed to improve health quality and outcomes in the clinics.

**Technical Support.** Midwives expressed considerable concern about their technical self-efficacy, which has been found to be an important predictor of technology adoption by clinicians (Brown & Coney, 1994; Carayon, et al., 2011). Opportunities for improving technical skills appear to be limited. Extensive on-site support during the initial rollout will likely be required,
placing an additional human resource burden on MVP. On-going technical support via the IT and data staff at the main MVP administrative site may be possible, however, the distance may prove challenges. Solutions for providing remote support should be investigated. Currently, there are only two full-time staff members working in the IT department at MVP-Ghana. This level of staffing will likely be inadequate given the amount of support that the midwives indicated that they would require.

Technology

Technology, particularly with regards to infrastructure, will remain a limitation to the deployment of mClinic. During both the first and second site visits, cellular coverage was only adequate at five of the seven sites. While increasing use of cellular phones and mobile technology indicate wider technology acceptance, the bandwidth capacity is not keeping pace with the number of new users. During the first visit, bandwidth was sufficient for making video calls via Skype and there was only one instance of a network outage in a 14 day period. During the second visit, eight months later, bandwidth was no longer sufficient for video calling and there were at least three instances of network outages over a 14 day period. In addition, during the second trip, the internet connection at the main administrative site, where the OpenMRS server for this project is housed, was unavailable for three continuous days as well as occasionally being out of service on other days.

Though ICT infrastructure is expanding rapidly in Sub-Saharan Africa it is not keeping pace with demand (Gerhan & Mutula, 2007). We must continue to account for low and unreliable bandwidth in our system design as the issue will not likely be resolved in the near future.

Design Cycle
Build

While our research questions did not include the actual software development process, the coded-in-country initiative has long-term implications for this and other mHealth and HIS projects. The long-term sustainability of HIS in Sub-Saharan Africa will not be possible with building human resource capacity in information technology to support the implementations and on-going maintenance of the software and equipment.

Usability

Midwives identified usability issues through testing, completion of the Health I-TUES survey, and post-testing interviews. While the results of the Health I-TUES survey were generally positive the heuristic evaluation suggests there are still some important usability issues that need to be addressed prior to implementation. This, however, is to be expected in the first round of field testing. Some of the heuristic flaws observed, such as frequent typos or difficulty entering numbers, were related to the hardware selected for the project rather than the software. This stresses the importance of the careful selection of hardware in addition to the attention and detail paid to the actual software development.

The Health I-TUES survey proved useful in providing a tool to measure of usability. Post-test interviews qualified the results of the Health I-TUES survey as midwives were able to express what features they found easy to use and which they found difficult. As is consistent with the literature, the midwives preferred when the screen contained less data and did not require scrolling (Gong & Tarasewich, 2004). Questions regard ability to learn and use the system were ranked lower than the others. This may be attributed to the midwives low technical self-efficacy and reinforces the need for hands on training in general technology in addition to mClinic itself.
**Applicability**

Overall, the midwives indicated that they felt the use cases in development reflected their clinical practice while some of the prototypes that called for more narrative note documentation would not be useful to them or too cumbersome to use. They indicated that the need to collect registry data was a top priority and that electronic documentation of clinic notes may be too burdensome given their high patient loads. Completing the usability tests prior to the applicability checks provided a technical baseline whereby the midwives became familiar with the potential of mobile technology. This allowed the midwives to provide richer feedback on the functional requirements and use cases developed in this research. This work provides further evidence to the appropriateness of low-fidelity testing for developing country HIS projects as proposed by other researchers (Maunder, et al., 2007; Ramachandran, et al., 2007).

**Functional Specifications Revisited**

The field testing resulted in further refinement of functional specifications. A focus on registry data, as suggested by the applicability checks, will streamline data collection and be more suitable to the workflow and mental model of the midwives. Reduction of scrolling and text-based data entry will allow for more rapid form filling and better ease-of-use given the high patient volume seen by the midwives.

**Contributions**

This study makes contributions in three areas: information systems theory; user-centered design methods; and, mHealth for developing countries.

**Theory**

Few formal studies have used design science research in a developing country context. Our study provides evidence to the growing body of literature on design science research. We
modified the framework from previous researchers proposed use by incorporating earlier field testing (Hevner, 2007; Iivari, 2007). This research will contribute to the literature on design science research and help illuminate how design science can be used to improve the quality of artifacts produces for developing countries.

**Methods**

At the 2010 mHealth Summit many attendees called for increased use of user centered design methods in mHealth (Torgan, 2010). Traditional user centered design methods often assume a baseline understanding of technology that may not be present in a developing country context (Smith & Dunckley, 2007). Our methods will contribute to the literature on the use of user-centered design techniques in developing countries. Including low-fidelity prototyping after testing of mClinic allowed the Midwives to provide us with richer feedback on the applicability of our application and plans for future work by increasing their technological baseline. Applicability checks were important in validating the results of the relevance cycle and providing important information for the refinement of mClinic.

**mHealth in Developing Countries**

While there has been increased enthusiasm for using mHealth for improving healthcare infrastructure in Sub-Saharan Africa there is little evidence in the literature to guide design and implementation of such tools and even less data on their effectiveness (Mechael, 2009a; Tamrat & Kachnowski, 2011). This work will contribute to the much needed evidence to support mHealth for development. Furthermore, few mHealth implementations have targeted midwives despite the important role they play in the rural healthcare systems of Sub-Saharan Africa. Understanding the distinct needs of midwives, as opposed to other types of clinicians or
community health workers, will be an important contribution to building health information systems infrastructure in Ghana and other parts of Sub-Saharan Africa.

**Project Implications**

The results of this project stressed the need to alleviate and streamline the midwives administrative reporting burdens with multiple expected outcomes of improving job satisfaction, increasing data accuracy, and moving midwives away from passive data collectors into a true knowledge worker role. Our top priority will be to reduce the redundancy and increase the quality of malaria data reporting. Additionally, we will continue to improve upon the mClinic framework so that additional forms can be created and used for other purposes. We are already in the process of form development for collecting verbal autopsy data. This form will help us improve the quality of data and better understand the causes of mortality in the Millennium Village clusters.

**General Implications**

This research has implications for both informatics and midwifery. We have shown the utility of design science research for developing countries. Increased usage of design science research and user centered methods should help decrease the failure rate of health information systems implementations. Furthermore, even with successful projects, time and money can be wasted on features that lack utility to end-users. The framework and methods used in this study may help increase the utility of earlier prototypes resulting in reduced development costs.

The methods used in this work will be of particular interest to those who do research and development in ICT for developing countries. As noted in the literature review, participatory design methods assume more familiarity with technology than is commonly found in developing
countries (Gitau, et al., 2010). Increased use of contextual inquiry and low-fidelity testing may result in more relevant artifact development leading to more successful HIS deployments.

Evidence from this study indicates the central role that midwives play in the reporting of public health data. This role would be considered atypical for clinician from developed countries. It was clear from the interviews that midwives mental model for documenting patient care centered on collecting data for reporting registries rather than the collection of narrative data. Understanding this difference in clinical documentation practices will be important in the design of any health information system that collects data from midwives in Ghana. As the data from these reports are needed for aid organizations, it is likely that these findings are generalizable to other developing countries that depend on foreign aid to support their healthcare infrastructure. Furthermore, this study directly targeted midwives. Midwives are the largest group of primary health care providers in Ghana and much of Sub-Saharan Africa yet studies regarding their information needs and tools supporting their work have been few and limited (Prosser, et al., 2006; Tamrat & Kachnowski, 2011). Building a continuing body of evidence to support nurses and midwives in developing countries is a key element to supporting the healthcare infrastructure where extreme workforce shortages exist.

**Strengths**

This study had several strengths. First, the framework provided clear guidelines for the overall study and balanced the research between the behavioral and design science paradigms. Secondly, nearly all of the requirements data was collected on sites at the clinics and MVP administrative offices using multiple methods in both the relevance and design cycles. This allowed for triangulation of our results, improving their credibility and validity. Additionally, this provided a rich picture for how mClinic could be used and gave greater insight to the
cultural and organizational challenges the future implementation might face. Third, interviews with midwives took place at least once at each site, allowing us to reach our entire target end-user population.

**Limitations**

Our study was limited by several factors. Poor recording quality and background noise in made post-interview analysis challenging. Secondly, the study site, which is part of the Millennium Villages Project, is a unique initiative that may limit generalizability of the results to non-MVP clinic sites. Third, only one observer was used to collect data. Additionally there was some indication that the clinic staff perceived the researcher to have some type of managerial role within MVP and this may have affected their behavior or willingness to share. Finally, each phase of the study was conducted in two-week trips. Longer in-country time could have provided more detailed data, particularly regarding time-specific tasks such as end-of-the-month reporting.

**Future Research**

Future research on this project will include the continued iterative development of mClinic using the ISR framework. Additionally, measuring the impact of mClinic post-implementation on midwives time and job satisfaction and effect on data quality will be an important component of evaluating its utility. It will be important to measure if use of mClinic aids midwives ability to conduct knowledge work, improves opportunities for collegial communication, and contributes to improved perceptions of professionalism. Future studies may also include patients’ perceptions on how mHealth impacts the quality of care and effects privacy.
Conclusions

Ghana continues to face a critical shortage of midwives, particularly in rural areas. A multifaceted approach is needed to improve the recruitment and retention of midwives in rural Ghana. The use of mHealth can provide mechanisms for improving the efficiency and effectiveness of care provided by midwives while reducing their administrative burdens. The midwives in our study voiced high levels of frustration regarding reporting requirements and the lack of feedback, information, and support available to them. mClinic can address some of these issues; however, careful and thoughtful design is essential for successful implementation, scalability, and long-term sustainability of the project. This study contributes to the use of design science research in developing countries. It is imperative that we seek and employ frameworks and methods for rapidly designing highly useful tools given the limited resources and increasing health challenges in rural Ghana. Supporting the work of rural Ghanaian midwives is essential for maintaining the country’s progress towards reduction of maternal mortality and improves in rural primary healthcare services.
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APPENDIX A. MODIFIED HEALTH I-TUES SURVEY

For each of these statements, circle the number that represents how you feel about the application you have tested today.

1. I think mClinic will make it easier to find information about patient.
   1  2  3  4  5
   Strongly Agree  Agree  Neither  Disagree  Strongly Disagree

2. I think mClinic will save time spent on monthly reports.
   1  2  3  4  5
   Strongly Agree  Agree  Neither  Disagree  Strongly Disagree

3. mClinic will be an important part of documenting patient care.
   1  2  3  4  5
   Strongly Agree  Agree  Neither  Disagree  Strongly Disagree

4. I am comfortable with my ability to use mClinic.
   1  2  3  4  5
   Strongly Agree  Agree  Neither  Disagree  Strongly Disagree

5. Learning to operate mClinic is easy for me.
   1  2  3  4  5
   Strongly Agree  Agree  Neither  Disagree  Strongly Disagree

6. It is easy for me to become skillful at using mClinic.
   1  2  3  4  5
   Strongly Agree  Agree  Neither  Disagree  Strongly Disagree

7. I find mClinic easy to use.
   1  2  3  4  5
   Strongly Agree  Agree  Neither  Disagree  Strongly Disagree
8. mClinic gives error messages that clearly tell me how to fix problems.

   1       2       3       4       5
   Strongly Agree  Agree  Neither  Disagree  Strongly Disagree

9. Whenever I make a mistake using mClinic, I recover easily and quickly.

   1       2       3       4       5
   Strongly Agree  Agree  Neither  Disagree  Strongly Disagree

10. The information (on-screen messages) provided with mClinic is clear.

    1       2       3       4       5
    Strongly Agree  Agree  Neither  Disagree  Strongly Disagree
APPENDIX B. MOBILE DEVICES USED IN STUDY

- Huawei IDEOS
- Xperia X10 Mini Pro
Samsung Galaxy Tablet
APPENDIX C. SAMPLES OF LOW-FIDELITY PROTOTYPES

Samples of low-fidelity prototypes derived from use cases and used in applicability checks.