Research Article

Understanding Sociotechnical Implications of Mobile Health Deployments in India, Kenya, and Zimbabwe

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Abstract

Health workers in understaffed and overstrained low-resource environments suffer from complex and demanding workloads. We discuss three mobile health (mHealth) deployments in India, Kenya, and Zimbabwe that we designed to assist frontline health workers. Drawing on rich empirical findings, we describe how we situated the technology, how the workplace relationships were reconfigured as a result, and how the projects grew organically beyond their intended scope. We adopt a reflexive approach to analyze how these projects address longevity as a critical shared goal and discuss how they negotiated the durability of technologies, resulting organizational stability, and sustained community engagement.

1. Introduction

Developing healthcare solutions for low-resource environments around the world entails a set of unique contextual challenges. Access to infrastructure is limited, costly, and cumbersome. Literacy rates are persistently low, and much of the public remains inadequately informed about wellness practices commonplace in the developed world. The shortage of doctors requires many health services to be delivered by frontline health workers with limited training. Various technology-supported global health initiatives have focused on making existing health approaches more effective by factoring in these resource constraints (Berwick, 2004; Howitt et al., 2012; Malkin, 2007). Mobile health (mHealth) has emerged as a popular domain of research and practice (Free et al., 2013) due to the increasingly ubiquitous presence of mobile phones in these regions.

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UNDERSTANDING SOCIOTECHNICAL IMPLICATIONS OF MOBILE HEALTH DEPLOYMENTS

In this article, we study the deployment of three mHealth projects that we designed to aid frontline health workers in bringing globally approved norms and practices to resource-constrained local settings. These frontline workers are employed in understaffed and overstrained work environments that place excessive demands on their time and expertise. The need to ease their burden has motivated several mHealth initiatives to offer tools and processes to improve their workflows. Our first project is Projecting Health,[1] in which rural Indian community health workers use portable projectors and locally produced videos to teach women about antenatal (before birth) and postpartum (after birth) health care. Mobile Women and Child Health (WaCH), our second project, is situated in peri-urban Kenya and entails a bidirectional SMS messaging platform that allows nurses to provide timely advice about antenatal/postpartum care. In our third project, ODK Diagnostics, Zimbabwean nurses use a smartphone-based application to analyze diagnostic tests for infectious diseases. All three projects are the products of collaborations with global health nongovernment organizations and research institutions.

We use Irani, Vertesi, Dourish, Philip, and Grinter's lens of postcolonial computing (2010) to reflect on the sociotechnical aspects of our deployments. While their work focuses on the processes of designing suitable technologies for resource-constrained settings in the developing world, we assess the deployment of these technologies, a challenging task for several reasons. Each site has a unique set of sociotechnical configurations that researchers or practitioners must appreciate before deploying a project. The Human-Computer Interaction for Development (HCI4D) community that examines HCI concerns in the context of resource-constrained environments recognizes at this point that comparing sites across countries is complex because of wide disparities in cultures, social structures, and technological infrastructures. What does it mean then to compare a project in India to one in Kenya? How is an HCI4D researcher working in Kenya to draw lessons from a project deployed in India? In our article we attempt this challenging comparison by turning the focus on ourselves and reflexively analyzing three deployments across starkly different landscapes.

Our projects have a common source (U.S.-based researchers) and aligned destinations (frontline workers in low-resource environments), but they differ in three critical ways. First, all projects are at different stages of deployment. At this writing Projecting Health has been operational for two-and-a-half years, Mobile WaCH ran for one year, and ODK Diagnostics for eight weeks. Second, they entail varying levels of community engagement. In Projecting Health, the health workers' responsibilities lie entirely with the community and out in the field. The nurse using Mobile WaCH, on the other hand, regularly interfaces with the clinic, which new and expecting mothers are encouraged to visit. ODK Diagnostics, by contrast, was deployed entirely within the boundaries of health clinics and hospitals. The engagement of health workers with care-seekers varied accordingly. Third, the projects differ in the way they balance social and technical elements. Unfolding social interactions are far more relevant than the devices used in the Projecting Health project. Mobile WaCH, on the other hand, aims to balance the social and the technical to facilitate communication between nurses and mothers. By contrast, ODK Diagnostics focuses more on the technical components than the social. In this article we embrace the challenge of addressing and highlighting these differences to arrive at a meaningful, cohesive discussion that demonstrates how these (and other similarly situated HCI4D) projects across disparate landscapes may be viewed side by side. Our article contributes uniquely to mHealth and HCI4D by bringing these three distinct health-technology initiatives under one lens to understand sociotechnical tradeoffs and develop a more robust and relevant interpretive frame.

We begin by situating our research in the context of prior work. We then provide case studies of our deployments, organizing our field experiences to highlight how we situated the technology, how the workplace relationships evolved, and what the impact was across the community. We identify *longevity* as a critical shared goal of our projects, aligning with Marsden's (2009) emphasis on long-term engagement. We then collectively analyze our deployments by deconstructing longevity in terms of the *durability* of the technology, the resulting *stability* of the organizational structure, and *sustained* community engagement.

1. Participant names have been changed to preserve anonymity.

2. Related Work

Designing technology for low-resource environments entails a unique set of challenges, as has been discussed extensively in recent years (Brewer et al., 2005; Heeks, 2008). There has been great interest in developing low-cost technologies for global health, and a recent Lancet survey recommends that "when possible, technology that is already available in resource-poor settings (such as mobile telephones) should be used as a platform for health interventions" (Howitt et al., 2012, p. 508). HCI4D researchers have leveraged the rapidly increasing mobile penetration in developing regions to design healthcare technologies for application areas such as data collection, providing access to information, training, disease surveillance, and monitoring health services (DeRenzi et al., 2011). Health workers have been the focus of several of these initiatives (Chib, 2013). Some of this work includes Ramachandran, Canny, Das, and Cutrell's (2010) study of the creation and use of mobile videos by Indian community health workers, DeRenzi et al.'s (2008) e-IMCI mobile phone tool that guided Tanzanian health workers step by step through the Integrated Management of Chronic Illness (IMCI) treatment algorithm, and Chaudhri et al.'s (2013) smartphone-based monitoring system in South African human milk banks.

In this article we focus on the sociotechnical implications of such deployments and how we might collectively analyze them. We draw particularly on Marsden's exhaustive work on subjects such as designing appropriate, low-cost technologies especially for mHealth efforts (Molapo & Marsden, 2013), capitalizing on local production of content (Robinson, Vartiainen, Jones, & Marsden, 2012), emphasizing the role played by community (Marsden, Maunder, & Parker, 2008), addressing dilemmas that plague the processes of HCI4D research (Maunder, Marsden, Gruijters, & Blake, 2007; Maunder, Marsden, & Tucker, 2006), and more. We extend this work with our cross-deployment study of mHealth initiatives and discuss projects that are local, situated in existing practices, and variously disparate.

Sengers, Boehner, David, and Kaye (2005) have emphasized the importance of integrating critical reflection—bringing unconscious aspects of experience to conscious awareness—into the practice of technology design, also suggesting that research and design be practiced concomitantly, not as separate disciplines. We look at our deployments—as Schön (1992, p. 11) suggests—as "reflective conversations with design situations," some deeper than others, and reflect on our experiences. We also find Irani et al.'s lens of postcolonial computing (2010) helpful, as it sheds light on some of the difficulties of contending with interculturality in HCI4D. While their work highlights engagement, articulation, and translation as key components of the design process, we discuss the challenges that unfold after the technologies are taken into the field. In doing so, we contribute to a growing body of postcolonial research that includes, for example, Bidwell's (2014) discussion of translations from a postcolonial perspective.

3. Case Studies

We offer a brief synopsis of each project as it was designed, then describe how we situated the technology and challenges we faced therein. We also discuss the feedback we received from the community and how the project grew organically beyond its intended scope of deployment. Our experiences were messy and disparate, and the discussion that follows ties these differences together into a cohesive analysis.

3.1 Projecting Health

Projecting Health involves the dissemination of information about maternal and newborn health to new and expecting mothers in rural Uttar Pradesh, India, aiming to ameliorate the high maternal and infant mortality rates in this region (Kumar et al., 2015). The dissemination takes place via group screenings of short films produced locally as part of our implementation.[2] Our partner organizations train their teams to produce videos based on input from the Community Advisory Board (CAB), a volunteer group of community members with diverse expertise. Frontline health workers or accredited social health activists (ASHAs) then screen these videos

2. We draw on Digital Green's contributions in the agricultural domain (Gandhi, Veeraraghavan, Toyama, & Ramprasad, 2009), well documented here: www.digitalgreen.org.

Figure 1. The ASHA uses a pico projector to teach new and expecting mothers the benefits of exclusive breastfeeding.

using pico projectors[3]—"job aids" that reduce the ASHA's burden of remembering and repeating information individually for every mother.

Situating the Technology

The pico projectors have a complex and non-intuitive user interface. Our field partners trained the ASHAs to pause and play videos, perform simple troubleshooting, and keep the devices charged. The ASHAs we interviewed claimed they were comfortable operating the devices, although the disseminations we observed showed that there was a wide variation in the ASHA's expertise with the projectors. The project staff was generally available, however, for more complex troubleshooting.

The pico projectors are outsiders to the rural communities that Projecting Health targets; thus, when they break, repair is nontrivial and expensive. According to project staff, broken devices must be sent to Bangalore; repairing a US$180 pico costs US$90. Currently, 12 of the 29 picos are awaiting cheaper repair options or replacement. Since they are a scarce commodity, not every ASHA has her own pico. For safekeeping, they are stored centrally for easy procurement by a cluster of ASHAs. This results in a delicate sharing situation; the ASHAs must coordinate regularly with project staff and sometimes travel many kilometers to access the device when needed. Managing the sharing logistics for picos is more time-consuming than the actual dissemination. It is not enough for ASHAs to remember to charge the projector; intermittent availability of power further adds unpredictability.

Despite the logistical complications, the ASHAs we interviewed said the picos (and videos) had made their duties simpler. The disseminations create a structure within which the ASHAs can perform their role. In one ASHA's words, "Now holding meetings has become easy." As with other teaching aids, there is no longer a need to memorize the content to be disseminated, allowing the ASHAs to focus on reinforcing the lessons in the videos.

3. These battery-powered projectors project an image of size 1x1.5m from an internal memory card.

Our deployment objective was to situate the video creation locally. The CAB was an outcome of this and consists of stakeholders from varied backgrounds and professions, including ASHAs, other frontline workers, state-appointed medical officers, functionaries from our partner organizations, and local media representatives. The CAB holds quarterly meetings to review and approve the videos. These meetings have also created effective communication among members, as one of them (an ASHA) said:

> At CAB meetings, we are able to give voice to our community. At the same time, we get to learn from informed doctors and health officials. Any doubts about how to talk on a particular topic get clarified at these meetings.

Community Engagement

The videos aim to inform and engage. The fact that they are created locally, in local dialects and with local songs, has helped their acceptance. One ASHA shared: "So far we have only seen films from Bollywood, shot in cities or abroad. This is the first time we are seeing films shot in our very villages." Since the videos feature local villagers, they attract family and friends of the cast beyond our target audience. This has led to greater community engagement in at least two ways: by attracting spectators during the filming process and through circulation of mobile versions of these videos (Kumar & Anderson, 2015).

We interviewed a mother who had recently given birth. Complications arose during labor that she *and her family* had learned about from a Projecting Health video. They contacted the ASHA to facilitate an institutional delivery, ensuring the safety of mother and child. It is unusual for husbands or fathers-in-law to be present at disseminations; social norms generally assume a woman-only audience. On inquiry, we found that the mother had married into a conservative upper-caste household, where family elders commonly prohibit young daughters-in-law from leaving the house. Her ASHA had taken the initiative to schedule and organize a private screening in this mother's home. Interviews with this and other ASHAs indicated that it had become a fairly common practice to reach similarly disadvantaged mothers thus. Moreover, neighborhood disputes are common in these parts, so ASHAs must frequently conduct multiple "unofficial" disseminations in the same neighborhood to accommodate everyone.

Projecting Health operates in a patriarchal society in which women have limited social standing, and the ASHAs (all women) initially struggled to gain credibility. Before Projecting Health, one ASHA, Lata, said she felt like a "loser" and frequently shirked her duties, such as following up with mothers or keeping track of their progress. Another frontline worker agreed, saying that Lata was "transformed" by Projecting Health. The project, Lata told us, made it easier for her to fulfill an ASHA's responsibilities, and she no longer considers herself an "outcast." Other ASHAs we interviewed also shared that they and their work were taken more seriously by their communities after Projecting Health was introduced. With the project receiving greater publicity, the increasing involvement of the CAB members, and the growing viewership of the videos, ASHAs have come to acquire a role of greater significance.

3.2 Mobile WaCH

This project introduces a web-based platform to support message exchanges between pregnant women and a clinic nurse in Mathare North Health Center, 20 miles outside Nairobi (Perrier et al., 2015). High infant mortality rates in Kenya make this an important and relevant need to address. Further, waiting times at Kenyan clinics are notoriously long, dissuading women from making their recommended visits to the antenatal care (ANC) center. This project is part of a larger global health study that aims to draw women into deeper engagement with the health system through SMS communication.

A local nurse named Kioni (see Figure 2) has used the Mobile WaCH platform for a year to communicate with 100 pregnant women who enrolled in the project during a routine antenatal clinic visit. When Kioni enrolled participants, she told them they would receive SMSs from her at various stages of their pregnancies that would ask questions about their health and remind them about clinic visits. She also told them that they could send her SMSs, free of charge,[4] with questions or concerns about their or their child's health. Kioni uses the web-based platform to read and respond to these messages.

4. A Kenya-based short code allowed the project to pay for incoming participant messages.

Figure 2. Kioni uses the Mobile WaCH interface to communicate with pregnant women via SMS.

Situating the Technology

We address two challenges with the Mobile WaCH platform. First, by providing a direct connection to Kioni we alter the popular perception that a clinic visit is time-consuming and/or unhelpful. Second, we provide necessary and useful information to pregnant women and new mothers so they may better care for themselves and their newborns. We leverage SMS to support a large audience of mobile owners.

Mobile WaCH has 318 pre-composed SMSs in English and Swahili for different pregnancy stages, designed according to Kenya's ANC guidelines. Women provide their mobile phone number and expected due date, and Mobile WaCH uses this information to automate timely SMS dispatches. For example, at 20 weeks pregnant, women receive a reminder to drink eight glasses of water daily; four weeks after delivery, they receive a reminder to check that their baby has been vaccinated. All messages appear as if Kioni sent them herself. Kioni monitors the sent and received messages daily and uses the interface to communicate with women as needed. For Kioni, keeping track of these women on a weekly basis would be impossible without a tool like Mobile WaCH. It did not take her long to learn the system:

> At first Matt came and showed me how to use the computer. I had a little knowledge so it wasn't too bad. . . . I had used wifi before. Then it became easier. I was able to use the system. It wasn't too hard to know which mother had problems with breastfeeding or which was having pain. . . . I could sort the mothers out.

When we asked Kioni if she was comfortable enough to train others to use Mobile WaCH, she exclaimed, "I already have." Kioni needed help using the system during a phase when she had other domestic responsibilities to balance. Instead of quitting, she trained her sister Milicent to use the platform and offer additional support. Milicent helps Kioni with record keeping, allowing Kioni to focus on providing health-related advice.

It was challenging for Kioni to learn to effectively manage the time she puts into communicating with the women. Though she knew at the start of the study that the system was not designed for emergencies, many women messaged Kioni saying that they were anxious, stressed, or in pain. Kioni needed to triage these situations and decide when to reassure the women that some pain during pregnancy is normal and when to recommend that they visit the clinic for additional care. These decisions were especially important when a woman

was anxious, as in this SMS: "My child is hot, coughing, has rashes, flu, loss of apetite, what do i do?" Although the women were told that Kioni would respond to messages during business hours, she received this message late at night and responded at 1:00 A.M., "please take your baby to the doctor tomorrow so that she can receive medical attention." Through Mobile WaCH, Kioni has provided many patients with care and attention, developing patient relationships and increased trust in her capabilities. However, she has also needed to define her own boundaries and has often found herself eager to do more for her patients than her position allows.

Kioni must also exercise diligence to keep her laptop safe. She told us that because she did not have her own vehicle and did not want the laptop to get stolen on her daily commute, she would carry a paper register with her, record participant visits on it, then update the web interface at night from home. This data entry further augmented her workload.

Community Engagement

The Kenyan health system is overburdened, and the availability of a nurse to address women's questions was welcomed with surprise. One woman shared:

> It can encourage because if you send me a message, it will remind me to go to hospital to give birth, as a mother I will feel that there is someone who cares and is ready to assist you . . . and as such I will have morale to come to hospital because you cannot send me a message if you will not assist me.

The women were able to look to Kioni for various kinds of assistance. Kioni recognizes that she fills this need the mothers have for greater care, taking pride in the fact that she knows "what problems they all have" and can now keep track of them. Although she did not know these women initially, she now feels personally connected to them, despite having met them once or, at most, twice. This experience is very different from those of other nurses at Mathare North, who have too many patients and too little time for each.

Since Mobile WaCH has tended to include only women, the involvement of male family members came as a surprise to Kioni. She reported that she occasionally hears from husbands of the women:

> There are about 10 husbands or so. . . . I have one who gets in touch so often . . . because he said you can never trust people in Nairobi. He used to ask everything . . . every time there would be a message, he would respond . . . every week for the first five weeks. At first, he would ask who we are, what we do. Then he asked about questions that we sent. "What do you mean vaccine? What do you mean when you say you want my wife to come for vaccine. What vaccine should she get?" I would have to explain.

Kioni draws great encouragement from this unanticipated community engagement. Although her responsibility was to engage with 100 women, many more requested to participate as they learned about the project from their friends. Kioni added that her fondest memory was of being offered a "bribe" to add another woman to her list. Though she did not oblige, this incident reaffirmed for her that the community recognized her efforts.

3.3 ODK Diagnostics

Rapid diagnostic tests (RDTs) are low-cost, disposable tests routinely used to diagnose a variety of infectious diseases in low-resource settings (Moody, 2002). RDTs are able to provide a diagnosis within a single clinic visit, protecting against under- or over-treatment. However, the number and variety of RDTs available is increasing rapidly, and research has shown that health workers often make mistakes when reading test results (Rennie et al., 2007) since the visual interpretation that determines the result can be subjective. To standardize RDT interpretation, we designed ODK Diagnostics (Dell, Francis, Sheppard, Simbi, & Borriello, 2014), a smartphone application that automatically interprets RDTs and records the results digitally. As we tested ODK Diagnostics extensively with clinical experts, we were approached by our partner organization working with the support of the Zimbabwe Ministry of Health (MoH) to deploy our system in five clinics and hospitals (two rural, three urban) in the Manicaland Province. We started our deployment by training nurses who administer RDTs to use our system. They take a photo of the RDT using the smartphone's camera, then the system automatically processes the image, provides the diagnosis, and wirelessly transmits the test result and metadata to a server.

Situating the Technology

Introducing the mobile system into the clinical workflow connects nurses to supervisors and other stakeholders at central offices, such as the MoH. The objective is not only to ensure that medical records and test results are transmitted to the MoH, but also to create a feedback channel to frontline workers regarding concerns or errors with the transmitted data. Traditionally, as in Mobile WaCH, nurses would manually update patients' paper records with their test results and maintain several registers for collecting monthly statistics on disease occurrences. Doing this by hand is a tedious and error-prone exercise for the nurses and significantly cuts into their time with patients. By dramatically shortening the paper reporting cycle, we streamlined the nurses' workflow, allowing them to see more patients in the same time. However, we found that an additional complication was introduced by the need to transmit diagnostic reports to the centralized database. Since network connectivity is often unstable, the workers had to develop workarounds for transmitting data. Those working at one hospital, for instance, noticed that more bandwidth was available at night, so they started to leave the devices on after work for overnight transmission. At another, more rural site, the distance from the clinic to the cell tower made data transmission untenable, so a health worker traveled by bus every few weeks to a town 40 minutes away to upload the data. These problems frequently arise in HCI4D research and have been documented early on (Brewer et al., 2005). In our case, although connectivity was available, it was bandwidth constraints that impacted the deployment.

The ODK Diagnostics tool underwent considerable lab testing before deployment, but testing does not eliminate the possibility of human error. Because the MoH was concerned about losing data if the new system failed, it required nurses to do both paper-based and smartphone-based reporting at the start to minimize reporting errors. This meant the nurses had to spend roughly two additional minutes per patient doing largely redundant paperwork. The system made their workflow more complex, contrary to expectations. In the short term, they saw fewer patients overall—a consequence we were alarmed to discover after deployment—and we were brought face to face with ethical dilemmas of deploying such a system (Dearden, 2013; Glantz, Annas, Grodin, & Mariner, 1998).

The nurses' roles in relation to coworkers and supervisors changed, which influenced workplace power dynamics. Previously, nurses had reported directly to the matrons. However, the matrons associated our system with laboratory tasks and instructed the nurses to go to laboratory technicians for technical assistance. These technicians operated sophisticated medical devices and machinery and were more comfortable with the new system, so system updates and technical issues came to be handled by them. An example of their new supervisory role became apparent within week one of our deployment. In monitoring the uploaded test data, certain RDT images indicated that tests had been performed incorrectly. For example, several RDTs had dark red backgrounds, which may have resulted from the nurses putting excessive blood on the test or reading the result too early. Instead of discarding the tests, nurses incorrectly reported them as valid diagnoses. Since the laboratory technicians were the MoH's primary point of contact, they became the point persons for reviewing the guidelines with the nurses. The nurses were now "accountable" to the technicians.

As with our other projects, the safekeeping of devices was a concern. At Mutare, the largest hospital in our deployment, our participants were afraid the smartphones could be stolen if left unattended and would keep them locked in a cabinet when they left the room. This made them inaccessible to other participants who would then have to track down the key.

Community Engagement

Community engagement was hard to ascertain in an eight-week deployment, unlike our other projects. However, we introduced the project to nurses who were new to smartphones, and several were initially hesitant to interact with the devices for fear they might break. After using the system for a few weeks, several nurses told us they planned to buy smartphones for themselves, for taking pictures and going online. One of them shared: "I love this phone. For a long time my daughter has been telling me to buy a smartphone, and I've been resisting, but after using this phone I want to buy this one."

We found that the nurses, in addition to conducting the tests, had been using the phones for email, Facebook, and checking the weather. This was apparent from applications that had been downloaded and

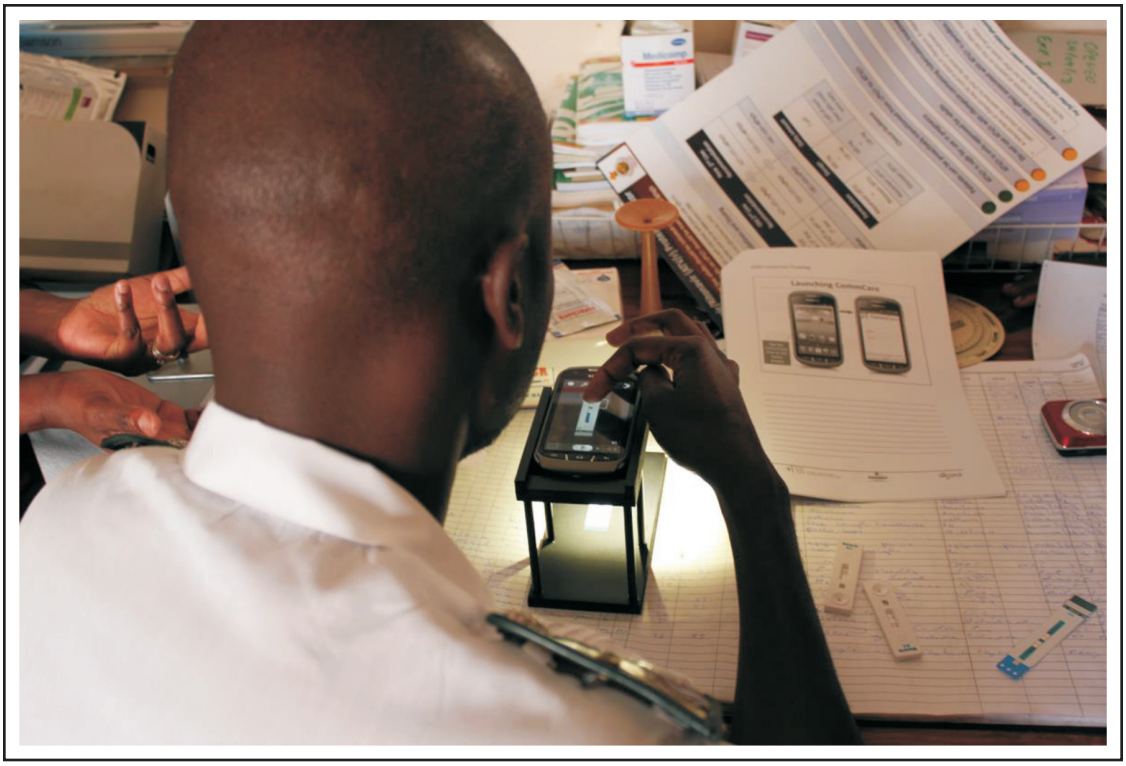

Figure 3. A nurse uses our smartphone-based ODK Diagnostics to read a malaria rapid diagnostic test (RDT).

activity viewable from inspecting the smartphones. The nurses had become much more comfortable with the smartphone after having learned various other uses of it.

4. Discussion

This article draws on rich qualitative data, collected using U.S.-based institutional ethics and IRB approval, factoring in our partner organizations' availabilities and constraints. For Projecting Health, we observed 10 disseminations, conducted 10 in-depth interviews, and held four focus group sessions to understand the roles of the different stakeholders. We analyzed six Community Advisory Board meeting minutes and 16 interview transcripts received from the project staff. All data was collected in the Raebareli district of Uttar Pradesh, where the project has been running in 87 villages for over two years. For Mobile WaCH, we used data from focus group interviews with 35 users, conducted by our partner organization before the deployment. We interviewed the project nurse in four semi-structured 30-minute sessions and the study coordinator in one. We also conducted participant observations in Mathare during visits and reviewed approximately 950 messages sent on our platform. For ODK Diagnostics, we conducted participant observations over 10 days during its eight-week deployment. We also held post-deployment interviews with various stakeholders, including 25 nurses, three laboratory technicians, and five supervisors, to assess the ease of use and adoption of our application across five clinics/hospitals (two rural, three urban). All interviews were semi-structured, lasting about 30 minutes.

We analyzed this data in multiple passes (Elliott & Timulak, 2005), with the aim of extracting experiences that were compatible across projects and could inform future deployments. As we coded our data, we found that commonalities were hard to distill, especially given the widely disparate environments in which we had worked. A self-reflexive lens, however, was revelatory, since we as HCI4D researchers in the public health domain shared great similarities in our deployment objectives and the challenges we faced in meeting them.

These became the anchors for the discussion that follows. We deliberately attempt to refrain from speaking for our target audiences and focus instead on ourselves, with the intent of informing others in the research community who contend with similar challenges.

In deployments such as ours, success can be an ambiguous term. Defining success in terms of achieving goals that were imagined at the outset is difficult, particularly because unexpected consequences repeatedly arise, forcing constant revision of our goals. From our analysis and in line with Marsden's (2009) emphasis on long-term engagement, we arrived at *longevity* as a common measure of success for all three projects. We deconstruct longevity into the dimensions of *material durability,* or how long material limitations allow technologies to persist as deployed; *resulting organizational stability,* or how smoothly a new set of technological practices may be incorporated by the organizations in question; and *sustained community engagement,* or how engaged the community remains as the project continues. We then reflect on these dimensions in the context of our findings.

4.1 Material Durability

Our design process brought us to focus on low-cost, "workable" technologies appropriate—in varying degrees—to our deployment settings. Taylor, Cheverst, Wright, and Olivier (2013) draw attention to the iterative development of technologies so that the designers/researchers and the target users/communities can graduate toward a steady state, given the various limitations and challenges highlighted by real-world scenarios. This reinforces Irani et al.'s (2010) notion of design as a set of conversations that must take place over time so technologies are better adapted to target users' needs. A design must go through three stages to pass the durability test, extending beyond deployment. We discuss these stages below, based on lessons from our projects.

The *in-lab* stage of design came first, where we developed a proof of concept and identified partner organizations for our deployment. Although the smartphones that ODK Diagnostics used were not expensive, the need to use computer vision to analyze RDTs meant that the cheapest smartphones would not suffice. "Low-cost" does not imply inexpensive on an absolute scale; the cost must support the functionality to be provided. This can mean that, in some cases, the "appropriateness" of the technology comes under doubt. Similarly, pico projectors are expensive, but they are the least expensive among projecting devices and certainly more usable than the bulky car batteries and television sets used until recently in Digital Green (Gandhi et al., 2009). Research grants may have allowed the deployment of smartphones and projectors, but they were perceived as novel and expensive in their new environments and their safekeeping needed to be ensured. In an ODK Diagnostics field site, the devices were kept under lock and key. In Projecting Health, they were stored centrally, and ASHAs would borrow them from the central repository and return them after use. Kioni would leave her laptop at home because she felt unsafe carrying the laptop bag on public transport. These concerns are common in HCI4D research and have been widely documented (Anderson, Anderson, Borriello, & Pal, 2010). Workarounds must be developed to account for newness and to prevent theft and breakage, but they can only be agreed on in conversation with target users, not planned for beforehand. This is our second stage of design, or *in-field design,* wherein the technology must be appropriately situated based on inputs from the target population.

In this second stage, we organized training sessions so our target frontline workers were comfortable using our technologies so the use of these technologies could continue beyond our field presence. However, managing safekeeping concerns for shared resources made things doubly complex. Keeping the smartphones under lock and key meant that access was limited and their availability questionable. If the worker with the key was missing, other workers had to wait for his or her return. In one health center, the matron maintained a sign-up sheet to track the devices' use. ASHAs would often have to walk long distances to procure and return the projector. Kioni would create paper records at the clinic, transferring them to her laptop when she got home.

New technologies are attractive to use, charismatic even (Ames, 2015). However, with unfamiliar and varied uses, additional liabilities are introduced. Settings could be changed inadvertently, viruses could be introduced (disrupting workflows), and projectors could break or mysteriously stop working. When technologies are alien, their breakage and repair must have available workarounds. As Jackson, Pompe, and Krieshok discuss (2012),

these are more difficult to offer. For instance, the pico projectors, which are expensive to fix, await replacement with newer models once the project receives renewed funding. This brings us to the third stage of design conversations: "Is this a design we can scale?"

Without the purchase and maintenance of pico projectors and additional staff to manage their use, Projecting Health cannot be scaled. Mobile WaCH requires comparatively less financial investment, but keeping messaging low-cost for patients as in our deployment would result in a recurring monthly cost that the clinic may not be able to afford. Likewise, several ODK Diagnostics participants suggested that it would be better for each health worker to have his or her own device and carry it around the hospital (for safekeeping). This would substantially increase the number of devices and the cost of deploying the system.

Scaling the project would also entail the cost of supplying more technology and airtime. If we consider the durability of a project from the material or technological perspective, we must pay close attention to the delicate balance among cost, usability, workability, and "repairability." Then we must factor various stakeholder concerns in all three stages—in-lab, in-field, and designing for scale. We agree with Marsden that there are often insurmountable challenges in the path to at-scale deployment (Marsden, 2009), but it must, nevertheless, remain a key consideration. Though our projects did successfully get through the first two tests for material durability, each of them struggled with the third, designing for scale. Regardless, we outline these three tests as essential milestones to be traversed for deployments like ours.

4.2 Resulting Organizational Stability

The introduction of new technologies can lead to changes that impact the stability of an organization in various ways. New workflows are incorporated, some more streamlined than others; workplace relationships are introduced or reconfigured, possibly with new power dynamics to address; workers gain digital and domain expertise, only some of which may ease their workload. Here, we look at three levels of concern within the organizational unit. First, we examine the frontline workers and their relationship with their own work, whether they are more or less burdened and whether they have the expertise and confidence to fulfill their duties. Our second concern is the impact on relationships among coworkers and how these may be reconfigured. Finally, we have relationships across hierarchies, where power dynamics may be affected. We now discuss these relationships in the contexts of our projects.

Although Kioni's patient interactions were independent of the clinic's operations, her focus was on motivating more women to visit the clinic since this was where the care was to be provided. Her new work responsibilities required her to establish appropriate boundaries. The increased workload of communicating with so many patients personally could threaten the stability of the deployment, especially if the competition to participate continued to grow. One bribe attempt was a fond memory, but as more people recognized the value of the services Kioni provided, the pressure on her could become harder to manage. Although the technology was interpreted as giving greater authority and responsibility to the nurse, it also caused an organizational realignment that was helpful in ways, but introduced new burdens, also evident in the case of ODK Diagnostics. Bandwidth was a challenge in rural Zimbabwe, and health workers had to travel a long distance to upload their data. This placed additional pressure on the workers beyond their earlier workflows. In addition, introducing new technologies for "effectiveness" and "efficiency" becomes more complex when compared across the long and short terms. For example, in the long run the nurses in Mobile WaCH and ODK Diagnostics might have secured a more streamlined workflow, but in the short run they found themselves doing both paper and digital reporting. Thus, in the hope of finding a long-term solution, short-term stability was compromised when the health workers' workloads and workflows became unexpectedly overburdened. A final consequence of our deployments on health workers' practices, particularly in the case of the ASHAs in Projecting Health, was improved domain expertise and increased confidence.

We turn our attention now to the power relations that Irani et al.'s lens of postcolonial computing (2010) foregrounds for HCI4D settings among coworkers as well as across workplace hierarchies. In ODK Diagnostics, the reconfigured relationship between the nurses and the lab technicians that we presented earlier highlights the change in power dynamics. In Projecting Health and Mobile WaCH, we know that the ASHAs and Kioni were the target users of our deployments. However, it is possible that their privileged access to new

technologies, such as those we introduced, created an imbalance in their relationships with other frontline health workers or would do so over time.

Looking across hierarchies, in ODK Diagnostics the key role played by the MoH officials meant they were eager to receive the data entered into the smartphones by the nurses. This implied that the nurses' activity was newly subject to scrutiny by the MoH, which had not previously been the case. Although we intended that our design would enhance the nurses' workflows, it is unlikely they would have desired this extra, forced accountability. Were we to give them a voice circumventing the authority of the MoH, it is unlikely they would have supported the data reporting. The Projecting Health CAB was instituted precisely to factor in power differentials among the community actors. CAB meetings offer a venue for representatives from different groups to voice their ideas and suggestions. This kind of structure aims to address the questions of participation that Irani et al. (2010) raise as they highlight the need for considering what different individuals across hierarchies bring to the table. Creating this venue does not imply that power differentials are erased. Nor are all community needs necessarily voiced and addressed. However, the meetings do offer a venue for participation that did not exist before, giving ASHAs and other frontline workers a forum to ask questions and possibly benefit from the presence of other CAB members.

4.3 Sustained Community Engagement

Marsden et al. (2008) proposed "communitization" of software as a goal for developing world contexts, suggesting that we design for a community of users, not individuals alone. Our work similarly targets the community, where individuals are users to varying degrees and in varying capacities, borrowing Rode's (2011) view of users from "proximate" and "distal" perspectives. We now discuss how our projects aimed to activate and sustain the engagement of their respective communities by building on existing community skills, trust, and community ties (or not). This topic has been the focus of recent HCI research. For example, Bidwell et al. (2013) discuss how existing community practices and perspectives affect the long-term sustainability of projects, while Taylor et al. (2013) offer a set of guidelines for researchers involved in long-term community-based deployments, suggesting better, more ethical ways to conclude deployments than to leave once a Ph.D. is completed or funding runs out. Among other things, they propose that researchers prioritize managing stakeholder expectations, use low-cost parts when possible, work on building community skills, and plan in advance for handing over the project to the community.

Projecting Health set up video production teams in which the role of the camera operator was given to a theater artist in one case and a wedding photographer in another. Although no one in these villages had created videos before, finding skills that were close enough to be appropriated allowed the project to start local and stay local. Similarly, the lab technicians in ODK Diagnostics were able to help with the deployment because they were adept at dealing with technology in their workplaces. Building on existing skills—both domain-related and technology-related—draws on and adapts local resources that are easier to procure and manage. This also makes it more likely for the project to operate in the absence of external facilitators.

Expertise is correlated with trust. Understanding existing trust patterns is useful for sustaining engagement around a project. For example, technology without human interaction could potentially impact the receptivity to automated system messages. The women in Mobile WaCH were willing to participate because they trusted Kioni to provide information of value to them. Mobile WaCH automates certain tasks (e.g., sending standardized reminders), creating a mechanism for Kioni to personally respond to the mothers needing specialized attention. This hybrid approach capitalizes on the trust that mothers have in a nurse's advice (otherwise hard to access). The Zimbabwean MoH officials wanted to include community health workers in their deployment but targeted nurses instead because they had more trust in the nurses' abilities to read RDTs while the new system was being tested. Their plan was to use their trust in the nurses to build trust in the system, then use it to feed their trust in lower-level health workers' use of this system in the future. In Projecting Health as well, new elements were injected into an existing and trusted state health system.

This brings us to the importance of leveraging community ties and relationships. Mobile WaCH and Projecting Health did not explicitly target the participation of husbands, but we found the husbands wished to be kept informed. Given existing patriarchal structures, as we observed, women in these settings are often reliant

on their male family members (or mothers-in-law) for access to mobile phones. We recognized the need to additionally target household members to ensure they did not oppose the pregnant women's participation. Moreover, as previously mentioned, the ASHAs regularly took the initiative to conduct "unofficial" disseminations in the homes of women whose in-laws were too conservative to let them attend outside disseminations. A few men also got involved in these viewings, which gradually helped in reaching a larger audience beyond the mothers. Projecting Health's CAB example additionally demonstrates how drawing on community expertise can help to operationalize a project in a variety of ways.

Building on existing skills, trust patterns, and ties has received considerable attention in Projecting Health. This was less so in Mobile WaCH, and even less in ODK Diagnostics, directly correlating to levels of community engagement. However, here the intended duration of the deployment also plays a role. Community engagement was not prioritized in ODK Diagnostics because the deployment was intended to last eight weeks, with plans to begin a longer pilot if this deployment proved successful. Greater community engagement would have made it more challenging to end the deployment and leave. Thus, although we identify longevity as a shared objective among the researchers, this could be complicated by other factors such as the availability of research/donor funding or the state's willingness to continue the program. When we do leave, we must embrace the complications that arise with "leaving the wild" (Taylor et al., 2013). For instance, could the projector screenings continue if funding for Projecting Health were to run out? Could the CAB continue its meetings (since it was a purely volunteer-based set-up) and new videos still be created? Would the nurses and lab technicians in the case of ODK Diagnostics revert to their earlier relationship once the deployment was over and the smartphones were removed? Would patients continue to interact with Kioni if their SMSs were not subsidized by Mobile WaCH? We stress the importance of considering the deployment's lifecycle to its conclusion and beyond.

5. Conclusion

With the migration of HCI into resource-constrained settings across the world, there is a need to invest greater time and attention in understanding the disparate contexts in which deployments must take place. Irani et al.'s (2010) lens of postcolonial computing deconstructs this process into engaging the target users in conversation, articulating user needs, and translating these needs into technologies. By offering our in-depth analysis of three HCI4D projects, we deconstructed the process of deployment of these technologies, outlining key considerations for the design of such similarly situated deployments in the future.

In this article, we presented three mHealth deployments in India, Kenya, and Zimbabwe, where we introduced technologies for health workers in understaffed and overstrained work environments to improve the allocation of their time and skills. We provided case studies of our deployments, organizing these to highlight (1) how we situated the technology, (2) how the workplace relationships were reconfigured as a result, and (3) how the project grew organically beyond its intended scope. These cases enabled us to conduct an in-depth, reflexive analysis of these varied deployments and arrive at a set of criteria for evaluating success. We defined this success in terms of *longevity,* identifying it as a common design goal of our projects, and discussed how it was negotiated—consciously or inadvertently—at the level of the technology used, the organization, and the community. First, for *durability* of the technology we identified three iterations of design that play a critical role: in-lab design, in-field design with the target population, and design-for-scale. Next, for *resulting organizational stability* we stressed that consideration be given to the resulting relationships between the worker and his or her own work, among coworkers, and across several levels of hierarchy. Finally, for *sustained community engagement* we discussed the importance given by each project to building the skills present in the community, existing trust patterns, and ties among community members. ■

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