

# The Midwife's Assistant: Designing Integrated Learning Tools to Scaffold Ultrasound Practice

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## ABSTRACT

Ultrasound imaging is an effective tool for identifying maternal mortality risk factors. However, the high cost of ultrasound devices and the scarcity of ultrasound training are two major barriers to adoption in the developing world; complicated and expensive medical technologies are unlikely to meet the needs of users with limited opportunities for formal training and continuing education. To address these particular barriers, we have designed an inexpensive ultrasound system composed of off-the-shelf hardware and custom software. Our system is designed for use by rural midwives—often central medical figures in resource-constrained communities. This paper presents our work integrating help and tutorial software into the ultrasound system we developed. Our goal is to supplement a midwife's conceptual and operational knowledge of diagnostic ultrasound through appropriate and adaptive scaffolding. The design of our help system is informed by interviews with sonographers and radiologists in the United States and Uganda, and data collected during two fieldwork visits to Uganda. Through our fieldwork and preliminary evaluations, we have found that in addition to in-context reference material accessible during an exam, midwives need in-depth learning materials that can be accessed outside of a medical exam scenario.

## Categories and Subject Descriptors

H.5.m [Information Interfaces and Presentation (e.g., HCI)]: Miscellaneous

## General Terms

Design, Human Factors, Human-Computer Interaction

## Keywords

Maternal mortality, ICTD, ultrasound, medical device design, midwives, HCI, mobile diagnostic devices, learning software

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## 1. INTRODUCTION

A woman in a developing region is over 35 times more likely to die due to maternal complications than a woman in an industrialized country. The maternal death rate is even higher in sub-Saharan Africa, where women have an estimated lifetime maternal death risk of 1 in 31 [45]. Ultrasound, a common imaging modality used for maternal care in the developed world, is a safe and effective means of identifying pregnancy complications. Although ultrasound has proven to be diagnostically useful, it is rarely available in developing regions both because of device costs and the amount of training required to effectively identify pregnancy complications.

To assess whether introducing ultrasound screening into prenatal exams can contribute to a reduction in maternal mortality rates, we are participating in a University of Washington Department of Radiology ultrasound pilot project in Uganda that tracks a variety of outcomes, including 1) whether mothers return to healthcare facilities for follow-up care, and 2) whether midwives can accurately detect pregnancy complications. Pregnancy complications targeted by this project include placenta previa, multiple gestation, and breech presentation—all of which can contribute to obstructed labor or hemorrhage. Once high-risk pregnancies are identified, mothers can be referred to healthcare facilities for appropriate follow-up care. Midwives in the pilot study are trained in partnership with the Ernest Cook Ultrasound Research & Training Institute (ECUREI), located in Kampala, Uganda's capital city. Currently, midwives are being trained to perform exams with a GE LOGIQ Book XP ultrasound machine, which costs around USD20000. Our role in this larger project is to design a simplified ultrasound system that is more appropriate for village midwives—the critical link between rural healthcare centers and more advanced treatment facilities. By increasing the effectiveness of prenatal screening, we hope to see an increase in appropriate referrals to facilities where pregnancy complications can be best treated before they become potentially fatal.

Over the past two years, our team has been involved in an ongoing process to design an ultrasound system for rural midwives (called Ultrasound PLUS: Portable, Learning- and User-Centered System). Our initial design focus was to create a simplified user interface (UI) and a streamlined workflow to decrease the costs of training. In our previous work [3], we described our efforts to design and build this system, and we demonstrated that our low-cost solution was viable for specific

diagnostic uses. In that work, cost savings for the hardware was achieved by using a modular design approach; instead of designing an all-in-one system, we combined an Interson SeeMore USB probe with a low-cost netbook and custom, simplified, open-source software.

We conducted a variety of inquiry to inform the initial system design, including usability tests with local sonography students and midwives, feasibility tests in local hospitals, interviews with referring physicians, radiologists, and sonographers, and workplace observations at radiology departments in area hospitals. Interviews with U.S.-based sonographers and radiologists were also conducted to better understand the unique educational challenges presented by diagnostic ultrasound [3, 22]. To evaluate and improve the Ultrasound PLUS system, we conducted interviews and usability studies with midwives in Uganda in March and July of 2011, which will be discussed in this paper. In our interviews with midwives, we were particularly interested in the work environment of rural medical professionals, so that we could tailor our system to match the realities of their work practices. In order to investigate the contextual appropriateness of our help system, we also conducted a variety of other research activities in Uganda (e.g. focus groups with rural mothers) aimed at understanding the role ultrasound might play in the existing prenatal care system.

Findings from our fieldwork visits to Uganda suggested that complicated medical technologies are unlikely to meet the needs of users with limited opportunities for training and continuing education. These findings indicated a need for complex medical systems deployed in the developing world to incorporate education and training materials into the device itself to compensate for a likely missing training and education ecosystem. To this end, we have concentrated our efforts on designing an integrated help system that includes both in-context help and integrated, in-depth materials for continuing education. In this paper, we present our efforts to design and integrate a help system, called the ‘Midwife’s Assistant’ into our ultrasound scanning software. This goal of this system is to supplement a midwife’s conceptual and operational knowledge of diagnostic ultrasound through appropriate and adaptive scaffolding, which, we argue, can reduce the training costs required for obstetric ultrasound. Improving medical resources for frontline providers is important in underserved regions where trained physicians are scarce. In Uganda, there are only 12 physicians per 100,000 people, meaning that many healthcare decisions will be made by midwives and other frontline healthcare providers; tools that scaffold a provider’s medical decision making capabilities can lead to improved patient care [44]. We acknowledge that ultrasound as a technology can be problematic due to issues like feticide, but a detailed consideration of these issues is outside the scope of this paper.

## 2. BACKGROUND

The domain of technology-enhanced learning is a broad one, but most relevant for our work are explorations conducted by a variety of projects concerned with rural education, in-context help systems, and educational scaffolding. These projects illuminate both technical factors important to consider when planning help system functionality, and sociotechnical factors that may influence technology adoption and educational outcomes.

### 2.1 Education in Rural Environments

Several projects have looked at addressing the problem of education in rural environments. The Digital Green project [14]

disseminates agricultural information by having rural farmers view digital video created with the help of local farmers and mediated by a human mediator. Literacy Bridge’s Talking Book project [36] has designed an affordable, durable, audio device specifically for people who cannot read and who live without electricity. The battery-powered device can be used to distribute content in audio form on any topic (agriculture, health, education) in local languages and dialects. Chu et al. [6] gives a taxonomy of featherweight multimedia devices for disseminating information to illiterate and semi-literate people and describes experiences deploying such devices in the agriculture and healthcare domains.

Several projects have looked specifically at the problem of distributing information related to maternal health. Ramachandran [34] employed short videos on mobile phones designed to persuade village women in India to adopt new health practices. The work showed videos had positive effects on health worker motivation and learning. In Ghana, the MoTeCH project [29] is developing a suite of services delivered over basic mobile phones to provide relevant health information to pregnant women and encourage them to seek prenatal care from local facilities. These projects show promise in the adoption and adaptation of technology to fit in rural education contexts.

## 2.2 Help Systems

### 2.2.1 Electronic Help Systems

Traditional models of electronic help systems include online help text documentation, knowledge-based help, tutorials, and other similar text-heavy applications [7, 13, 18, 40]. Multiple studies have shown that traditional help systems are not generally used in practice. Users sometimes do not know help functionality exists or tend to use trial and error instead because they do not want to read help text. Traditional help is also disliked because it takes the user out of the current application and into a separate help system [2, 31]. In contrast, *embedded help systems*, where help is accessed side by side as part of the main application, allow a help system to be less intrusive and yet show a more obvious context of use [11, 17, 30]. *Adaptive or intelligent help systems* show content adapted to suit only the current needs of the user [35, 37]. One way to implement intelligent help is to introduce scenario-based logic to guide help-seekers to complete goals using limited step-by-step human-computer interaction (e.g. [5]). Selecting the appropriate type of help system to implement can depend on a myriad of factors, including context of use, available infrastructure, and user characteristics.

### 2.2.2 Medical Help Systems

Basic help systems are included in many medical devices. One example is the GE LOGIQ Book XP, a portable ultrasound machine designed for expert use. Designers of this device have presupposed formalized knowledge of ultrasound; the help system is obviously not designed to support novice users who are learning how to perform an ultrasound exam. When a technician selects the “Help” button on the LOGIQ Book, she is taken completely out of the exam process to an external help system displayed in a web browser, regardless of the type of help that is needed. This help system is disruptive to users because it forces users to stop the exam in progress in order to access information. Instructions on how to optimize image quality, for example, are presented in a web-browser that is detached from the exam process where it might ultimately be most useful.

Other systems integrate help more fully with the application in question. For example, the HELP (Health Evaluation through Logical Processing) system is an integrated hospital patient record

tool, which monitors patient information such as lab results and drug regimen in real-time and automatically notifies clinicians of potential problems and makes suggestions for therapy [10, 15, 12]. The ADNEXPERT system helps specialists diagnose and classify suspected ovarian tumors based on 15 questions about the ultrasound image [4]. These tools help experts automate their decision process rather than provide consultation references for lightly trained healthcare workers.

### 2.2.3 Medical Help Systems in the Developing World

With the shortage of human experts in the developing world, the implementation and use of expert guided help systems would serve health care well in those areas [20]. Help system content is usually designed for use by a clinician in the developed world who is assumed to have prior knowledge of skills, procedures and terminology [21]. However, in the developing world, users are typically less skilled in clinical observation, less knowledgeable about medicine, and have fewer tests available to them [20]. They also have less access to continuing professional development activities or extensive local professional communities.

Expert help systems patterned from successful implementations in developed world hospitals have not always been successful when adapted for the developing world. For example, the ESTROPID project was designed to provide decision aid and diagnostic support in primary health clinics in tropical Africa [9]. However, the ESTROPID knowledge base was drawn directly from existing hospital protocols used by skilled health workers in the developed world, resulting in a mismatch between the user's skill level and the system content [8]. ESTROPID illustrates the importance of assessing the user's prior knowledge (novice versus expert) as it changes the type of help most effective for the user.

In contrast, researchers at University of Edinburgh took into account the user's level of knowledge and context of use when designing their system for nurses in Zimbabwe, by using the Zimbabwean nursing training manual and drug list as a guide for content [21]. Help for related procedures are also provided in their prototype, which supplements the health worker's known skills. In designing our ultrasound help system, we adopted a similar strategy in tailoring the content intentionally for midwives, using material familiar to them from their training.

## 2.3 Instructional Scaffolding

Instructional scaffolding refers to the process by which experts (or embodied expertise) support novice users as they learn complex material; support, or scaffolding, is generally provided until no longer needed. Scaffolding in technology-enhanced learning environments can support different kinds of learning, such as facilitating routine tasks, providing unique representations for conceptual information, or motivating learners to explore new material. Designers must consider factors such as the learner's level of expertise, target tasks or learning goals, available resources, etc. in order to choose appropriate scaffolding elements to effectively support the learners' needs [38].

Research on software-based instructional scaffolding suggests a variety of guidelines and strategies that can be used to inform the design of scaffolding frameworks for science content [33]. These guidelines address the needs of learners in three components of scientific learning: sense-making, process management, and articulation and reflection. Sense-making is the core of learning, where learners acquire domain-specific knowledge and develop intuition and strategies in order to become more expert in the subject matter. Process management enables the learner to

determine necessary actions and control the tools they have at hand in order to create a meaningful interpretation of available data. Articulation and reflection improves the learner's overall understanding of the subject and promotes lifelong learning.

Many artifacts exemplify scaffolding applied to medical education software, including simulation-based software (e.g. [24] and [39]) and online training modules (e.g. [43]). In our project we build upon such scaffolding guidelines to create a medical help system for ultrasound.

## 2.4 Informal Learning in Work Contexts

Ultrasound is widely used in developed world contexts, but almost exclusively that means facilities with multiple practitioners, technology-centric work practices, and multiple communication tools. Referring physicians routinely consult with radiologists about medical imaging results to make decisions about patient care. In prior work, we investigated how radiology residents in the U.S. learn to interpret medical images. This learning takes place primarily in the workplace, and is supported by the teaching relationship between radiology residents and co-located attending radiologists, with whom they can review studies and ask questions easily and in-person [22].

Having co-located colleagues, and/or a suite of reliable communication and information technologies, means that consultation and continuing education is a well-supported and fairly routine activity. For remote practitioners in rural settings, however, learning from colleagues—or having an expert review one's work, as in the case of attending radiologists and residents—can be a difficult endeavor. Healthcare systems in rural settings employ a tiered structure, where lower level clinics can be located in remote areas, leaving healthcare workers there with no readily available expert resource. There is a need to provide solutions for mediating communication gaps within healthcare systems in developing areas, and several researchers are working in this area. [25] and [26], for example, describe their work in Ghana to facilitate expert consultation in remote working environments, deploying both synchronous and asynchronous communication tools.

## 3. DESIGN APPROACH

Midwives often work in remote villages far from ultrasound experts and have limited opportunities for continuing education. Therefore, we have concentrated our continuing work on developing a robust help system that can approximate the guidance and expertise of a skilled radiologist. Our goal is to support the work practices and autonomy of midwives by providing them with integrated tools to learn how to acquire, optimize, and interpret ultrasound images. In this section, we will briefly describe challenges specific to understanding ultrasound, and also describe various design choices we have made to mitigate these challenges. Section 4 describes the initial fieldwork we have done to investigate the contextual and educational appropriateness of our first prototype.

### 3.1 Understanding Ultrasound

Our work with both U.S.-based sonographers and novice midwife sonographers in Uganda suggests that conducting ultrasound exams and interpreting ultrasound images requires considerable expertise. In the United States, for example, practitioners often participate in training programs that last two years or more [41]. Effective diagnostic ultrasound requires a detailed understanding of human anatomy, pathology, and medical imaging, and sonographers must be able to discern anatomic abnormalities

strictly from images in order to refer patients appropriately. For example, to diagnose placenta previa—a complication in which the placenta covers the cervix—a sonographer must be able to recognize both the placenta and the cervix, determine the spatial orientation of the image, and then estimate their proximity to one another.

In addition to requiring extensive anatomy and pathology knowledge, understanding ultrasound requires operational knowledge of physics and planes of imaging. Ultrasound physics helps learners make sense of what they are looking at. For example, learning about attenuation (a loss of energy as sound waves travel through a particular medium) can help sonographers understand why an image may have a certain appearance as it passes through different tissues. Understanding planes of imaging (transverse, sagittal, and coronal) affects how a sonographer will position the probe on the patient’s body. Sonographers must learn to translate 2-dimensional images of anatomical structures taken on each plane into a 3-dimensional interpretation.

Lastly, ultrasound requires the combination of these conceptual skills with information technology and communication skills. For example, practitioners must learn knobology (how various kinds of controls afford functionality in a particular ultrasound device) in order to acquire and optimize ultrasound images. Strong communication skills are also necessary because ultrasound is an active imaging procedure. Unlike X-ray, for example, the patient can usually see the screen as the sonographer acquires images. Because of this, patients often ask questions about the images during the procedure, and a sonographer must learn to describe what she sees in a way that patients will understand.

## 3.2 Design Choices

Based on co-design work with U.S.-based sonographers and radiologists, initial field observations from members of our larger research team, and instructional scaffolding theory, we chose a design approach that emphasizes self-directed and adaptive learning. We found scaffolding, described in a section 2.3, a useful strategy for creating the help content, which needs to be tailored to learners of varying skill levels. Quintana et al.’s work on designing instructional software suggests three main learning components that benefit from scaffolding: 1) sense making, 2) process management, and 3) articulation and reflection [33]. We focus on 1) and 2) here, and mention 3) in the discussion section.

### 3.2.1 Scaffolding Sense Making

As discussed above, ultrasound practitioners must learn ultrasound physics, anatomy, and sonographic appearances of various structures. In order to facilitate sense making of ultrasound content and exam best practices, we employed a variety of scaffolding strategies suggested by [33], such as *using semantics of the discipline* and *embedding expert guidance*.

Shared vocabulary is an important component of both learning and participating in a disciplinary community. During our observation of novice ultrasound classes at ECUREI in July 2011, we noticed a student attempting to describe to the instructor how the uterus appeared in an ultrasound image. The instructor—not certain what the student was referring to—reminded the student that she must “learn to talk like a sonographer now” if she wanted to be understood. In addition to facilitating learning and basic disciplinary communication, shared vocabulary is critical for diagnostic ultrasound referral networks to work. In our interviews with referring physicians, sonographers, and radiologists in the United States [22], multiple participants described how shared

medical vocabulary contributes to mutual understanding between practitioners, some of whom may only see small parts of the entire patient history. When all of the actors in a referral network can communicate and be understood by their colleagues, it is more likely that patients will receive appropriate treatment and care.

Our system *uses semantics of the discipline* by introducing sonographic and medical vocabulary to describe ultrasound content whenever possible. For example, if a midwife is browsing the list of topics, she will see “Anencephaly,” instead of “missing brain,” or another colloquial term for the complication. Although the description for the complication may include metaphors and colloquial terms in order to resonate with the learner, it is important for midwives to also see and use the appropriate medical vocabulary for each topic allowing them to communicate with other members of their larger community of practice [42]

*Embedding expert guidance* can mitigate some of the problems experienced by remote learners who cannot easily ask a professional for guidance. We have included many examples of ultrasound images taken by professionals—some taken with our system—and designed an interface to allow midwives to compare their scans with those of professionals (see Figure 1). Presenting learning materials in a variety of different media forms—all authored or created by experts—can deepen a user’s understanding of complex information.

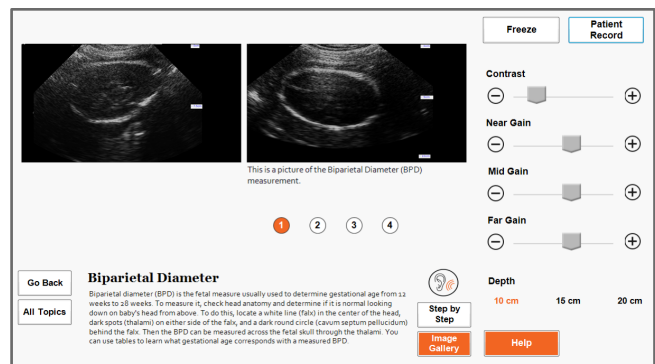
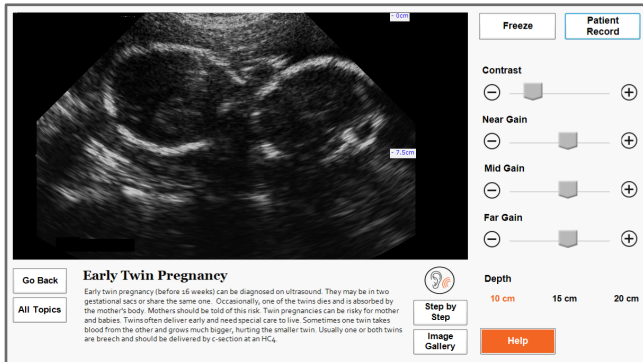


Figure 1: Midwife’s Assistant: Image Comparison Gallery

An example of a complex skill is learning how to best optimize an ultrasound image. One tool that can help optimize an ultrasound image is gain control, which compensates for attenuation as sound waves penetrate the body and, when correctly applied, makes an image more readable. Conceptually, gain can be described by graphical or textual representations of principles of ultrasound physics. The complementary skill of learning how and when to adjust gain, however, may be better supported by comparison graphics and on-screen pointers to the interface controls associated with this process. All of these media types support conceptual and operational knowledge of gain (what it is, when to use it, and how to use it) and deepen the user’s overall understanding of the topic.

In our system, we scaffold not just for sense making and content understanding, but also to mitigate learning challenges faced by low-literacy users. Although the midwives we interviewed in Uganda are literate (in English, an official language in Uganda), proficiency with dense, English-language materials about complicated medical topics was limited. By presenting content in multiple formats—such as text, images, and videos—we aim to support both the learning preferences and needs of low-literacy users. Other researchers have shown that videos are an effective

tool to describe technology to low and non-literate users [28]. Additionally, we have chosen to include speak-aloud audio descriptions (see round ear icon in Figure 2), which supports users with limited reading abilities and also affords us the opportunity to adapt information to local dialects should we expand our deployment to regions in which English is not an official language. On our most recent trip to Uganda, we recorded descriptions for each topic with a local voice actor.



**Figure 2: Topic Description, showing Speak-Aloud Function**

All of the text in our interface and help system can be easily switched out for text in a different language, and users will be able to set language preferences within their user accounts. Of course, localization is complex and not simply contingent upon switching out languages; future localization efforts will involve an appropriate design review.

### 3.2.2 Scaffolding Process Management

As described in section 3.1, ultrasound requires an intricate coupling of both anatomical knowledge and technical expertise. Novice users can quickly become overwhelmed with the process of conducting an ultrasound examination. In order to support process management, we employed a variety of scaffolding strategies suggested by [33], such as *automatically handling non-salient, routine tasks* and *constraining the space of activities by including functional modes*.

With the recognition that process management requires the user to perform and connect discrete tasks to complete a useful diagnostic exam, our efforts to scaffold process management reside both within and outside of the confines of the help system proper. We leveraged ways that existing commercial ultrasound systems *handle non-salient, routine tasks* outside of the help system by creating a streamlined the patient record system. The system was maximized for efficiency based on the keyboarding skills of users who do not interact with computers on a regular basis. The patient record system is quickly accessible from the scanning screen and aggregates information from the exam, such as photos and measurements. Sonographers often take measurements of fetal anatomical structures to calculate the ultrasound age of a fetus. This ultrasound age can help midwives estimate when a mother will give birth. Our system is consistent with commercial machines in that it calculates the ultrasound age from the measurements a midwife takes and saves this information automatically to the patient record.

*Constraining the space of activities by including functional modes* can help prevent learners from getting overwhelmed with complex topics and processes. In our system, midwives can only view one topic description at a time in the bottom bar of the window while

conducting an exam (see Figure 2). If a midwife wishes to compare her current image with images in the “Image Gallery,” she will only be presented with a subset of images that are relevant to her current inquiry (determined by her choice of topic), instead of being presented with all of the images in the Image Gallery (see Figure 1).

In addition to scaffolding sense making, as described in the previous section, embedding expert guidance can help scaffold process management. To simulate expert guidance, we implemented a decision tree based on best practices in diagnostic ultrasound. In order to develop expert content, our team collaborated with Seattle-area physicians, sonographers, and radiologists with experience in rural medicine and international public health. The decision tree supports users who need more information about a particular topic but may not know specifically what they are looking for. Some users will have broad questions with many answers (e.g. “Why can’t I detect breech presentation?”) and some may be looking for step-by-step reminders of the process of taking a particular measurement. The decision tree helps users refine broad questions by asking them more specific questions and giving them hints about how to narrow their focus to find questions with specific answers. For quick reminders of linear processes, we have implemented a “Step-by-Step” feature, which can walk learners through the process of taking a specific measurement, or identifying a complication. The design for decision trees and step-by-step instruction delivery is preliminary, and future user studies in Uganda will address to what extent they help with in-context ultrasound problem solving.

## 4. FIELDWORK FINDINGS

The findings in this section are primarily drawn from fieldwork trips to Uganda in March and July 2011. In July of 2011, we interviewed 10 midwives involved in a sonography training program, two nursing and midwifery educators, five ultrasound instructors, a traditional birth attendant (TBA), a community health worker (CHW), and 59 rural mothers split across eight focus groups and seven individual interviews. We visited 15 health centers (a mix of public, private, and private-not-for-profit models) in three districts in Western & Central Uganda to understand the variance in infrastructure, services offered, and patient load. We also conducted an initial evaluation of our overall system (which includes the current version of the Midwife’s Assistant) with five midwives and one sonographer. Some of these fieldwork results appear in publications unrelated to the help system.

Ugandan ultrasound instructors participating in our study were recruited from ECUREI, an institute with whom members of our umbrella project have been collaborating to refine an ultrasound curriculum for midwives. Midwives were recruited from the network participating in the University of Washington Department of Radiology pilot ultrasound training project. Patients who participated in focus groups were approached as they waited for prenatal or other care at rural health clinics in the Isingiro District of Western Uganda. Their decision to participate in the study had no effect on the care they received. All participants were enrolled using standard informed consent procedures.

### 4.1 Rural Midwives’ Training & Experience with Ultrasound

The midwives we interviewed had between two and three years of formal midwifery training, in addition to six weeks of formal

instruction in ultrasound. In Uganda, there are multiple midwifery programs, though most of them fall into two categories: programs with a strict focus on midwifery, and nursing programs with some emphasis on midwifery [32]. Midwives who graduate from a public midwifery program are posted to serve a specific location upon graduation. Ultrasound training for midwives is uncommon in Uganda; although ultrasound may be mentioned in one of the general midwifery courses, the majority of midwives do not learn to conduct exams or interpret images. During our most recent fieldwork in Uganda, we observed three anatomy lectures given to novice midwife sonographers and two hands-on practical scanning sessions in which a group of eight midwives used an ultrasound machine for the first time. We also observed midwives providing patient care in six health clinics in Western Uganda. From these observations, we found that novice midwife sonographers face two major groups of challenges: those posed by ultrasound as a discipline, and those posed by a lack of access to continuing education resources.

Ultrasound requires the development of pattern recognition skills to reconcile one's knowledge of anatomy with typical sonographic appearances, which proved challenging for the novice midwife scanners we observed in Uganda. For example, after being shown an ultrasound image of the ovaries, one midwife asked, "Which part is the ovary? Which part is the fallopian tubes?" At this point, the instructor had to clarify that in the image, the fallopian tubes were much too small to be seen. In addition to pattern recognition skills, ultrasound requires familiarity with knobology, described in section 3.1. For several of the midwives we observed, who often have limited experience with electronic devices like computers, knobology was challenging. Learning how to use a trackball or sliders, for example, was a difficult but necessary part of their practical hands-on scanning sessions.

Not all midwives were satisfied with the education they received. One midwife we spoke with a year after her graduation from ECUREI, Namutebi, was particularly vocal about gaps she perceived in her education. Namutebi explained that during her ultrasound training program, students would receive lectures days in advance of the relevant hands-on training, and that they had often forgot everything from lecture by that time. We discovered that this wasn't just her experience: all of the hands-on lectures we witnessed at ECUREI were days after the relevant classroom lectures. As Namutebi examined the help system topics in our system, she mentioned, "Before I started I did not know anything about these [topics], but then I learned from examining patients."

Though many programs in Uganda require continuing education credits in order to retain certification, it is not clear to what extent these requirements are enforced or whether continuing education is even possible or effective for the majority of health care workers in this largely rural country. All midwives we interviewed expressed difficulties receiving continuing education because of the remote location and solitary nature of their practice. Transportation, especially in rural settings, can be extremely limited and midwives may not be able to afford to travel to educational facilities as often as continuing education programs require. Furthermore, traditional continuing education programs may be ineffective. One researcher reported, that continuing education programs in India are often led by largely disinterested instructors and may even be detrimental instead of helpful, since health care workers must take time off to attend these programs [34].

The remote practitioner scenario makes it challenging to consult colleagues when images are difficult to interpret or to stay abreast

of current best practices. In the Ruhira area, most midwives we interviewed said they only received continuing education through the local sonographer, via cellphone, when a problem arose. One midwife did attend a continuing education conference immediately before meeting with us, but this seemed an exception. The same midwife had occasional Internet access (when she traveled to a larger town an hour away) and would stay up to date on best practices by consulting her social network via e-mail.

## 4.2 Competing Responsibilities & Patient Education

In addition to using ultrasound to screen women for high-risk pregnancy conditions, all of the midwives we interviewed have many other responsibilities, including delivering babies, conducting patient education sessions and outreach activities, and providing other types of patient care (e.g. vaccination and AIDS management services). At the clinics we visited, the number of babies delivered per month ranged from 30 at the smallest clinic, to 150 at the largest clinic. Each clinic we visited employed between one and six midwives, though midwives are often absent for a variety of reasons, including illness or maternity leave. This often led to midwives remaining on duty for extended periods of time. For example, one midwife we talked to had been on duty for 20 hours prior to meeting with us. Not surprisingly, most of the midwives we interviewed cited under-staffing as a major barrier to providing high-quality, timely patient care.

Midwives play a crucial role in educating not only patients, but family members as well. Community education, called "community sensitization" by midwives, is a critical service that midwives provide. For example, though women are encouraged through public education programs to receive four prenatal care visits, one midwife said that very few patients knew this until she explicitly told them. Other community sensitization efforts include group information sessions mediated by recorded audio, visits to churches or other gathering places, home visits with community health workers (CHWs), and the hanging of informational posters in health center waiting areas. Many clinics encourage family members to attend prenatal care visits by offering educational material or other incentives; for example, several clinics have a policy that allows a woman who arrives with her husband to be seen before other women.

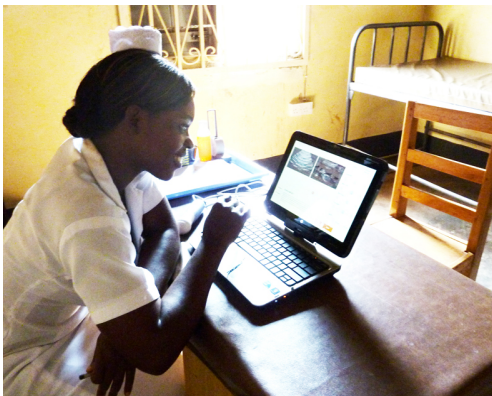
In our fieldwork we also learned how patients receive education from other sources as well, such as traditional birth attendants (TBAs). In Uganda, TBAs are still typically present at live births instead of midwives. Midwives differ from TBAs in that they have formal certifications and are overseen by the government. TBAs have no standardized training or oversight, but may have a great deal of practical birthing experience. TBAs often use traditional methods for detecting and managing pregnancy complications (e.g. palpating the stomach or prescribing herbal medicines), though some have begun embracing more modern medical practices. Recently, TBAs have come under much scrutiny by the Ugandan government and are currently illegal, though our interviews with midwives and mothers indicated that TBAs are still widely used. Several midwives expressed frustration about their relationship with TBAs, stating that they often had to combat misconceptions about the effectiveness of traditional practices. Though midwives are seen as authority figures, almost all of the midwives we talked to admitted that TBAs often have a personal relationship with the mothers that advanced healthcare providers cannot replicate.

Some professionals leverage the relationship between mothers and TBAs to provide indirect patient education. We talked to a TBA and a nurse at a referral hospital in the Kayunga region of Uganda who had a congenial relationship. This particular TBA rejected herbal remedies and referred high-risk patients to the nurse at the hospital, but still handled low-risk deliveries—as many as 50 a month. When mothers receive an ultrasound exam at the hospital in Kayunga, they often go back to this particular TBA with a sheet from the healthcare provider explaining what was found on the ultrasound exam. In this way, the healthcare provider can indirectly educate the patient through a trusted TBA.

### 4.3 Midwife Assessment of Prototype

The focus of our July 2011 fieldwork was to assess our approach and the initial design decisions that led to the first functional version of the Midwife’s Assistant (See Figure 3). Our assessment consisted of interviews with 10 midwives about our help system, among other topics, and six usability tests of our overall system. Usability tests were conducted with five midwives and one sonographer.

All ten of the midwives we interviewed were enthusiastic about the help system. One midwife asked if there was a way we could integrate the help system into the ultrasound machine she was currently using, citing the difficulty of consulting textbooks for reference while conducting an exam. Another novice scanner who we interviewed on her second day posted at a clinic claimed that a help system like ours would increase her ability to identify unusual complications or anomalies that, as a beginner, she had not seen before.



**Figure 3: Midwife in Ugandan clinic using Midwife’s Assistant**

Most of the features of the Midwife’s Assistant were well received. All midwives liked the idea of being able to hear the text as opposed to reading it—even those who did not think the feature would be personally useful. Midwives especially liked features that allowed quick comparisons (e.g. the “Image Gallery” feature). The decision tree, however, had mixed results; some midwives found it extremely useful and others said that they would likely not use the decision tree because it was too time-consuming.

A consistent theme during our initial assessment was the need for separation between in-context reference material, and in-depth learning material. One midwife expressed concerns about the time commitment involved in using an in-depth help system rather than just referring a difficult examination to the regional sonographer. She expressed a fear that mothers would lose faith in her if she spent a significant amount of time using the help system during an

exam, but did, however, want a resource she could investigate on her own time. Three other midwives expressed a similar desire to have access to broader information (including videos and information about anomalies) outside of an exam context. When using our help system, two midwives noted that the content would be more useful to their practice if it focused primarily on technique, as opposed to providing gross anatomical information.

Interestingly, none of the midwives we talked to regularly used the help system included with the GE LOGIQ Book XP, which is the device they currently use. One midwife noted the difficulty of navigating the GE help system, and also pointed out that the information contained in the GE help system was not broad enough to be useful as an educational tool. From our experiences interacting with these midwives, we hypothesize that midwives are interested in both embedded reference material and a computer-based, comprehensive educational tool, with each covering distinct knowledge domains.

We discovered a few relatively minor problems during our six usability tests as well. Pagination proved to be a confusing concept to most users, even after a brief tutorial and repeated demonstrations. Midwives seemed to think that if a topic was not on the currently displayed page, then it was not available at all. Though we tried to avoid an ethnocentric design, some of our content turned out to be culturally inappropriate. For example, we described one topic using a simile, saying that the image “looked like a sandstorm,” which we were later informed was an inappropriate choice because no one in that region would be familiar with sandstorms.

## 5. DISCUSSION

Findings from our fieldwork have led us to consider additional ways to address midwives’ educational challenges, how we can develop learning resources that match existing infrastructure such as limited Internet connectivity, and reflect on ways to improve our study design.

### 5.1 Educational Challenges

All midwives we interviewed desired continuing education, but were mostly isolated (both physically and digitally) from other healthcare professionals. Because the midwives have few opportunities for formal continued education and often work alone, the context in which they will learn to perform an ultrasound exam can be described as an open-ended learning environment [23], or an environment in which there is limited external direction and learning is dependent on the learner’s voluntary engagement. Other researchers developing technologies for resource-constrained environments found that help features made users more eager to explore the described system [27], which could provide motivation for independent learning, mitigating the challenge presented by limited external direction.

Based on the feedback we received from midwives, a separate module providing more in-depth information outside of the exam context (a “Virtual Textbook”) is something we intend to investigate as we move forward in our design. This proposed module would provide detailed anatomical and ultrasound information some of the midwives desired, including more information on anomalies and complications. By collaborating with radiologists and instructors of clinical ultrasound at the UW and at ECUREI in Uganda, we aim to identify the gaps in knowledge between developed and developing world prenatal medical education and develop more comprehensive content sections that address fundamental knowledge about maternal

health. A goal in designing this virtual textbook is to scaffold articulation and reflection, a key guideline of Quintana's framework [33] that we felt was inappropriate for in-context referencing. We envision that midwives would use this application outside the examination context when they have time for self-directed learning.

## 5.2 Connectivity, Teleradiology, & Distance Learning

Other projects have leveraged Internet connectivity to address some of the issues we found in our fieldwork, allowing midwives to both get advice from experts when needed and to extend their training. However, Internet connectivity was non-existent throughout the clinics we visited in Uganda, except for the Ruhira area that serves as the focal point for the Millennium Villages Project (MVP) in Uganda. GPRS modems provided some limited connectivity, though reliable cell service was often only available using multiple service providers. For example, many healthcare providers in the area carry multiple cell phones with different carriers in order to remain reachable. Recognizing that connectivity is either limited or prohibitively expensive, we have avoided both teleradiology and distance learning approaches.

Often in teleradiology, images are ordered by a referring clinician, taken by an ultrasound technician, and then sent to an off-site radiologist who interprets the images, suggests a diagnosis, and returns this information to the clinician. Projects such as *Imaging the World* [19] use remote radiologists to diagnose conditions. In our proposed scenario we scaffold remote practitioners to learn how to optimize, interpret, and act on the results of ultrasound images so they do not need to rely on Internet connectivity or outside assistance.

Some educational institutions have successfully adopted Internet-mediated distance learning programs, but in rural areas, Internet is commonly only available via cellular phones and pay-per-bit data plans, which makes continuous interactive training costly over time. Consequently, midwives in the field cannot currently leverage Internet-based medical expertise (e.g. chatting with a live expert or posting questions to a forum). We recognize that increasing Internet connectivity will likely make distance learning feasible in the future, however we believe that other models for continuing education can be implemented with similar effectiveness and more immediate availability. One of the results of the modular design of the Midwife's Assistant is that help system content can be easily updated or modified via a set of XML files that can be transferred via a USB drive (or perhaps eventually via the Internet). While this may not provide instant access to the latest materials, it is a flexible framework that can easily incorporate new material into a familiar learning environment.

## 5.3 Study Design

Through our evaluations and interviews, we also discovered several problems with our study design and evaluation technique. Some were high-level problems; for example, many of the Ugandan midwives we interviewed were not within our target audience—they had been scanning for over a year and had little need for an exam-based help system. Our study design lacked any method to assess continuing education learning, so the effectiveness of that content is an open question that needs to be addressed with a longer-term study. Evaluating educational outcomes can be challenging in classroom scenarios in the developed world. Evaluating learning outcomes in a medical context in the developing world is even more challenging. Not

only is it more difficult to evaluate midwives with a variety of educational backgrounds and experience, but designing such a study is challenging from an ethical perspective. As we conducted our prototype evaluations we were constantly aware of the preciousness of the midwives' time. Large groups of patients were always waiting outside the clinic to be seen and every time we asked midwives to do an evaluation of our system we were taking time away from clinical time.

In a similar vein, as with creating all medical technologies, iterative design is challenging. While in general with iterative design one would like to get a prototype of the system out into the field as early as possible for feedback, the bar for 'getting a system into the field' is significantly higher for a system to be deployed with real patients. When dealing with healthcare and possible medical decisions that affect patients, users appropriately expect a system free of bugs. However, this makes iterative design harder because of the higher bar for getting a prototype ready. In our case, even though scans with our system were repeated using the midwives' original GE devices, we needed to actively mitigate the risk that bugs in our system could affect midwives' diagnoses. All of these factors will be more carefully considered when designing our next study.

## 6. IMPLICATIONS & NEXT STEPS

Findings from our 2011 fieldwork have helped us recognize the limitations of our system. We have identified several next steps that must be taken to make our system more appropriate and useful to midwives. We plan to expand the capabilities of the help system in a number of dimensions:

*Expanded Audio and Video Content* – Our in-country usability testing confirmed the need to expand the text-free interface features of the system. We will continue to design culturally appropriate graphics, audio, and videos—allowing midwives to see or hear how to physically operate the tool without the help of a facilitator or text.

*In-Context Reference vs. Self-Directed Learning* – Our current system includes in-context reference material, but based on feedback from the midwives we interviewed, we recognize the need to develop supplementary tools that support self-directed learning outside an exam context. This proposed module (the 'Virtual Textbook') would provide detailed anatomical and ultrasound information, as well as more information about pathology. We propose including full-screen videos and tutorials, as well as tools to scaffold articulation of learning, reflection, and assessment.

*Adaptive Interfaces* - We plan to use artificial intelligence to modify the help system to display information appropriate to users depending on their level of understanding. We could also adapt the information displayed to be populated with content directly related to the current exam stage or help system content that was recently selected by the user. It is important for an in-context medical help system to provide information that relates to the current exam stage so that users do not spend excessive time seeking information and so the credibility of practitioners (who may just need to quickly access specific reference material) is not compromised in front of patients.

*Computer Vision Assistance* - We intend to explore how computer vision techniques could allow the system to automatically extract important information from the ultrasound image to aid midwives in identifying potential issues. Researchers have previously applied computer vision techniques to analyze ultrasound images

of breast nodules to determine whether malignant tumors were present [1], and other researchers are planning on simplifying ultrasound use through image analysis and other techniques [16]. We imagine our device suggesting locations of specific anatomical structures (for example, the placenta and cervix) and pointing out these structures to the user. In an ideal scenario, the user could supplement her knowledge about anatomy with the real-time suggestions of a computer vision application. The suggestions of the computer vision application could help scaffold new ultrasound practitioners with limited pattern recognition skills but could be disabled by experienced practitioners. As with any system that approximates diagnostic expertise, it will be important that midwives using the system are experienced enough to call into question the computer vision analysis when appropriate.

## 7. CONCLUSION

Maternal mortality is a major problem in the developing world and many pregnancy complications contributing to mortality could be identified with ultrasound. We have developed a low-cost and easy-to-use portable ultrasound platform for rural midwives that serves as both a diagnostic tool and a learning tool. To achieve this goal, we have designed a contextual help system that will both assist the user in navigating the interface and supplement the user's conceptual foundation of diagnostic ultrasound through appropriate scaffolding. Appropriate and adaptive scaffolding will allow midwives to continue learning after their formal training period, leading to better patient care and higher overall midwife and patient satisfaction when integrating ultrasound exams into the traditional prenatal exam process. We are currently working to incorporate computer vision to assist the user in recognizing anatomical structures, and researching ways in which we could adaptively modify the user interface in response to the user's changing educational needs. In the future, we hope that our device will be deployed to receptive developing regions at a low-cost, requiring minimal training to use.

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## 9. REFERENCES

[1] Alemán-Flores, M., Alemán-Flores, P., Álvarez-León, L., Fuentes-Pavón, R., and Santana-Montesdeoca, J. M. 2008. Computer Vision Techniques for Breast Tumor Ultrasound Analysis. *The Breast Journal*, 14, 483–486.

[2] Andrade, O. D., Bean, N., and Novick, D. G. 2009. The macro-structure of use of help. In *Proceedings of the 27th ACM international conference on Design of communication*. SIGDOC '09. ACM, New York, NY, USA, 143-150. DOI=<http://doi.acm.org/10.1145/1621995.1622022>.

[3] Brunette, W., Gerard, W. Hicks, M., Hope, A., Ishimitsu, M., Prasad, Anderson, R. E., Borriello, G., Kolko, B. E. & Nathan, R. 2010. Portable antenatal ultrasound platform for village midwives. In *Proceedings of the 1st Annual*

*Symposium on Computing for Development* (London, United Kingdom, December 17-18, 2010). ACM DEV '10.

[4] Brüning, J., Becker, R., Entezami, M., Loy, V., Vonk, R., Weitzel, H., and Tolxdorff, T. 1997. Knowledge-based system ADNEXPERT to assist the sonographic diagnosis of adnexal tumors. *Methods of Information in Medicine*. 36, 3 (Aug. 1997), 201-206.

[5] Callaghan, M. J., Harkin, J., McGinnity, T. M., Maguire, L. P. 2008. Intelligent User Support in Autonomous Remote Experimentation Environments. *IEEE Transactions on Industrial Electronics*. 55, 6 (Jun. 2008).

[6] Chu, G., Satpathy, S., Toyama, K., Gandhi, R., Balakrishnan, R., Menon, S. R. 2009. Featherweight Multimedia for Information Dissemination. In *Proceedings of International Conference on Information and Communication Technologies and Development* (Doha, Qatar, April 17-19, 2009), 337-347.

[7] Covi, L. M. and Ackerman, M. S. 1995. Such easy-to-use systems!: how organizations shape the design and use of online help systems. In *Proceedings of Conference on Organizational Computing Systems*. COCS '95. ACM, New York, NY, USA, 280-288.

[8] Doukidis, G., Cornford, T., Forster, D. 1994. Medical expert systems for developing countries: Evaluation in practice. *Expert Systems with Applications*. 7, 2 (Apr.-Jun. 1994), 221-233.

[9] Doukidis, G., Forster, D. 1990. The potential for computer-aided diagnosis of tropical diseases in developing countries: An expert system case study. *European Journal of Operational Research*. 49, 2 (Nov. 1990), 271-278.

[10] East, T. D., Morris, A. H., Wallace, C. J., Clemmer, T. P., Orme Jr., J. F., Weaver, L. K., Henderson, S., and Sittig, D. F. 1991. A strategy for development of computerized critical care decision support systems. *International Journal of Clinical Monitoring and Computing*. 8, 4, 263-269.

[11] Ellison, M. 2007. Embedded user assistance: the future for software help?. *Interactions*. 14, 1 (Jan. 2007), 30-31. DOI=<http://doi.acm.org/10.1145/1189976.1189997>.

[12] Evans R. S. 1991. The HELP system: a review of clinical applications in infectious diseases and antibiotic use. *M.D. computing: computers in medical practice*. 8, 5 (Sept.-Oct. 1991), 282-288.

[13] Fenchel, R. S. 1981. An integral approach to user assistance. *SIGSOC Bull.* 13, 2-3 (May 1981), 98-104. DOI=<http://doi.acm.org/10.1145/1015579.810969>.

[14] Gandhi, R., Veeraraghavan, R., Toyama, K., Ramprasad, V. 2009. Digital Green: Participatory Video for Agricultural Extension. *Information Technologies & International Development*. 5, 1 (Spring 2009), 1-15.

[15] Gardner, R. M., Maack, B. B., Evans, R. S., Huff, S. M. 1992. Computerized medical care: the HELP system at LDS Hospital. *Journal of American Health Information Management Association*. 63, 6 (Jun. 1992), 68-78.

[16] GE Global Research. 2011. GE, MIT Collaborate on Smart Ultrasound Technology Development. *GE News Press Releases*. (May 24, 2011). Retrieved July 21, 2011. <http://www.genewscenter.com/content/detail.aspx?releaseid=12507&newsareaid=2>.

[17] Grayling, T. 2002. If We Build It, Will They Come? A Usability Test of Two Browser-Based Embedded Help Systems. *Technical Communication*. 49, 2.

[18] Houghton Jr., R. C. 1984. Online help systems: a conspectus. *Commun. ACM* 27, 2 (Feb. 1984), 126-133. DOI=<http://doi.acm.org/10.1145/69610.357985>.

- [19] Imaging the World. *About, Imaging the World*. Retrieved October 2010. <http://imagingtheworld.org/about>.
- [20] Kahen, G., Sayers, B. McA. 1997. Health-care technology transfer: expert and information systems for developing countries. *Methods of Information in Medicine*. 36, 2 (Feb. 1997), 69-78.
- [21] King, K., Carstairs, M. 1997. Supporting multi-level medical education with knowledge-based systems. *Methods of Information in Medicine*. 36, 2 (Feb. 1997), 201-206.
- [22] Kolko, B., Hope, A., Gerard, W., Brunette, W. Saville, K. & Nathan, R. 2012. Adapting Collaborative Radiological Practice to Low Resource Environments. In *Proceedings of Computer-Supported Cooperative Work 2012*(Seattle, USA, February 11-15, 2012). CSCW '12.
- [23] Land, S. 2000. Cognitive requirements for learning with open-ended learning environments. *Educational Technology Research and Development*. 48, 3, 61-78.
- [24] Laerdal Medical Corporation. 2009. Virtual Phlebotomy. [http://www.laerdal.com/binaries/AFGGINTC/4757\\_VirtualPhlebotomy\\_SS.pdf](http://www.laerdal.com/binaries/AFGGINTC/4757_VirtualPhlebotomy_SS.pdf).
- [25] Luk, R., Ho, M., and Aoki, P. M. 2008. Asynchronous Remote Medical Consultation for Ghana. In *Proceedings of ACM SIGCHI Conference on Human Factors in Computing Systems*. (April 2008). CHI '08.
- [26] Luk, R., Zaharia, M., Ho, M., Levine, B., and Aoki, P. M. 2009. ICTD for Healthcare in Ghana: Two Parallel Case Studies. In *Proceedings of Information, Communications Technology, and Development 2009* (Doha, Qatar, April 18-19, 2009). ICTD '09.
- [27] Medhi, I., Sagar, A. and Toyama K. 2006. Text-Free User Interfaces for Illiterate and Semi-Literate Users. In *Proceedings of IEEE/ACM International Conference on Information and Communication Technologies and Development* (Berkeley, USA, 2006).
- [28] Medhi, I., Toyama, K. 2007. Full-context videos for first-time, non-literate PC users. In *IEEE/ACM International Conference on Information and Communication Technologies and Development* (Bangalore, India, 2007).
- [29] Mobile Technology for Community Health (MoTeCH). Retrieved July 2011. <http://www.grameenfoundation.applab.org/section/ghana-health-worker-project>.
- [30] Mobley, K., Deloach, S. 2003. Embedded Help: An Overview of This Special Section. *Technical Communication*. 50, 1 (Feb. 2003), 11.
- [31] Novick, D. G., Andrade, O. D., and Bean, N. 2009. The micro-structure of use of help. In *Proceedings of the 27th ACM international conference on Design of communication*. SIGDOC '09. ACM, New York, NY, USA, 97-104. DOI=<http://doi.acm.org/10.1145/1621995.1622014>.
- [32] Orach, C. G., Nabiwemba, E., Akello, B., Kibira, S. P. S., and Onama, V. 2009. Assessment of Midwifery Training, Service and Practice in UGANDA. Makerere University School of Public Health (July 2009).
- [33] Quintana, C., Reiser, B.J., Davis, E.A., Krajcik, J., Fretz, E., Duncan, R.G., Kyza, E., Edelson, D., and Soloway, E. 2004. A Scaffolding Design Framework for Software to Support Science Inquiry. *The Journal of the Learning Sciences*. 13, 3 (July 2004), 337-386.
- [34] Ramachandran, D., Canny, J., Das, P.D., and Cutrell, E. 2010. Mobile-izing health workers in rural India. In *Proceedings of the 28th international conference on Human factors in computing systems*. CHI '10. ACM, New York, NY, USA, 1889-1898. DOI=<http://doi.acm.org/10.1145/1753326.1753610>.
- [35] Schiaffino, S., Amandi, A., Gasparini, I., Pimenta, M. S. 2008. Personalization in e-learning: the adaptive system vs. the intelligent approaches. In *Proceedings of the VIII Brazilian Symposium of Human Factors in Computing Systems*. IHC '08. 186-195.
- [36] Schmidt C., Gorman T., Gary, M. S., Bayor A. A. 2010. Impact of Low-Cost, On-Demand Information Access in a Remote Ghanian Village. In *Proceedings of Information, Communications Technology, and Development 2010*. ICTD '10.
- [37] Sessink, O. D. T., Beeftink, H., Tramper, J., Hartog, R. 2007. Proteus: A Lecturer-Friendly Adaptive Tutoring System. *Journal of Interactive Learning Research*. 18, 4 (Oct. 2007), 533-554.
- [38] Sharma, P., Hannafin, M. J. 2007. Scaffolding in technology-enhanced learning environments. *Interactive Learning Environments*. 15, 1, 27-46.
- [39] Taber, N. 2008. "Emergency response: Elearning for paramedics and firefighters". *Simulation & Gaming*. 39, 4 (Dec. 2008), 515-527.
- [40] Turk, K. L. and Nichols, M. C. 1996. Online help systems: technological evolution or revolution?. In *Proceedings of the 14th annual international conference on Systems documentation: Marshaling new technological forces: building a corporate, academic, and user-oriented triangle*. SIGDOC '96. ACM, New York, NY, USA, 239-242. DOI=<http://doi.acm.org/10.1145/238215.238302>.
- [41] U.S. Bureau of Labor Statistics. *Occupational Outlook Handbook, 2010-11 Edition: Diagnostic Medical Sonographers*. Retrieved October 2010. <http://www.bls.gov/>.
- [42] Wenger, E. 2000. Communities of Practice and Social Learning Systems. *Organization*. 7, 2, 225-246.
- [43] Whitson, B. A., Hoang, C. D., Maddaus, M. A. 2006. Technology-enhanced interactive surgical education. *The Journal of surgical research*. 136, 1 (Nov. 2006), 13-18.
- [44] WHO. World Health Statistics 2011
- [45] WHO, UNICEF, UNFPA and the World Bank. Trends in Maternal Mortality: 1990 to 2008. 2010. Retrieved November 2010. [http://whqlibdoc.who.int/publications/2010/9789241500265\\_eng.pdf](http://whqlibdoc.who.int/publications/2010/9789241500265_eng.pdf).