The Design and Implementation of the PartoPen Maternal Health Monitoring System

Heather Underwood  
ATLAS Institute  
University of Colorado Boulder  
heather.underwood@colorado.edu

S. Revi Sterling  
ATLAS Institute  
University of Colorado Boulder  
srsterling@colorado.edu

John K. Bennett  
ATLAS Institute  
University of Colorado Boulder  
jkb@colorado.edu

ABSTRACT

The World Health Organization advocates the paper partograph as the single most effective tool for monitoring labor and reducing labor complications in developing countries. Used correctly, the partograph can serve as a tool for early detection of serious maternal and fetal complications during labor, allowing sufficient time for an appropriate response. However, in order to be effective, the partograph must be used correctly. Recent studies in Kenya reported that less than one fourth of partographs were completed in accordance with WHO guidelines. In developing countries, lack of training and continuing education, exacerbated by limited resources, represents a serious barrier to effective partograph use. The goal of the PartoPen project is to increase the effectiveness of the partograph using an interactive digital pen with custom software, together with partograph forms printed with a background dot pattern that is recognized by the pen. This paper describes the design and implementation of the PartoPen system, and the technical evolution of the PartoPen system during studies that evaluated the PartoPen in use in Nairobi, Kenya from June 2012 – August 2012.

Categories and Subject Descriptors

D.2.0 [Software Engineering]: General

General Terms

Design, Human Factors

Keywords

ICTD, partograph, digital pens, maternal health, Kenya.

1. INTRODUCTION

Emmanuel Friedman first conceptualized what would later become the ‘partograph’ in 1954 when he determined that the rate of cervical dilation versus time was highly consistent among birthing women [1]. This discovery precipitated the creation of standardized S-curves representing the progression of normal, uncomplicated labors. In 1972 R. H. Philpott, a professor of obstetrics and gynecology at the University of Rhodesia (now Zimbabwe), used these S-curves to create a graphical, real-time decision support tool that allowed birth attendants to monitor cervical dilation over time, plot those measurements on the graph, and determine if labor was progressing normally or abnormally [2]. Philpott and his colleague, W. M. Castle, added other components to the partograph in addition to the cervical dilation graph, which provided a more comprehensive evaluation of the health of the mother and child during labor. These components included fetal heart rate, molding of the fetal skull bones, amniotic fluid color, contraction patterns, blood pressure, pulse, temperature, and urine output [2]. Initial studies in Zimbabwe showed that use of the partograph resulted in a significant decrease in prolonged or obstructed labor cases and an improvement in neonatal outcome [2].

Obstructed labor is one of the leading causes of maternal deaths worldwide. Obstructed labor results from a disproportion between the fetal presentation and the mother’s pelvis. The most recent statistics from the World Health Organization (WHO) show that 8% or 42,000 of all maternal deaths are caused by obstructed labor [3,4]. Obstructed labor is rarely a cause of maternal death in the developed world, where obstetric procedures (e.g., cesarean sections) and well-staffed and equipped facilities exist. In addition, deaths due to obstructed labor are often underreported because complications caused by obstructed labor, such as hemorrhage and sepsis, are often reported instead [3]. Obstructed labor is also a major cause of maternal morbidities such as obstetric fistula. Between 50,000 and 100,000 women are affected by fistula every year [5]. Without surgical repair, fistula can result in severe pain, infertility, fetid odors, and urinary infections, which all contribute to painful social isolation and abandonment by families and communities [3].

While many countries regionally adopted the partograph in clinical practice, global adoption began in 1987 during the Safe Motherhood conference in Nairobi, Kenya when the WHO promoted the partograph as an essential part of maternal health improvement strategies worldwide. The WHO conducted the first large-scale partograph outcome study in 1994 with 35,484 women in Southeast Asia [6]. The results of this study showed that comprehensive partograph training for nurses, and subsequent use of the partograph in labor and delivery clinics reduced prolonged labor cases, labors needing augmentation, emergency cesarean sections, and still births [6]. The 1994 WHO study underscores the incredible impact of careful labor monitoring on maternal health outcomes in the developing world, and highlights the partograph as an inexpensive one-page form that significantly enhances birth attendants’ ability to give patients the care they need.
However, several recent studies in Kenya have reported a significant gap between knowledge and practice. One study from the University of Nairobi showed that while 88.2% of the 1057 evaluated patient records contained a partograph, only 23.8% of the forms had been used correctly [7]. A 1999 study of partograph use in Nigeria found that 94% of doctors thought the partograph was useful, although only 25% used it on a routine basis. In addition, only 35% of participants in this study could correctly explain the purpose of using the partograph [8]. These results are consistent with other partograph studies conducted in developing countries where lack of training and continuing education, exacerbated by limited resources, represent serious barriers to effective partograph use [7,9,10].

The WHO has tried to address form complexity and usability issues by creating several versions of the partograph that use simplified graphs and color-coding, which were released in 2000 and 2006, respectively. However, the new forms have not been widely distributed and, consequently, have not been adopted in Kenyan hospitals. The WHO has also released a partograph eLearning tool to facilitate partograph training and continuing education [11]. The WHO e-Learning tool is distributed to facilities like KNH via CD-ROM, but an insufficient number of copies are produced for every nurse and nursing student to receive one. Also, this distribution model places the responsibility for finding time and a computer to learn the material directly on the nurses.

The E-Partogram project, started in 2011 by John’s Hopkins University and the associated non-profit, Jhpiego, is intended to provide a digital alternative to the paper-based partograph using tablets and digital clipboards [12]. While digital partograph systems have the potential to be more interactive, and may offer enhanced data collection opportunities, this potential is limited by the challenges present in most developing countries: intermittent power and connectivity, low literacy levels, low levels of technical training, and unsustainable maintenance and scalability costs.

The PartoPen [13,14,15], in contrast, provides a low-cost, intuitive solution to partograph barriers in the developing world using digital pen technology that enhances, rather than replaces, the paper partograph system already in use. The PartoPen project addresses training and point-of-care issues without introducing significant training or financial costs, and even in the event of complete PartoPen failure, since a dead PartoPen is still a pen, practitioners are able to use the existing labor monitoring system exactly how they used it before the PartoPen was introduced – an essential feature for technological solutions deployed for “mission critical” systems like healthcare delivery.

The goal of the PartoPen project is therefore to increase the effectiveness of the partograph using an interactive digital pen with custom software, together with partograph forms printed with a background dot pattern that is recognized by the pen. The digital pen uses internal handwriting recognition and paper-based location awareness to interpret the measurements made on the partograph form. These interpreted measurements can then trigger alerts for attending health care providers when conditions arise that require additional observation or intervention. In addition, timers on the digital pen can be triggered when measurements are plotted in order to provide audio reminders to take routine patient measurements at specified time intervals. The PartoPen thus addresses both form complexity and data interpretation challenges cited as significant barriers to partograph use.

This paper describes the design and implementation of the PartoPen system, and the technical evolution of the PartoPen system during two preliminary studies that evaluated the PartoPen in use in Nairobi, Kenya from June 2012 – August 2012; the first by ninety-five third and fourth-year nursing students at the University of Nairobi School of Nursing Sciences, the second by nurses and nurse midwives in the labor wards of Kenyatta National Hospital (KNH) over a period of one month. This paper focuses on the second study. During this evaluation, the PartoPen improved the ability of nursing students to accurately complete partograph worksheets using synthetic maternal data, use of the PartoPen during actual labor increased both the rate of partograph completion and partograph accuracy, and the PartoPen was readily accepted and adopted by both students and practitioners [14,15]. In addition to describing the focused design changes that allowed the PartoPen to better respond to user needs, we describe several broadly relevant lessons learned during these studies.

2. PARTOPEN EVALUATION

Thirty nurse midwives at KNH used the PartoPen during the study, and twenty-three completed the post-study survey. Participants’ average age was 41 years; the average number of years experience as a nurse midwife was 8. The majority of the nurses who participated in the study were female; four of the thirty nurse midwives were male. KNH is the largest teaching, training, and referral hospital in Kenya. The labor ward at KNH has a 20-bed capacity, as well as two surgery theaters. KNH was chosen as the study site for this project because of its reputation as a research hospital, and its history of testing, evaluating, and recommending innovative health technologies for inclusion in Kenyan Ministry of Health policy. Additionally, KNH is a leader in advocating and promoting partograph use throughout Kenya. As a result, the PartoPen was well received as a viable solution for furthering these efforts.

The goal of the PartoPen study at KNH was to evaluate the use of the PartoPen in an active labor ward, and to compare partograph completion rates before and after the period of PartoPen use. Our hypotheses were: (1) using the PartoPen will increase the number of partographs that are completed relative to the number of patients, and (2) using the PartoPen will improve the accuracy and quality of the partographs completed during the study. In order to test these hypotheses, patient records from one month prior to the PartoPen intervention were scanned electronically by a local research assistant, and are being analyzed and compared to the patient records that were completed during the one-month period of PartoPen use. Over 400 scans of patient files were collected during the month prior to the study, but only 350 of these files contained a partograph, and many of these partographs were blank. Over 500 scans of patient records were collected during the month-long PartoPen study.

For the first week of the PartoPen study, researchers facilitated training sessions every day during the morning shift change to ensure that all nurses knew how to use the PartoPen. Also during the first week, researchers were present in the labor ward 12-14 hours per day answering questions, observing how and if the PartoPen was being used, and identifying high priority design issues. Problems identified during the first week were immediately addressed in the PartoPen software, and nurses were informed of the changes the following day. After the first week, the PartoPen software was stable and perceived to be effective, and no changes were made to the code base for the remainder of the study. Data from the first week has been excluded from the
PartoPen study. At the conclusion of the study, nurses were asked to fill out a brief survey about the PartoPen system.

The effectiveness of the PartoPen during clinical use is reported elsewhere [14,15]. This paper focuses on the impact of observations and participant feedback collected during the study on the design of the PartoPen, and how the resulting design and implementation responded to that feedback.

### 3. PARTOPEN SYSTEM ARCHITECTURE

The current implementation of the PartoPen system uses the Livescribe (LS) Echo digital pen running a custom software “penlet”. The Echo pen (see Figure 1) has a built in microphone, speaker, and OLED display. The pen relies on a rechargeable lithium ion battery, which is advertised to last about 36 hours during normal use. We have observed a battery life of about 20 to 26 hours, depending upon the amount of audio played during that time. Pens can store between 200 and 800 hours of audio, or the equivalent amount of text data, depending on the pen model, and all stored data can be downloaded to a desktop computer using a standard micro-USB cable.

![Image of the digital pen used in the PartoPen system](image1)

**Figure 1.** The digital pen used in the PartoPen system is depicted. The speaker, microphone, OLED display, USB connector, audio jack, memory storage, and replaceable ink tip are identified.

Over the past fifty years, a large body of work on pen-and-paper computing and pen-and-paper user interfaces (PPUIs) has been created. Most of that work falls into one of the following categories: digitizing paper content [16,17], page identification and location tracking [18,19], capturing touch and gesture input [20,21,22], capturing pen input [18,23], and augmented printed documents [24,25]. The LS digital pen technology [26] captures pen input and digitizes paper content by using a unique location tracking and page identification technique patented by the Anoto AB group [18].

The Anoto “dot pattern” (Figure 2) used by LS pens employs an invisible grid system on each sheet of paper where each gridline is spaced 0.3mm apart. At each grid intersection, a microdot is printed on the page slightly offset in one of four directions – up, down, left, or right of the intersection itself. Each dot encodes two bits of location information based on its location relative to the grid and relative to the dots around it. The digital pen tip contains an infrared camera that captures 72 snapshots per second of these 6x6 grids of dots (i.e., each photograph contains 36 dots). The X and Y coordinates represented by the dots in the photograph are translated and interpreted by the digital pen, and are mapped onto a specific page address in the Anoto pattern space. The entire pattern space covers an approximate area of 4.6 million km², which represents roughly 73 trillion unique sheets of letter-sized paper [18]. Using this technology, the LS digital pens are able to interpret where on a page the pen-tip is at all times, and recognize ink strokes from the stored coordinate data.

LS differentiates between two types of pattern space – open paper and fixed print regions. Open paper is designed for free-form note taking and drawing, whereas fixed print regions are defined visually on the page, often as buttons, and provide specific functionality such as menus or audio controls. The PartoPen system uses standard button-like fixed print regions for accessing use instructions, but also extends the fixed print paradigm by implementing user-generated fixed print regions. For example, a user might plot a measurement with an ‘X’ on the graph. The PartoPen system takes the users’ handwritten ‘X’ and interprets this symbol as a fixed print or dynamic area that will now function as a button that can be tapped to initiate some action. This functionality will be described in more detail in the explanation of the PartoPen decision support mechanism, but this example provides an introduction to how regions are created and defined on a page.

![Image of the Dot Positioning System (DPS)](image2)

**Figure 2.** The Dot Positioning System (DPS) uses printed microdots, as seen above, arranged in specific patterns. The dot pattern allows the digital pen to determine where on the form it is placed, thus allowing the pen to interact in meaningful ways with specific form regions. The dot pattern is patented by Anoto AB Group.

The LS SDK provides a tool for creating custom “paper products,” which, in the case of the PartoPen, is the partograph form capable of interacting with the digital pen (see Appendix B). To design a custom paper product, a developer imports images (e.g., the standard WHO partograph) and defines regions on this image that will trigger a response from the digital pen. In the “penlet,” or digital pen software program, the developer defines the functionality for when the digital pen writes in these regions. Touching the pen-tip to the paper will trigger a “pen down” event,
and execute the program code associated with that area on the page.

The LS digital pen was chosen as the PartoPen platform because of its unique abilities to record and playback audio, and synchronize audio with handwritten text. LS digital pens, like other digital pen models, also create searchable, digital copies of handwritten notes in a desktop-based software application. Early on, the availability of the LS SDK allowed for rapid development, deployment, and iteration of the PartoPen system, as well as documentation and a developer community. Livescribe discontinued its development program in July 2011, but worked with PartoPen researchers to ensure the ongoing development and implementation of the PartoPen system.

4. PARTOPEN “PENLET”

The PartoPen software or “penlet” is activated when the digital pen makes contact with a partograph printed with a dot pattern known to the pen as part of the PartoPen pattern space. The “pen down” event that triggers the PartoPen application initiates three simultaneous events that are shown in Figure 3. First, the pen retrieves the unique page ID encoded on the form, and attempts to locate a file in internal penlet storage corresponding to that page ID. If a file for that page exists, this indicates that this pen has been used with this form in the past. If a file is not found, it is assumed that this is the first time this pen has been used on this form, and a file is created in internal storage. The information that is stored in the file, if the file exists, is a string that maps the unique page ID to a human-readable, user-generated patient identifier (i.e., patient initials, name, room number, etc.) Patient identifiers are used by the reminder system to give nurses patient-specific, rather than general, reminders. This file storage and patient ID retrieval system is described in more detail in the discussion on reminder implementation.

Second, the pen retrieves the region ID. The software determines the correct pen output based on where the user has tapped or written data on the form by using this region ID. Any region designed to produce pen output (instruction buttons and audio controls) corresponds to a delegate method in the code that executes the correct program functionality.

Finally, the initial “pen down” event initiates the hand writing recognition engine, which is used to process handwritten input. The handwriting recognition engine is instantiated with a general text resource package. The PartoPen software adds an additional resource package containing a custom lexicon of common user input for the partograph form, which improves the handwriting recognition of the application. The handwriting recognition engine, once initiated, waits for a “user pause” event that is defined by the developer before compiling. The PartoPen currently uses a one second user pause time. A “user pause” event calls the “processText” method, which in turn initiates the appropriate workflow based on text input and region ID.

The implementations of the three main PartoPen components – use instructions, decision support, and reminders – are described in detail in the following sections.

4.1 Use Instructions

One of the goals of the PartoPen system is to enforce birth attendant training on correct use of the partograph, as this has been cited as a significant barrier to consistent use of the form. The WHO partograph user manual, and a local partograph manual issued to clinics by the Kenyan Ministry of Health, are the primary resources for partograph instruction in Kenya. These manuals, however, are not generally portable, and are not easily located or utilized in busy labor wards. The PartoPen system makes the instructions found in these manuals accessible directly from the partograph itself. The PartoPen uses fixed print “button” regions around the partograph text to provide verbatim audio recordings of the instructions found in the partograph use manuals. Thus, by tapping on these “buttons,” nurses and nursing students can get short informational prompts on how to use each section of the form correctly.

The audio for each partograph section (e.g., fetal heart rate, contractions, etc.) is divided into short prompts less than 20 seconds long. By tapping the button a second time, users will hear the second prompt, and so on until all of the instructions have been played and the first prompt in the series repeats. The audio prompts are organized such that well-trained nurses can quickly access the high-level “refresher” prompts with only one or two taps, while students or new nurses can explore additional details of correct partograph use by tapping repeatedly on the same button.

During the first two days of the three-week PartoPen study at KNH, researchers pared down the number of available instruction prompts for each button because nurses were using them infrequently. Removing the unused audio showed a small, but noticeable improvement in application response time. However, later in the first week of the study, a group of nursing students began their clinical rotation in the labor ward at KNH. Researchers began observing nurses using the PartoPen and the instruction buttons to teach the new students how to use the partograph. This became an increasingly common event, and prompted researchers to add the full set of instructional audio back into the system. The practice of nurses using the PartoPen to teach nursing students in the clinical setting introduces a training reinforcement component for nurses, and a standardized
partograph training curriculum for students. Providing standardized instructions accessible directly from the form also gives students a way to gain the same level of partograph knowledge regardless of nurses’ availability to spend one-on-one time with them, which is often difficult in busy and understaffed labor wards. The observed use of the instruction buttons therefore directly addresses two specific barriers to partograph use: inadequate training and staff shortages. Nurses also reported feeling “empowered” and “like a good role model” when they were able to use the PartoPen technology to teach students.

Based on user observations and feedback, several other modifications were made to the instruction audio prompts. First, tapping multiple times on the same button to access the next instruction prompt was not intuitive. To address this issue, researchers re-recorded the audio prompts to include the phrase “tap here again to hear more instructions” at the end of each prompt. However, researchers found that using this phrase made users feel like they had to tap the button again even if they weren’t interested in hearing more instructions. Researchers then reverted the audio back to the original instruction prompts, and implemented a new fixed print “next” button on the partograph form itself. Users indicated that having a separate audio control on the page specifically for advancing the instruction prompts was much more intuitive, and researcher observations supported this finding. A “repeat” button was also added to the form during this iteration after nurses complained of having to tap up to ten times to hear the same audio prompt again. The repeat button was an important (and retrospectively obvious) feature that was immediately and consistently used by nurses in the teaching scenario described above.

Based on nurse feedback, future iterations of the instruction audio will be recorded by a local nurse or doctor to address the accent problem reported by some participants. Native speakers of multiple languages and dialects can quickly and easily record the audio prompts – a process that will be facilitated based on future interest and deployment locations of the PartoPen. The simple recording process will also allow the software to easily adjust to WHO or local health ministry changes to standard partograph protocols.

4.2 Decision Support

One of the most commonly cited barriers to partograph use is the inability to interpret the data plotted on the partograph and take appropriate action. Nursing students and less-experienced nurses often plot the data correctly on the partograph, but fail to derive the meaning of the plotted data, or do not remember what actions to take based on the data that they have plotted. The decision support functionality of the PartoPen addresses these issues by interpreting plotted data based upon page location, and providing real-time feedback on the appropriate actions to take. Currently, the PartoPen provides decision support in three of the partograph sections: cervical dilation, liquor/amniotic fluid, and fetal heart rate.

The cervical dilation versus time graph has two decision support lines: the “Alert” line and the “Action” line. Normal labor measurements are expected to stay on or to the left of the “Alert” line. If a measurement is plotted between the Alert and Action lines, the WHO protocol for the management of labor suggests several actions that should be taken for this patient. The “Alert” line was originally added to the partograph to provide an indicator of when to transport a woman to a facility that could provide emergency cesarean sections. Thus, in the event that the next measurement reaches the “Action” line, the patient can receive quality care at an appropriate facility. Timely decision-making based on the cervical dilation measurements can be life-critical. The PartoPen system attempts to improve the speed of this decision-making process by immediately calling attention to a concerning measurement and suggesting appropriate actions. On the PartoPen partograph form (Appendix B) four regions are defined: above the latent phase line, normal labor, between alert and action lines, and across the action line. Any measurement plotted above the latent phase line should be transferred onto the Alert line and the current clock time should be written below the measurement on the Alert line. Therefore, if a nurse plots a measurement in this area, he or she will hear the decision support tone from the pen and the following text will scroll across the pen display: “Transfer measurement to the Alert line. Patient is now in active labor.” The second region – the triangle to the left of the Alert line indicating normal labor – does not trigger any response from the pen when a measurement is plotted there. Measurements plotted in the region between the Alert and Action lines will again trigger the decision support tone and suggested actions will scroll across the display. The region to the right of the Action line also responds to pen events by playing the tone and scrolling the suggested set of actions for that measurement.

One particularly confusing aspect of the standard partograph form is that cervical dilation and descent of the fetal head are plotted on the same graph. Cervical dilation is plotted with an ‘X’ and descent is plotted with an ‘O’. However, there are cases when an X and an O can be plotted in the same place on the graph, which requires the PartoPen to determine which measurement (either dilation or descent) is being plotted in order to produce the appropriate response. LS pens use third-party handwriting recognition (HWR) software, which is available for use in custom pen/pad applications like the PartoPen. In the initial implementation of the PartoPen software, the HWR was used ‘as-is’ to differentiate between Xs and Os on the graph. However, the HWR is configured to interpret all alphanumeric characters and most UNICODE symbols. The HWR often interpreted Xs and Os as other characters or symbols, which exacerbated the challenge of differentiating between Xs and Os. To address this problem, researchers built a custom classifier, which takes the first character in a HWR string (to ensure only one letter is being used) and compares it to an array of letters, numbers, and symbols. The entries in this “X array” are characters that were often returned instead of an ‘X’ when an ‘X’ was in fact written. If the character does not match any of the entries in this array, an ‘O’ is returned. After implementing this classifier, recognition of Xs and Os was near 100%, and only one or two instances of misrecognition were reported during the entire study.

HWR is also used to provide the decision support for the liquor/amniotic fluid section of the partograph. This functionality was added during the first week of the study, after nurses consistently emphasized the importance of this particular measurement when determining the status and health of the fetus. Four possible entries can be made for this section: ‘I’ (intact), ‘C’ (clear), ‘A’ (absent), or ‘M’ (meconium stained). These data represent the state of the membranes and the color of the amniotic fluid. Meconium (excrement of the fetus) stained fluid is a reliable indicator of fetal distress, which necessitates an expedited delivery to ensure the health of newborn. The PartoPen uses HWR and another custom classifier to differentiate between ‘M’ and every other character. If an M is recognized, the pen plays the decision support tone and text scrolls across the OLED display indicating fetal distress, and suggests appropriate next steps.
The partograph section for recording fetal heart rate (FHR) was also decision-support-enabled. A normal fetal heart rate, as defined by the WHO, is between 120 and 160 beats per minute. However, the Kenyan Ministry of Health uses a national standard of 110 to 170 beats per minute. Initially, the WHO standard was used for PartoPen decision support in this area; however, it was changed a few days into the study to adhere with the nationally recognized rate. Fetal heart rate is recorded with a solid dot, and each dot is connected to the preceding dot with a solid line, which creates a graphical representation of heart rate over time. If a fetal heart rate above 170 or below 110 is recorded on the graph, the decision support tone will play and text will scroll across the pen’s OLED display indicating potential fetal distress.

In the first implementation of the PartoPen system, the decision support functionality used pre-recorded audio prompts similar to the use instructions. However, observation of the pen use in the labor ward prompted several design changes. First, the audio was too quiet, and often time, and based on survey data collected at the end of the study, nurses almost unanimously reported that staff shortage is insufficient for drawing nurses’ attention to the data they need measurements taken.

While the PartoPen does not replace nurses or supplement the usual, and then write the patient’s initials directly after the name. The WHO recommends a maximum ratio of 1 nurse to 3 patients to ensure compliance with partograph completion protocols. In the survey, nurses almost unanimously reported that staff shortage is the most common reason for low partograph completion rates. While the PartoPen does not replace nurses or supplement the shortage of nurses in the labor ward, it provides a reminder system intended to help busy and tired nurses keep track of when patients need measurements taken.

In general, measurements on the partograph are either taken every half hour, or every four hours. For example, fetal heart rate is recorded every half hour and cervical dilation is recorded every four hours. In theory, all of the half-hourly measurements should be taken during the same half-hourly exam; the same is true for all of the measurements taken every four hours. Using this information, fetal heart rate and cervical dilation measurements drive the half-hourly and four hour reminders, respectively, for all measurements in these time brackets. For example, if a nurse only plots pulse (a half-hourly measurement) on the partograph without plotting fetal heart rate during the same exam, he or she will not receive a reminder in half an hour. The decision to implement the reminders in this way was designed to reduce the number of reminders a nurse would receive for a single patient, as nurses are already caring for more patients than is recommended during any given shift. A prior PartoPen study [27] also showed that nurses quickly become desensitized to pen output if audio is frequently emitted from the pen. Using fetal heart rate and cervical dilation as the reminder drivers was based on data from a 2011 study that identified these partograph sections as the most commonly filled out, with fetal heart being filled out 90% of the time and cervical dilation being plotted 97% of the time [28].

One nurse midwife with over 20 years experience pointed out a unique case that can arise from using fetal heart rate as the half-hourly reminder driver. In the unfortunate case of an intrauterine fetal death (IUF), there will be no fetal heart rate to record, but other measurements will be recorded on the partograph because the woman still goes through labor to deliver the dead fetus. Researchers suggested making a straight horizontal line on the fetal heart rate graph to initiate the reminder, but a more appropriate solution has not yet been developed.

4.3 Reminders

The labor ward at KNH delivers approximately 1000 babies during the “busy” months from October to March, or roughly 34 babies every day. On average there are 4-6 nurses working at a time, and based on survey data collected at the end of the PartoPen study, nurses on average are responsible for 5-7 patients during a day shift and 7-10 patients during a night shift. The WHO recommends a maximum ratio of 1 nurse to 3 patients to ensure compliance with partograph completion protocols. In the survey, nurses almost unanimously reported that staff shortage is the most common reason for low partograph completion rates. While the PartoPen does not replace nurses or supplement the shortage of nurses in the labor ward, it provides a reminder system intended to help busy and tired nurses keep track of when patients need measurements taken.

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Reminders are implemented using separate timer threads that get created every time a nurse plots a fetal heart measurement or a cervical dilation measurement on the partograph. The timer is passed as a parameter the patient identifier that corresponds to the unique page ID encoded in the dots on the form. When the timer thread runs, the reminder tone (distinct from the decision support tone) is played, and the patient ID scrolls across the OLED display along with a summary of the measurements that need to be taken at that time. If the nurse has not entered a patient ID, or the pen has failed to capture an entered patient ID, a general reminder message scrolls across the screen indicating the measurements that “a patient” needs attention at that time.

4.3.1 Reminder Patient IDs

The initial PartoPen implementation attempted to use the HWR engine to capture the patient name as a string, and use this as the patient identifier corresponding to that unique page. However, observations and user feedback made it apparent that the HWR engine was unreliable for everyone, including nurses and the one second user pause time did not allow for nurses to take their time writing a patient’s name. This design resulted in nurses tracing a patient’s name several times to get the HWR to accurately capture the input, which often made the patient name unreadable on the actual form.

The second implementation of the patient ID system was a change to the instructions nurses were given rather than a change to the system itself. Nurses were instructed to write the patient name as usual, and then write the patient’s initials directly after the name. Every time a nurse would write in the patient name field, the previous patient ID would be overwritten, thus if the patient initials were written last, these would serve as a simple yet identifiable way of determining to which patient the reminder was referring. While this approach addressed some of the HWR issues
because not as many characters needed recognizing, timing problems were still an issue, and nurses did not like the way it looked on the form. The nurses also expressed concern with this system during shift changes, because nurses coming onto the shift could end up in one of two scenarios. First, a nurse could receive the same pen that was used on a patient’s partograph in the previous shift, and therefore would receive any scheduled reminders for this patient. The problem with this scenario is that the patient ID (i.e., the patient initials) is not a sufficient identifier for a nurse who did initially write them. Thus, nurses in this scenario are no better off than a nurse receiving a generic reminder from the pen. The alternative scenario is when an incoming nurse receives a new pen that has not yet been used on her patient’s partograph, but the partograph has already been partially completed by the nurse on the previous shift. In this scenario the nurse will not receive any of the previously scheduled reminders for this patient (because they have a new pen). If they want to receive future reminders for this patient, they must trace over the patient initials to store that patient ID in this new pen. Again, this is non-intuitive, and creates a messy looking, potentially unreadable form.

The current (third) implementation of the patient ID system uses a row of boxes titled “PartoPen Reminder IDs” below the summary at the bottom of the partograph form. Nurses use these designated boxes to create a patient ID of their choice. Nurses often used room number or patient initials as the patient ID. This implementation solves the HWR issues described above, separates the patient IDs from the standard patient information fields, and provides multiple ID boxes so that an incoming nurse working on a partially completed partograph with a new pen can create his or her own identifier for this patient in a new box.

At the beginning of the study, researchers did not insist that the PartoPens be handed over to the nurse on the next shift who was taking the current nurse’s patients. However, nurses found that this was a much more intuitive (and sustainable) way of handing off the pens, rather than obtaining a new pen from researchers at the beginning of their shift. In addition, the reminders that had been set for a patient by a nurse on an earlier shift would then carry over to the nurse on the next shift who was now taking care of that patient. There were several times when researchers observed nurses starting a shift, receiving their pen from the nurse on the previous shift, and shortly thereafter, receiving a reminder from the pen to attend to a specific patient that they had not yet checked on. This system created a level of continuity in patient care that had previously been absent in the KNH labor ward during nurse shift changes.

Another possible way of implementing the patient identifier system is to use the audio recording capabilities of the pen to record a nurse saying a patient’s name, and play that recording back when a reminder for that patient goes off. This design would avoid HWR issues, and create a more personalized way of creating patient IDs, but introduces some technical challenges including, but not limited to, simultaneous audio input and output (this is a known issue with LS pens).

As LS technology continues to progress, networking capability between pens is expected become a standard feature. The ability for pens to communicate information over a local area network would allow reminders for specific patients to be transferred between pens, thus allowing each nurse to have his or her own pen and still get reminders that were scheduled for their patients during the previous shift.

4.3.2 Reminder Cancelation

During the first week of the PartoPen study, one of the nurses approached a researcher and asked why he was getting reminders for a patient that had already delivered. In the initial PartoPen design, there was no way to cancel reminders for patients once a partograph was complete. The work around for the remainder of that day was to turn the pens off and back on after a patient delivered or went for a cesarean section. This was a “work around” because, not only did this action cancel reminders for the patient who had delivered, it canceled all reminders for all patients.

In order to allow nurses to cancel reminders, researchers modified the partograph form by adding a small blue “partograph complete” box in the upper right hand corner of the form. When a nurse completes a partograph for a patient who has delivered or gone for cesarean section, he or she uses the PartoPen to sign his or her initials in the blue box. When a “pen down” event occurs in the region encompassed by the blue box, the file stored on the pen corresponding to that unique page is deleted. When a reminder thread executes after waiting the specified 30 minutes or 4 hours, it will first check if the file corresponding to the reminder exists in internal penlet storage. If the file exists, the reminder is played, but if the file does not exist (i.e., it has been deleted by someone writing in the blue box for that page) the reminder does not play.

Adding the blue box to the form sufficiently addressed the reminder cancelation issue, but also had the unintended positive side effect of introducing accountability to the form. By signing their initials in the blue box, nurses acknowledge that they completed the form and monitored the labor. This accountability promotes an increased level of detail and attention to partograph completion and accuracy among nurses, and simplifies the work of hospital administration staff tasked with investigating potential malpractice and creating annual staff performance reports.

Nurses reported that the PartoPen reminder system was the most useful and helpful component of the device. It was also the component with the most technical and usability challenges. However, by making minimal changes to the standard WHO partograph form, the two main issues – patient reminder IDs and reminder cancelation – were addressed sufficiently for current use.

5. OTHER LESSONS LEARNED

The PartoPen functionality described in this paper was designed and implemented to address the most commonly reported barriers to partograph use, and to ultimately improve partograph completion and accuracy rates. There were, however, several aspects of the PartoPen design that focused on nurses’ willingness to use the PartoPen and complete partographs. For example, researchers configured the pen’s OLED display to return to the default screen, which displays the current clock time, after the nurses receive decision support or reminder text. Successful partograph completion relies on accurate recording of the time, and researchers frequently observed nurses using cell phones to check the time during patient exams. However, hospitals and clinics in Kenya are increasingly restricting the use of personal cell phones in the presence of patients to reduce distractions and to improve patient care. By the end of the study, using the time on the digital pen display had replaced the practice of nurses using cell phones to get the current time.

As described previously, researchers made several modifications to the partograph form to facilitate PartoPen interaction. In addition to these modifications, a new partograph form was
created using Adobe Illustrator. The new form increased the size of partograph sections to provide more room for nurses to write their measurements on the chart. Appendix A depicts the old KNH partograph – a skewed, blurred, many-times-photocopied document. Appendix B depicts the revised PartoPen partograph form. Nurses reported several times that the nicer form was easier to see and more pleasant to use, and two nurses told researchers on separate occasions that they felt like doing a better job filling out the partograph to “keep it nice.”

Researchers did not begin the study recognizing the importance of nurses’ attention to detail and appreciation for keeping things neat and clean, but this realization significantly shaped several of the more subtle design decisions that were made during the study. Initially, researchers did not distribute the standard caps for the digital pens because they are difficult to get on and off, and are easily lost or misplaced. The nurses wore the pens around their necks using a lanyard researchers had attached to the pen. However, without a cap, the pens would occasionally mark the nurses uniforms, especially when nurses placed the pens tip down in their pockets. This prompted some nurses to discontinue using the pens altogether. After realizing the problem, researchers distributed caps (and left a supply of replacement caps in the labor ward) for the pens, resulting in increased PartoPen use among the nurses.

The study greatly benefited from researchers attention to these details, and the simple adjustments that were made to address important, but not immediately obvious, issues. Innovative technologies can provide complex functionality to address specific health issues, but the importance of simple, non-technological improvements to the overall system should not be ignored when evaluating the impact and usability of the solution. Our high-level “lessons learned” can be summarized as follows:

1) provide for a rapid and flexible development process in-country so that changes can be made quickly and effectively,
2) budget time for implementation refinement in the study design that does not overlap with the data collection period in order to reduce bias and data inaccuracies,
3) to the extent possible, incorporate training into practice, so as to reduce training overhead for study participants, and
4) be responsive to issues raised by participants during the study, and seek creative solutions that address these issues, even if they are outside the original scope of the study.

6. CONCLUSIONS
In this paper, the three components of PartoPen functionality – use instructions, decision support, and reminders – are discussed in detail, and the study that shaped the design and implementation of these components is described. In the next design iteration of the PartoPen, researchers will address some of the technical challenges outlined in this paper, and will expand the functionality to encompass more of the partograph based on nurse feedback collected during the study. The next implementation of the project will focus on allowing data transfer between pens, especially pens at different clinics. Networking the pens and allowing partograph data to be transferred between clinics electronically will help reduce the number of maternal deaths caused by late patient referral between facilities, which was repeatedly raised as a serious issue by nurses and doctors at KNH during this study. In addition, the next phase of the PartoPen project will emphasize building capacity and skills among local health and IT professionals to maintain and advance the system. Custom paper products are currently time consuming to create, and require significant technical expertise to produce. One area of future work will be the creation of a desktop application that uses simple drag-and-drop functionality to create pen-enabled regions on any form. Users will be able to easily add audio or text prompts to these regions using the desktop platform, and the penlet code corresponding to the user-defined regions will be generated automatically.

After the one-month PartoPen study, the labor ward’s records office and two independent research groups working with patient records at KNH reported seeing a significant increase in the number of files containing a completed partograph. These encouraging reports are supported by the initial data analysis of pre- and post-PartoPen patient files. In addition, the post-PartoPen study survey results reveal that on average nurses gave the PartoPen a 9 out of 10 for usability and a 9.7 out of 10 for usefulness.

The overwhelming rate of PartoPen adoption and use during the study motivated researchers to leave 20 PartoPens, a laser printer, a 3-month supply of printer toner and paper, and 20 pen chargers at KNH for ongoing use. Today the PartoPens have been in use for two months, and the system – printing the forms, charging the pens, and transferring the pens during shift changes – is sustained entirely by the nurses and hospital staff at KNH.

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8. REFERENCES


APPENDIX A