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The PartoPen: Using Digital Pen Software to Improve Birth Attendant Training and Maternal Outcomes in Kenya

Problem and Motivation

The World Health Organization (WHO) estimates that 300,000 women die every year due to pregnancy-related complications, most of which occur in developing countries [1]. Timely and informed labor monitoring by a skilled attendant can help prevent many of main causes of maternal death – hemorrhage, infection, unsafe abortion, eclampsia, and obstructed labor. Globally, the WHO promotes the paper partograph as an effective and cost-efficient tool for monitoring labor, and preventing obstructed labor and resulting complications. Used correctly, the partograph provides decision support that assists in early detection of maternal and fetal complications during labor. Especially in rural clinics, early detection allows transport decisions to be made in time for a woman to reach a regional facility capable of performing emergency obstetric procedures.

Despite the positive reports of improved maternal outcomes resulting from correct partograph use [2], 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 [3]. 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 [4]. 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 [3,5,6].

Background and Related Work

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 [7]. 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 study the material directly upon 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 [8]. 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 [9, 10, 11], 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 software 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 set 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.

Approach and Uniqueness

The current implementation of the PartoPen system uses Livescribe 2GB Echo digital pens, which can capture and synchronize audio and handwritten text, and digitize handwritten notes into searchable and printable PDF documents. These pens use an infrared camera in the tip of the pen that is activated when a user presses the pen tip to a piece of paper. The camera captures a pre-printed unique dot pattern at a rate of 70 images per second. Each printed dot contains location information, which the pen interprets and uses to perform location-specific functions. The digital pens also include a speaker, a microphone, a 3.5mm audio headphone jack, up to 8GB of memory storage capable of storing approximately 800 hours of audio recording, an OLED display, a rechargeable lithium-ion battery, and a micro-USB connector for charging and data transfer.

The custom software developed for the PartoPen provides partograph training instructions, task-oriented reminders, and context-specific audio feedback in real time. Tapping the pen in different areas on the partograph form provides audio instructions taken directly from the WHO partograph manual, which reinforces birth attendant training. The pen also detects abnormal labor progression by interpreting handwritten data entered on the partograph form, and provides audio and text-based feedback to encourage birth-attendants to take appropriate action. Finally, the PartoPen uses time-based reminders to alert birth attendants when specific patients need a follow-up exam.

The PartoPen software or "penlet" is activated when the digital pen makes contact with a partograph printed with the dot pattern. The "pen down" event triggers the PartoPen application and initiates three simultaneous events. 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 provide patient-specific, rather than general, reminders. 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. I added an additional resource package in the PartoPen software, which contains a custom lexicon of common user input for the partograph form thus improving the handwriting recognition of the application.

The PartoPen is appropriate for use in resource-challenged environments. It does not require network connectivity to operate (although it can utilize available connectivity to transfer patient data between clinics), and uses a rechargeable lithium ion battery that can be charged using a standard cell phone charger. The dot pattern can be printed on standard printer paper using a 600dpi laser printer, thus form creation incurs a very minimal additional cost. The digital pens themselves are low cost, durable, consume very little power, require minimal training, and enhance – rather than replace – the common paper-and-pen system in near-ubiquitous use in the developing world.

Results and Contributions

In June 2012, I conducted a study with nursing students at the University of Nairobi (UoN). In the nursing student study, students were asked to use a PartoPen in one of three modes to complete a partograph worksheet. Students were asked to participate in a focus group discussion following the worksheet task. Ninety-five nursing students in their third and fourth years of study participated in the study. Local research assistants recruited participants from the population of 148 third and fourth year nursing students at the UoN.

All students had previously been taught how to use the partograph to monitor labor during a 10-15 minutes in-class discussion as part of the nursing curriculum, and during their clinical rotations in the maternity wards.

The 95 student participants were separated into three groups. Group 1 was the control group, and Groups 2 and 3 were the intervention groups, which focused on the discoverability of the functionality, and the affect on partograph performance, respectively. Group 1 students completed a partograph worksheet task with a PartoPen in "silent logging mode," and received no instructions on how to use the technology. In the "silent logging mode" the digital pen records student answers, and logs when and where on the form student answers would have triggered feedback from a fully functional PartoPen. This control group provided a baseline for students' performance on the partograph worksheet task.

Group 2 completed the same worksheet task, but used a fully functional PartoPen in "use" mode. The PartoPen software used for the student pilot had two key pieces of functionality: use instructions and decision support. For the nursing student study with nursing students completing a partograph worksheet, the reminders (enabled only for the maternity ward study) were disabled. In addition, playing pre-recorded spoken audio provided the decision support, in contrast to the maternity ward decision support, which was provided by scrolling text across the OLED display.

Group 2 received no training on how to use the technology. In "use" mode, the digital pen logged when errors were made on the form, which were compared to the baseline results recorded from the first class of students. Students in this group received audio feedback from the pen when data was entered incorrectly on the form, and thus, corrected errors were also recorded in this mode. The data collected from this group tested the discoverability and intuitiveness of the PartoPen functionality.

Group 3 received a fully functional PartoPen and a 15-minute introduction and demonstration of the PartoPen system before completing the partograph worksheet task. The digital pen recorded errors, corrections, and all marks made on the partograph form. By comparing the results of Group 3 with the results of Group 2, I was able to determine the affect of providing a PartoPen tutorial on partograph performance. Groups 2 attempted to simulate PartoPen deployments in which students/nurses do not receive training prior to using the device. Given that most of the PartoPen functionality is "pushed" to users during normal form completion, I hypothesized that training on the PartoPen system would not significantly alter the results of participants with the same level of prior partograph knowledge – Groups 2 and 3, respectively.

Scores were calculated as a percentage of total points correct out of the total possible points. I performed an unpaired t-test to identify any significant difference between groups, particularly if Groups 2 and 3 showed any improvement in performance over Group 1 – the control group. Group 1, which used the PartoPen in silent logging mode to complete the worksheet, had an average score of 58%. This means that on average students in this group correctly plotted 58% of the measurements from both case studies in the worksheet (with the highest possible score being 100%). The average score for Group 2, which used the PartoPen in "use" mode but received no instructions, was 63%. The average score for Group 3, which used the PartoPen in "use" mode and received instructions, was 66%. These data are recorded in Table 1.

Group # and PartoPen Mode	**Avg. Score**
Group 1 – silent logging mode	58%
Group 2 – use mode, no training	63%
Group 3 – use mode, training	66%

Table 1: Average scores on worksheet completion task for fourth year students divided by PartoPen functionality group number. This table illustrates an increase in student performance with increasing PartoPen functionality and training.

	Mrs. A	**Mrs. B**	**Mrs. C**
Group 1	61.3%	58.6%	**52.0%**
Group 2	63.5%	62.9%	62.9%
Group 3	65.2%	62.7%	**72.2%**

Table 2: Average scores on worksheet completion task for fourth year students divided by patient case study and group number. This table illustrates a significant difference (p-value = .0267, between Groups 1 and 3 for Mrs. C).

In each worksheet, students received two patient case studies. All students received the "Mrs. B" case study, and either "Mrs. C" or "Mrs. A," selected randomly. The three case studies represent three possible labor outcomes. Mrs. A's data represents an uncomplicated timely labor that progresses without medical intervention. Mrs. B's data illustrates a case of prolonged or obstructed labor, which is addressed by the administration of oxytocin – a labor-inducing drug. Finally, Mrs. C's labor progression data illustrates an increasing number of complications, including fetal distress, and ultimately results in a cesarean section. Thirty-four instructional audio prompts are available for all students and all patient case studies. However, only the Group 3 students were informed how to access the instruction prompts by tapping the pen on the text to the left of the graphs on the form. The average scores for each group based on patient case study are shown in Table 2. Using an unpaired t-test, the difference between Group 1 and Group 3 for the patient case study Mrs. C, was found to be significant (p-value = .0267). These data suggest that for more challenging or complex labor cases, the availability and utilization of the PartoPen instruction prompts promotes more accurate form completion.

After each group completed the worksheet task, the students were asked to participate in a short focus group session. The focus group discussion centered on how the partograph is currently taught and practiced, and the students' experience using the PartoPen to complete the partograph. Currently, the partograph is covered briefly in the nursing curriculum, but practice and actual use occur only during students' clinical rotations in the labor ward. The students were asked if there were particular parts of the partograph that were difficult to complete, or which were not adequately covered in class or during clinical rotations. Students unanimously reported that plotting contractions was one of the most difficult sections of the partograph, because both duration and frequency are plotted together using a combination of bar charts and coloring patterns. Students also unanimously reported that plotting descent of the fetal head was challenging. Difficulties plotting descent of the fetal head can also be attributed to having to plot on the same graph as another measurement (cervical dilation), but may also be due in part to the nursing school transitioning to a different partograph version that requires users to plot the descent in increments of one instead of two, and on the left side of the graph instead of the right.

In Chart 1, the completion scores for plotting contractions for each group are shown. These data illustrate that improvements were made in all three case studies (Mrs. A, B, and C) between groups that did and did not use the PartoPen. In Chart 2, the student data for completing descent of the fetal head measurement is shown. For the descent measurements, there was significant improvement in the most complicated case study, Mrs. C, which is expected, as audio from the pen is only triggered in cases where prolonged or obstructed labor occurs.

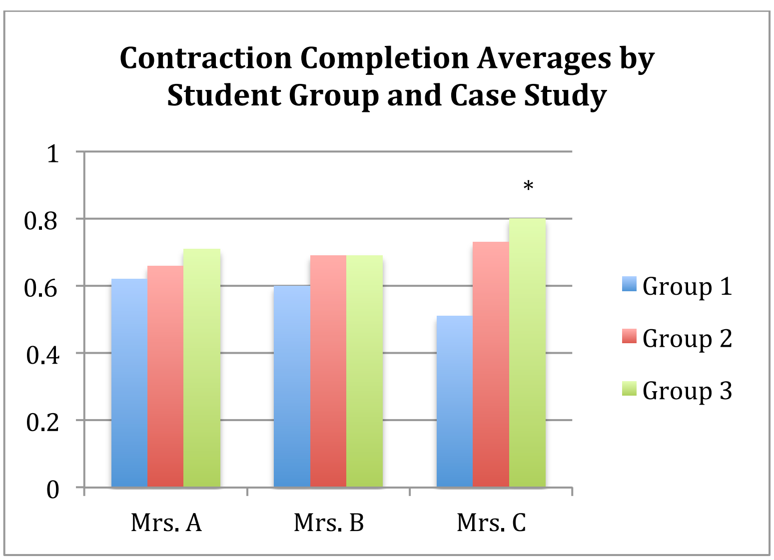

Chart 1: Partograph worksheet completion results for **contractions** organized by student group (Group 1: silent PartoPen, Group 2: functional PartoPen, no training, Group 3: functional PartoPen with training).

* = p < .05 using an unpaired t-test

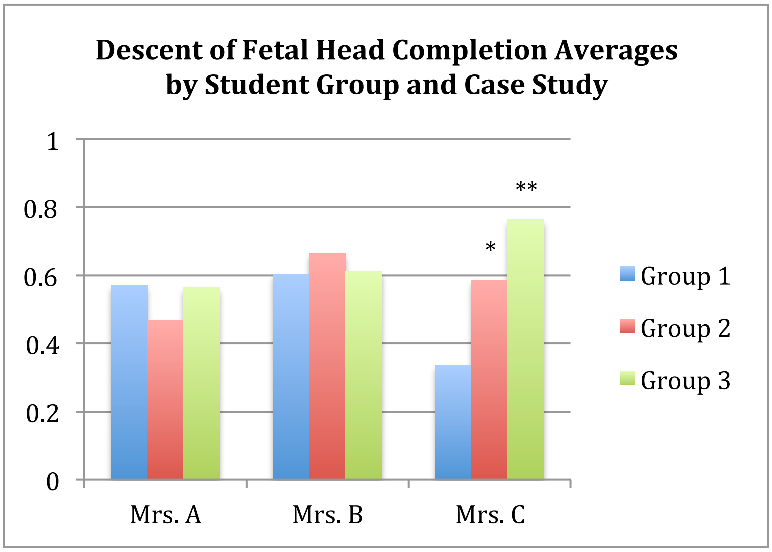

Chart 2: Partograph worksheet completion results for descent of the fetal head organized by student group (Group 1: silent PartoPen, Group 2: functional PartoPen, no training, Group 3: functional PartoPen with training), and by case study (Mrs. A: normal labor, Mrs. B: long labor, Mrs. C: obstructed labor and cesarean section).

* = $p < .05$ using an unpaired t-test

** = $p < .01$ using an unpaired t-test

Conclusions & Future Work

The preliminary results of the nursing student study indicate that student performance on a partograph worksheet completion task improves when using the fully functional PartoPen system. A significant finding of this study was that the PartoPen software significantly improved student scores on the more complex patient case study, suggesting that reinforcement of existing knowledge, as well as real-time decision-making, may be facilitated and improved by using the PartoPen system.

Future work on the PartoPen project will include clinical deployments at various levels of healthcare in Kenya, including rural health clinics, dispensaries, and district level facilities. I will also expand the nursing student study described in this paper, and evaluate the impact of long-term PartoPen use in the classroom, and how such use affects performance among students during clinical rotations and evaluations. The next step in determining the impact of the PartoPen system is to expand the goals of the study from looking solely at completion rates to include how partograph completion (or incompletion) affects maternal and fetal outcomes. I am currently collaborating with a larger maternal health project based at KNH to study this impact.

The PartoPen software provides a flexible and intuitive tool that differs from previous efforts intended to improve partograph adoption. The PartoPen supports existing WHO protocols, but can be easily adapted to local protocols and languages, making it adoptable by any clinic in any part of the world. By augmenting, rather than replacing the paper-based system, training overhead and failure risk are significantly reduced relative to other high-tech solutions. In addition, if the PartoPen software were to fail, the digital pen can still be used as a regular pen on the partograph and on any other paper form, thus eliminating technology-related disruptions to the critical labor monitoring process. There is also significant potential for interfacing with other commonly used paper healthcare-related forms by providing a seamless bridge between paper-based systems and electronic medical record systems. Providing a link between digital and paper data is a key feature of the PartoPen system that enables effective use across the maternal healthcare continuum. Finally, the flexible PartoPen software allows the tool to be used in both the developing and developed world at all levels of care, from undergraduate nursing students to experienced nurse midwives, from rural birth attendants to trained physicians.

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