Papyr: Automatically Generating “Smart" Paper Tools for Low-resource Settings

ABSTRACT

Despite the recent push toward leveraging information and communication technologies (ICTs) for replacing paper-based tasks, there remain many barriers to designing deployable and appropriate technical solutions that replace paper. As a result, paper tools such as forms, charts, and graphs continue to be widely used in low-resource organizations working in developing regions. Unfortunately, existing paper tools are often designed to be out of reach for end-users and depend on intermediaries to input data and interpret information. We apply ideas from computability and human-computer interaction to design a system to automatically generate paper tools that provide immediate computation, visual feedback, and independence from both ICTs and intermediaries at the point of use. Papyr is a system that is easy to use and allows low-resource organizations to quickly transform data tracking or information dissemination requirements into printable “smart” paper tools. In this paper, we explore how paper tools are currently being used by organizations in Ghana, explore the design space for smart paper tools, and describe Papyr's design and implementation.

1. INTRODUCTION

Even as computing devices proliferate and try to eliminate paper from a given ecosystem, it is undeniable that paper continues to be pervasive in professional and personal spaces. Paper is light, low-cost, familiar, accessible, easy to use, intuitive to manipulate, and convenient to distribute [20, 21, 12]. Moreover, in low-resource settings where technology infrastructure, such as stable electricity, cutting-edge computer hardware and software, and skilled human capital, is deficient, paper is an obvious choice because it can accomplish many of the same tasks that computers can, including tracking, recording, and look-up. Furthermore, generations of paper-based organizational and end-user tasks have ensured that national regulations seek compliance with paper-based record keeping rules. The enduring legacy of paper, especially amongst current paper-based workflows, provides inertia against switching to more technically intensive replacements.

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Still, paper is not without its constraints. When compared to information and communication technology (ICT) alternatives, paper is less malleable once data is inscribed, has less“computational output”, and is difficult to digitize. Electronic media that is designed and built to replace paper possesses an inverse profile of not only strengths but also constraints, unable to capitalize on paper's more accessible and tangible properties [12]. Can paper itself be designed to overcome some of its limitations? Can paper, for instance, make its static content dynamic? Or, perhaps, even more ambitiously, can paper provide computational feedback to its end users?

There already exist many examples of “smart paper” that demonstrate how these lofty objectives are in fact possible. Paper graphs, for instance, can provide computational feedback. The nomograph has three scales to represent a three-variable equation. In one illustration, by plotting along these scales using just a pen, a user can determine their ideal body mass by locating their results within the “overweight”, “desirable”, or “underweight” categories, while accounting for any gender differences [25]. The partograph, another example, is a graphical tool that can provide predictive feedback to doctors or midwives throughout the progress of labour[14]. It is popular in low-resource settings, a cost-effective and accessible tool that when coupled with well-defined protocols and appropriate instruction has been shown to demonstrate distinct benefits [9, 26, 8, 17].

These examples of “smart” paper tools indicate a particularly compelling research problem of leveraging paper's many useful properties and developing more standalone tools, validating their usefulness in low-resource settings where paper is cheaper, more familiar, and more accessible than its technological counterparts. Our study addresses this research problem and explores the “smart” paper space with the following contributions:

- Needs assessment of low-resource settings for microfinance and health in Ghana through an appraisal of existing paper artifacts and understanding of information gaps. (Section 3).
- Development of “smart” paper tools design iterations through brainstorming sessions and in the field feedback that are pushing the boundaries of paper and exploring how paper can contribute to existing processes, especially with low-literate populations in mind (Section 3).
- Discovery of basic design principles that highlight the

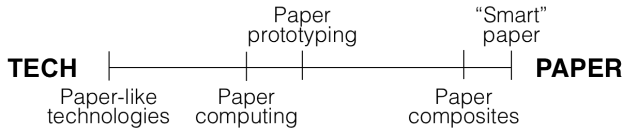

Figure 1: Spectrum between paper and technology (Section 2)based on the degree of integration with technology: leftmost end is most tightly coupled with technology and rightmost is most free of technology.

constraints of paper and user interaction with "smart" paper tools (Section 4).

- Construction of Papyr, a system for intermediaries from low-resource organizations to automatically generate "smart" paper tools by simply defining their tasks and their associated paramters. The intermediary can then select from suggestions based on resources available and capabilities of the end-user to print and construct the paper tools based on the resources available (Section 5).

2. RELATED WORK

The spectrum between paper and technology. There is a spectrum of innovations that attempt to bridge the gap between technology and paper and leverage the benefits of both, a spectrum based on the degree to which the innovation is integrated with technology, as described in Figure 1.

The tools that rest in the space between paper and technology most strongly integrated with technology are *paper-like technologies*. This includes a set of tablets and mobile devices, including PaperTab, PaperFold, and MorePhone, that are electronic devices that are as reconfigurable as paper itself [11, 10, 24]. The selling point of these technologies are their paper-like properties, including portability, maneuverability, and flexibility, a familiar look and feel to technology with the provision of the same capacities as a full-fledged tablet or phone. This reinforces the draw to include the benefits of paper in technological design, but does so in a fairly expensive way.

Other tools attempt to explore the role of paper documents as interfaces to the digital world, or the field of *paper computing* [13]. This includes systems that use paper to control technological environments, such as Digital Desk, the projection of graphics interfaces on a paper-based workspace, or PaperPoint, the control and annotation of PowerPoint presentations using printed slide handouts [15, 30, 22]. In addition, this includes tools that provide technological links to paper, such as printed visual markers (QR codes and barcodes); specialized devices for annotations and digitally inputted notes; computer vision based digitization of paper; and cloud computing [13, 2, 18]. However, these technologies often use paper as an aid to technology as opposed to utilizing paper's beneficial properties on its own.

Paper can be used to model technology in paper prototyping or paper composites. *Paper prototyping* utilizes paper's accessibility and ability to be easily manipulated to simulate and test the usability technological designs in a "wizard of oz" experimental structure [23, 3]. This shows a loose coupling of paper to technology in that technology is not used in the generation of the tool, but the tool is paradoxically dependent on technology because it has no power when used alone. On the other hand, *paper composites*, or combinations of paper with technological materials, such as the paper and conductive thread combination in pulp-based computing, can give these paper-based tools more power, but still only exist to simulate technology and are reliant on technological components [5].

Paper and technology in low-resource settings. One of the problems with this type of relationship with technology and technological components in the workflow is cost and a reliance on tools and materials low-resource organizations do not necessarily have. However, there there are some innovations that attempt to bridge the gap between existing paper materials with low-cost technological interfaces like mobile phones.

Looking specifically at some of the tools developed for low-resource settings, most are still tightly reliant on technology and would fall mostly in the *paper computing* category. This includes tools that recapture information that already exists on paper into the technological space, such as CAM, which uses a camera to record and store data from paper logs in rural microfinance groups in India; ODK Scan, which applies computer vision techniques on small "snippets" of the content for a single form field; and Shredder, a combination of computer vision, database, and crowdsourcing techniques to transmit and verify information from paper forms [16, 1, 7, 6, 4]. There are also tools that use technology to track the actual process for data input on paper-based forms such as Digital Slate, which uses the pen to paper writing motion to capture data in savings groups in India, and Partopen, which is a digital pen specifically developed for filling out the partograph in maternal labor [19, 27, 28]. And there are even tools that use a mix of technology and paper in the information gathering process itself, such as Local Ground, a barcoded geospatial surveying tool [29].

In addition to being tightly coupled with technology, these tools are used mainly for information collection, including both retroactive and active data capture. Most of these innovations do not give very much feedback to the user at the time of use, except perhaps PartoPen, and thus does not leverage one of the important abilities of computation.

We believe Papyr is an unusual but appropriate marriage between paper and technology for developing contexts: a computer is used to support the organization's design of context-specific paper tools, but the produced paper tools require no ICT support or leverage at the end user. Moreover, Papyr provides feedback to the end-users, encouraging utilization and adherence to the processes.

3. EXPLORING PAPER

After reviewing related work and identifying real-world problems in the health and microfinance contexts in low-resource settings where paper is already deeply rooted and in constant use, we developed two sets of design iterations: one based solely on brainstorming sessions and the other based on in the field feedback. In Section 3.1, we describe designs that attempt to push the boundaries of paper to explore the range of computational and visual feedback that paper in and of itself could provide. Afterwards, in Section 3.2, we discuss designs that are based on a needs assessment to see how paper is being used in the health and microfinance contexts at field sites in Ghana and feedback from real end users.

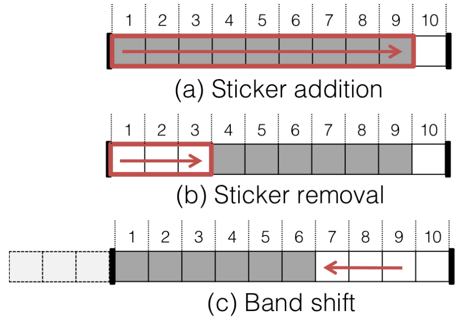

Figure 2: *Subtraction band (Section 3.1.1).* First populate the band with stickers to obtain the sum of cumulative addition (a). Then remove stickers up to the amount that is being subtracted (b). Finally, slide the band so the stickers line up with the start and the resulting difference (c).

3.1 Brainstorming Design Iterations

The primary goal of these preliminary brainstorming sessions was to push the boundaries of what "smart paper" could accomplish. In other words, how could we re-design paper in a way that makes it somehow better? Here, we describe a small subset of the "smart-paper" tools we designed.

3.1.1 The Subtraction Band

Use cases. One problem in the microfinance domain for low-literate users is keeping track of exactly how much is earned and where money is spent in a given day. We designed a tool that would help tackle one of the sources of difficulty for this problem, or doing addition and subtraction of expenditures more easily.

Proposed tool. The base is made of stiff paper, plastic, cardboard, or other material that could support two narrow slits through which a closed paper loop could be smoothly slid and rotated. There are two sections on the base, the top section is a basic scale of amounts with a predetermined interval and on the bottom is the band threaded through two slits. This band can be made with paper or waxed paper to ensure smoother sliding. A depiction can be seen in Figure 2.

An individual will place a sticker in each slot every time they earn money that day. To take a simple example, say an individual has earned cumulatively 10 cedi[1] today. The band would be marked up to the 10th slot. However, the individual now spends 3 cedis. They will remove the stickers up to the 3rd slot. Then, they can shift the band to the left such that the first filled slot moves back to the leftmost point, or the 1st slot. Depending on the resources available, the individual can opt to shade in the band instead of using stickers.

Lessons learned. This tool can be generalized from the basic use case to include any type of task that requires addition and subtraction.

3.1.2 The Addition By Matching Tool

Use cases. Low-income populations are typically engaged in the informal labour market, meaning their income inflows are irregular and variable, accumulated through a variety of financial instruments such as money earned through different jobs and money borrowed through different sources of credit. We decided to design a tool that can be used to compare income and expenses to determine when income-expenses can be met or matched versus when one exceeds the other as well as allow the user to flexibly update any changes in the projected values.

Proposed tool. Again, the base would be made of stiff paper, plastic, cardboard, or other material that would support two narrow slits through which a paper strip could be smoothly slid up or down. Figure 3 is a representation of this tool. The horizontal axes indicates where each separate strip would be strung and the vertical axes indicate the amounts accumulated on each strip.

If a user estimates that the incomes for the first day will be around 20 cedi, she or he would fill the cells in the income column for Day 1 up to the 20 cedi mark on the vertical axis. And then if the user estimates that on the second day, the income will be approximately 30 cedi, she or he would fill the cells up to the 30 cedi mark on the axis and then shift the band so that the stickers start after the filled income for the previous day, at the 20 cedi mark. In this case, the user can easily tell that over the two days, the income has been accumulated to 50 cedis. The user then can finish populating the rest of her or his projected income in a similar manner and continue in a similar manner for the expenses columns. In the example, the user can then see that over three days, she or he as earned and spent cumulatively 60 cedis. The user can also see that expenses exceed income on Day 1, income exceeds expenses on Day 2, and they match on Day 3.

While tracking incomes and expenses, if there is an unexpected 10 cedis of expense that is introduced on Day 1, then the successive stacks of expenses must be readjusted. This is achieved by sliding the paper strip for the expenses on the following day up so that the filled in units rest above the end of the filled units for the day that was altered, and continued through to all of the successive days.

Lessons learned. This tool can be generalized to calculate any cumulative sum and compare and match analogous variables.

3.1.3 Averages Tool

Use cases. Often times in villages, women are not actively tracking their menstrual cycle. Therefore, the woman does not necessarily know when ovulation is likely to occur to determine when she is most fertile or if she has missed her period and is pregnant. We create a tool to help women track their menstrual cycles to give them a sense of their average cycle length.

Proposed tool. In its simplest form, the tool is a long strip of paper segmented to represent different days. Every seven segments, the strip is highlighted with a different color to indicate the beginning of a week.

Each day the individual does not have their period, she will unroll the strips of paper. On the day the woman does get her period, she will rip the strip of paper at that point to get a segment of dates that represent that one cycle. Once there are paper sections for each of the cycles, these sections are arranged next to each other. This could give a good "eyeball" estimate of the average, and the woman can have a sense of where the average would lie, as seen in the dotted region in Figure 5. The next time, as the the woman is

[1] local currency corresponding to roughly 0.28 USD per cedi at the time of writing

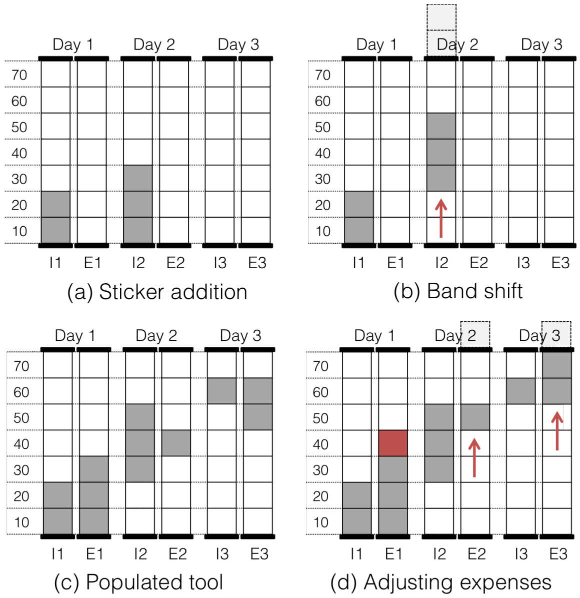

Figure 3: *Addition by matching tool (Section 3.1.2).* Populate each of the columns based on the scale on the y-axis (a) and shift the bands that so that their stickers stack above those of the previous band (b), see an example of a completed tool (c). In the case of an additional expense, adjust the bands that follow to maintain the “stacked” invariant (c).

unrolling her strip of paper, she will know that as her paper lines up similarly to the previous cycles, she should anticipate to be her period. This could be enhanced with the use of a tool that lines up with the shortest strip and the longest strip in the range of data points and, with springs or rubber bands attached to the middle mark, draws a line between the two to come up with an alternate means of estimating the average. This is seen with the bars and coils in Figure 5.

A different idea for determining averages is the wrapping method. The woman would still continue to unroll the strips each day that she does not get her period. However, she will not rip the strips of paper on the days that she does get her period. Instead, she will have a length of the strip that represents all of the cycles she has had from the beginning. In this example, the woman would have a strip with the length of 167 for her 6 cycles. Then, she will take this long strip and wrap it around two rods, potentially pens or pencils, the number of times she has her cycles. In this example, she has had 6 cycles, so she will wrap the strip tightly six times around the two rods while tracking the end of the 167 day length. She can then hold onto the rods and separate them in a parallel manner in opposite directions until one rod is lined up with the square for the first day and the other rod is lined up with the square for the last day. This should give an even six lengths for the 167 days, which represent the average of the days.

Lessons learned. The strips of paper with date increments can be used for any type of time or date tracking. And the methods of comparing these date strips can be used for any type of averages tracking.

3.2 In the Field Design Iterations

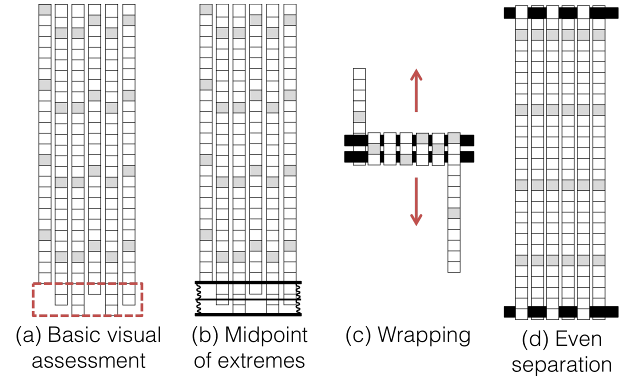

Figure 4: *Averages tool (Section 3.1.3).* Line up the sectioned lengths next to each other and visually estimate the average length (a) or use a tool that finds the midpoint between the shortest and longest lengths as an estimate (b). Or, instead of sectioning, take the full strip and wrap around a rod it that number of times (c) and slowly pull it apart to have the entire length be separated evenly (d).

We conducted contextual inquiries in the domains of microfinance and public health in the Greater Accra area in Ghana, including Tema, Dodowa, and Awutu, over a period of three weeks in July 2014. During this time, we observed the organizational settings, user practices, and existing paper artifacts.

3.2.1 Susu Tracker

Use cases. We spent time with a microfinance institution (MFI) in Tema, observing their daily “susu” (savings) operations. Clients deposit a standard amount for 31 days where 1 day is kept by the MFI as commission. These transactions are logged in a standard paper passbook along with the date on which a deposit was made, the amount deposited, and the running total for each cycle. However, the amount taken for commission and the cumulative sum across different cycles is not provided by the passbook. Therefore, when the customer goes for a withdrawal, they are unaware of how much money they have saved up in total and how much of the money they put in was separated for commission. We designed a tool that could give the customer this missing information, specifically geared toward those with low-literacy and arithmetic skills.

Proposed tool. We tested the usability of five design iterations with existing customers. The first iteration is a calendar with a stack of stickers that has the running total, with commission accounted for in the first deposit of a cycle by a red sticker. The final iteration utilizes no stickers, but, in a simple passbook format, has the running total over all of the different cycles already printed out in the overall balance column.

Lessons learned. With the feedback from the users, it was found that the layout that capitalizes on the familiarity of the existing passbook format and required the laast amount of additional materials (ie, using only a pencil vs. a separate stack of stickers) is the most effective.

3.2.2 Graph Reader

Use cases. We observed medical practices and conducted interviews with different doctors and nurses at a government

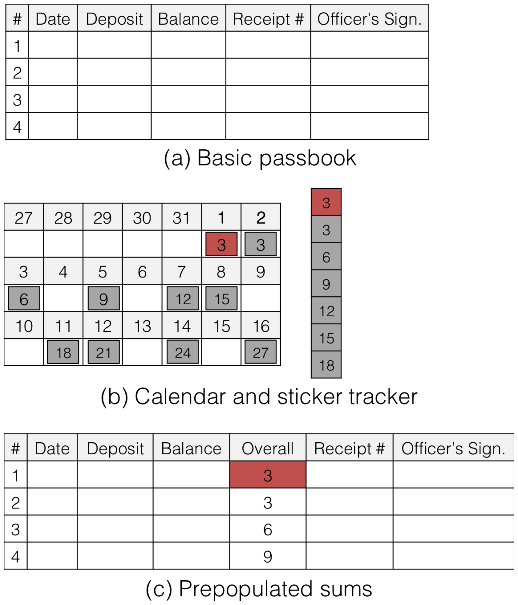

Figure 5: *Susu tracker (Section 3.1.3).* A basic passbook (a) can be improved to show commission and cumulative sum information by using a calendar and sticker tracker (b) that has preprinted sums on the stickers or a simpler augmented passbook that has the cumulative sum prepopulated (c).

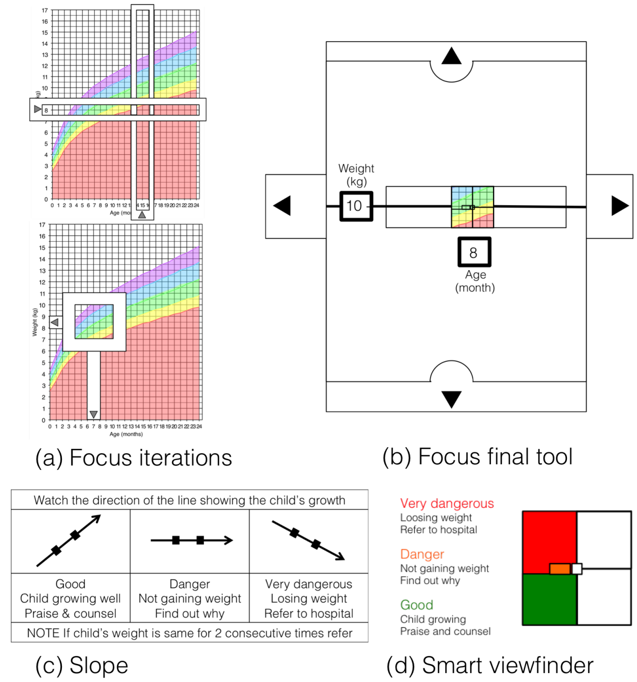

Figure 6: *Graph reader (Section 3.2.2).* Different contenders for trying to focus on the important information in the graph include hollow strips and a basic square (a) but the final tool is based on horizontal and vertical sliding tabs (b). Comparing two points is possible using positive, negative, and zero slopes (c) or a smart viewfinder sectioned into corresponding quadrants (d).

district and children's hospital in the greater Accra region and interviewed medical professors and intermediaries, such as local community health volunteers.

There is a chart that nurses use to determine whether the child is at a healthy weight-age balance based on the WHO regulations of child growth percentiles. This chart also tracks the child's weight over 24 months, accompanied by a legend to indicate the possible slopes between each of the points, and their implications, as seen in Figure **??**. Though this information is relevant to the mothers, the confusing and esoteric presentation makes it inaccessible for those who do not know how to read graphs, and clunky to use for those who could. Therefore, we decided to develop a tool that would help individuals read this graphical information more easily.

Proposed tool. To improve this tool for low-literate populations, the first challenge is finding a way pinpoint the location of the information of interest. Various ideas for tools were developed, including tabs that stretch to the numbers of interest on the graph and position the basic square viewfinder as seen in Figure **??**. Another idea was hollow strips that could be placed on the axes to point to a given region and would overlap to pinpoint the specific region in the center, as seen in the second example However, based on design principles for low-literacy users and feedback from the needs assessment, we decided we not only needed to highlight the important regions but also to cover the information that is not needed. Therefore, we toyed around with overlapping and sliding pieces of paper and developed a tool that uses horizontal and vertical tabs to slide the region of emphasis in place. An example of this tool can be seen later in the paper in Figure **??**.

Another design question was finding ways to compare two points with each other. This could involve something as basic as the slope comparison that the current child and maternal health records use. Or, this could use the viewfinder's space to compare the slope of two points. After feedback from nurses and doctors, the final iteration of the tool includes a viewfinder that compares points based on the quadrants they fall in, as seen in Figure **??**.

Lessons learned. We found that the tools that have a narrower field of view and focus on the important information are most effective. Additionally, we find that having a simple viewfinder can help increase the computational feedback provided by the paper graphs. These graph reading tools can be applied to any type of basic line graph.

3.2.3 Flowchart Booklet

Use cases. Through interviews with a reputable nonprofit organization engaged in public health interventions and interactions with community health volunteers, we learned that one of the tools used by nurses is a decision tree for diagnosing common ailments. This is derived from the Integrated Management of Childhood Illnesses (IMCI), which is a flowchart that instructs the intermediary which questions to ask the caretakers of the patient or which symptoms to check for and how to proceed depending on the results of these inquiries. However, the current representation of the logic for this process is too overwhelming with a lot of detailed information on a single diagram or oversimplifications to accommodate information in a way that is easily represented by a single diagram. Therefore, we decided to create a more efficient tool for presenting this information.

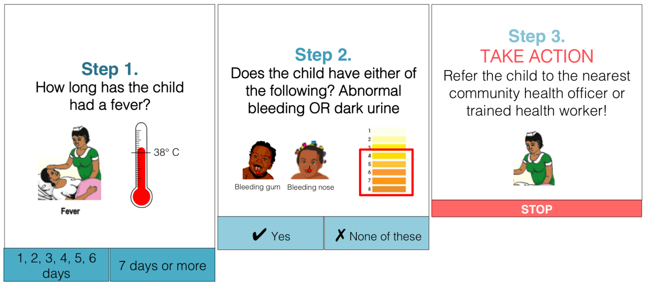

Figure 7: *Flowchart booklet (Section 3.2.3).* At each step, the user will be presented with either a question or instruction. The question will have two answer option tabs that they can flip to move onto the next step. The instruction will have a red "STOP" to notify them to take action.

Proposed tool. We started by simplifying the flowchart so that each potential option would be represented by a different section of the booklet. However, we soon found that this would decrease the amount of space that we would have on the page and detract from our ability to properly show all of the information. So we decided to use tabs to demonstrate the options that a user could take at a given point. After demonstrating our first iterations to an audience of doctors and nurses, it was found that the progress from one step to another was not self-explanatory. Even though the users would follow the steps on the booklet, it was difficult to know when to stop. We tried adding arrows to the pages to indicate the flow from one page to the next, but the arrows were unclear when it came to needing to choose which option to flip. Finally, we found that we would make the options more clear but also to append a long red bar that said "STOP" at the end of a given action sequence, as seen in Figure 7.

Lessons learned. We find that since any "smart" paper tool in a low-resource setting will most likely not come with many user instructions or training sessions, the progression from one step to another has to be fairly clear to the user.

4. DESIGN CONSTRAINTS

Given the immense design space of paper-based tools we had to limit our scope for this project. Here we consider the various constraints of paper itself, our target users, and our specific contexts to scope the eventual design of Papyr.

While the goal of this project was to manipulate paper's many properties in a way that could augment its computational and visual outputs, we were constantly aware of its limitations:

- Paper has *limited computational feedback* when compared to a computer. As an example, while generating the running total in the susu tracker, we were only able to do so because the intervals were of a fixed value. Therefore, providing a dynamic running total for successive numbers with a variable interval between them would be challenging.
- Paper is also constrained by the *limited amount of physical space* that is available for a specific tool. For instance, the range and the upper limit of numbers in the subtraction band must be directly correlated to the size of the base paper/cardboard sheet the user is willing to work with, and that is not unwieldy and difficult to manage.
- Paper has *limitations on physical manipulation.* Paper sheets, of course, can be folded or placed next to each other, in order to provide some dynamic re-sizing capabilities, but physical manipulation such as folding also has its limits with respect to the number of folds possible with paper. Paper can provide sliding or pulling/pushing movements (e.g. in the subtraction band as well as the addition/matching tool), but such movements can be awkward or suffer from wear and tear after repeated use. Comparable, low-cost material substitutes, such as ribbons, may be improve certain problems, but we limit our investigation here to paper.
- Paper has *limitations on being self-explanatory and intuitive*, especially to the low-literate populations we were targeting. User capabilities can be improved through training and other in-person support, but we limited our investigations to paper tools that required minimal training and intermediation.

5. PAPYR SYSTEM DESCRIPTION

Papyr is an interactive system that allows intermediaries working at low-resource organizations to rapidly and automatically generate customized paper tools that give computational and visual feedback. Through a series of questions, the intermediary, as the user of Papyr, specifies a task or tasks. They are then presented with a set of potential tools generated by Papyr and select the tool that best suits the resources available and the capabilities of the end user.

In developing Papyr, our main goal is to abstract the design iterations we conducted in both the brainstorming and field contexts in order to match them to the intermediary's task preferences. We decide to take a task-based approach and define three different categories: progress tracking, decision making, and information lookup. The main distinction between these is whether the information presented is dynamic and how much user interaction is necessary—tracking tasks require periodic user input and the resulting information is dynamic; lookup tasks have static information and minimal user input; decision tasks require user input but the resulting information is static.

The system is implemented as a web-based system with HTML/CSS and Javascript built utilizing the jQuery, Twitter Bootstrap, and D3 frameworks in 2134 lines of code. Papyr is developed using only client-side code so that it can be used in settings with low connectivity.

5.1 Progress Tracking

Use cases. Tracking encompasses tasks that require periodic user input, including marking the days a patient takes pills to visualize regularity of medication consumption or tracking the days the microfinance savings customer makes the required two cedi deposits to calculate cumulative sum. Other use cases include caloric intake each day over a month, amount of sleep each day, length of menstrual cycle each month, daily journaling or mood tracking, journaling each day, or spread of disease throughout a community.

Task representation. In the most basic form, each of these tasks can be done using a table. The main dimension of this table is the change in time, with each row as a single time interval, which varies based on the frequency and the duration for which it is tracked. Another dimension is the values in each one of the cells. Some tasks require only a simple yes or no of whether the event occurred to determine regularity, such as medication consumption, and other tasks require a numeric value that could contribute to a cumulative sum, such as daily deposits.

In the cases where there is more than one piece of data being tracked over time, each task can be defined separately and then, if the time intervals are compatible, automatically merged into a single table with multiple columns. For example, if the task is to track mood every day, and there are five different possible moods, each of the moods is considered a separate tracking task and merged into a single table with one column for each mood.

System implementation. One challenge is allowing users to input task specifications and parameters in an understandable way and to translate this input to paper tool outputs. We originally proposed to allow the user to string together a series of "per" and "over" phrases for each relevant time and location to specify their task. For example, an input could read "I am tracking the regularity of my medication consumption per day over three months." However, this method proves to be ambiguous and difficult for both the user and the computer with more complicated inputs. Eventually, the minimal series of questions was developed to determine the dimensions of the tracking task and differentiate between each of the potential outputs.

The system asks the user a series of questions about the tracking task they are proposing, including the values of the input and the frequency and duration of the tracking. The system is interactive—for each question, Papyr iterates on the user's answers and outputs suggestions, allowing the user to visualize the impact of each additional constraint. For example, after answering the first question, "What are you tracking?", the user is presented a blank one-column table where only the first row is filled with the task name. The next question asks about the possible values of the tracking task. If the user indicates that they are tracking only whether the event occurs or not, another suggested output is the same one-column table populated with "YES/NO" in each row so that the end-user can circle the corresponding word based on the occurrence of the event. The user can very clearly see the incremental difference between the blank table and the new "YES/NO" table when choosing between the two. From there, other options are built such as calendar-based charts for monthly tracking or outcome tallying to count the number of times someone does or does not take their medication. Some examples are seen in Figure 8.

Each of the output suggestions includes the base table that will be used, as well as a set of possible instructions that vary based on the level of literacy of the end user and the cost of any external materials. In the previous example, for the blank table, the user receives potential instructions of writing either "Y" or "N" on each of the lines depending on whether the event occurs, shading in the rows for the time intervals the event occurs, or placing stickers in those rows. The user then has the opportunity to compare all of the possible tools along with their associated instructions and select the one that matches their specific context.

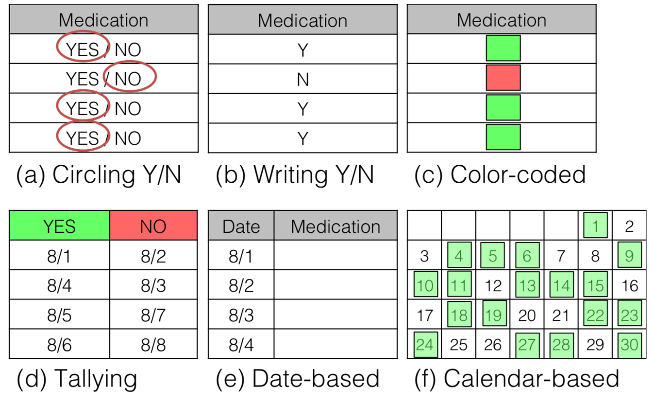

Figure 8: *Tracking example (5.1).* These are examples of potential outputs by Papyr for tracking whether medication was consumed or not on a daily basis over a month.

5.2 Information Lookup

Use cases. Information lookup includes tasks with static information, such as calculating an individual's body mass index to seeing if they fall in the percentiles for being over or underweight. Or finding out the number of calories for each food item eaten to checking the proper medication dosage.

Task representation. All of the information lookup tasks, calculations included, can be represented as a lookup table. The dimensions of these tables are the inputs (i.e. a lookup key) and the outputs (i.e. information the end user is looking up), which are likely numeric or can be reduced to being numerical (i.e. categorical). In the most basic lookup table, all of the inputs would be in the first columns and the associated outputs would be in the columns that follow, as in Figure 9.

However, there are ways to condense such a large, cumbersome table. One step is when there are two inputs and one output, they can be arranged so that one input is the columns and the other is the rows and the outputs as the corresponding intersecting cells. In this example, the columns are the weight and the rows are height. Or this can be extended into a case where there are two inputs and two outputs, it could be a similar setup but having a color coding for one of the outputs, such as the "status" in this example. And if there were more inputs included, such as age in differentiating between adults and children, then the graph can be placed on different pages.

Tables are relatively easy to use for low-dimensional lookups. But with more inputs and outputs, alternative visualizations are beneficial. A clock or calendar could visualize date and time information and a map can be used to visualize geospatial information. And two specialized lookup outputs we present are graph representations and calendar year calculations.

System implementation. Graph representations cover data that has two numerical dimensions as inputs and a numerical or categorical output. The previous BMI example falls in this category. In order to build these graph-based information lookup tools, intermediaries will be asked to input the data that they want to work with, and a graph will be built. Then Papyr will present graph enhancements drawn from the design iterations to help end users with understanding the content of the chart or encourage interactivity. The first improvement helps narrow the end user's focus on the relevant regions of the graph with tabs and cutouts. For graphs with two axes, this is a vertical sliding cover to isolate the y-axis and a horizontal sliding tab to isolate the x-axis. A second enhancement is a "smart viewfinder" that guides the

Inputs			Outputs	
Age	Weight	Height	BMI	Status
Adult	40	130	23.67	Normal
Adult	40	140	29.59	Over
Adult	40	150	35.50	Over
Adult	40	160	41.42	Obese

(a) Separated inputs and outputs

Height (cm) \ Weight (kg)	40	50	60	70
130	23.67	29.59	35.50	41.42
140	20.41	25.51	30.61	35.71
150	17.78	22.22	26.67	31.11
160	15.63	19.53	23.44	27.34

(b) 2 inputs, 1 output

Height (cm) \ Weight (kg)	40	50	60	70
130	23.67	29.59	35.50	41.42
140	20.41	25.51	30.61	35.71
150	17.78	22.22	26.67	31.11
160	15.63	19.53	23.44	27.34

(c) 2 inputs, 2 outputs

Figure 9: *Lookup table example (Section 5.2).* Different table-based representations of lookup tasks with different numbers of inputs and outputs.

end user in doing some basic approximations. For example, sectioning the "smart viewfinder" into different quadrants in relation to the midpoint helps to determine if the slope of the line from the previous point is positive or negative (e.g. Figure 6). A notched "smart viewfinder" could help the end-user compare the distance between the two points, whether it is comparing the sizes of bars on a bar graph or the amount needed to increase or decrease to be in a different category or region. A copy of output for a printout of the tool is seen in Figure 10.

Calendar year calculations are a specific type of calculation for which there is a tool is made of two concentric circles, the smaller layered on top of the larger. Users can specify the relative number of days between one event and another, provided the difference is within the 365 day range of a year. Then, by spinning the inner circle to line up with a date on the outer ring, the end user can calculate the date of the next event. For example, gestation occurs approximately 280 days after the last menses. A tool for this aligns the 0 day mark with the date of the last menses, the 14 day mark with conception, and the 280 day mark lines up with the predicted gestation day. This sample tool is seen in Figure 11. To generate this tool for other calculations, the Papyr system takes as an input an indication of which days are matched with which important event in the year range.

5.3 Decision making

Use cases. A specific case of information lookup is decision driven—though it has static information, the relevance of this information depends on the specifics of the situation. Examples include questions community health volunteers could use to diagnose a patient, decision diagrams to help a customer choose a savings scheme, or checklists for procedures that change based on the outcome of a step.

Task representation. This information could be presented using a table, with each of the potential factors that contributes to the classification of a given situation as an input and the resulting instructions as an output. However, this would result in a fairly sparse table or many sets of sparse tables separated on different pages or sections. More commonly, this type of information is presented in a flowchart

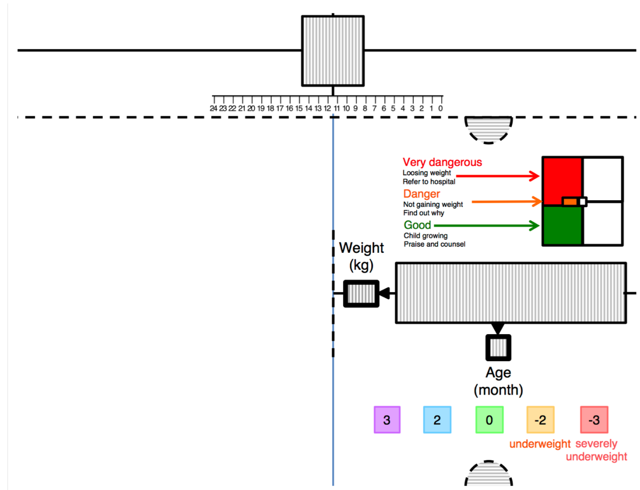

Figure 10: Printed output of the graph tool from the lookup module (Section 5.2) with all enhancements included. To assemble, cut along the dotted lines so that striped sections are removed and fold along the blue line.

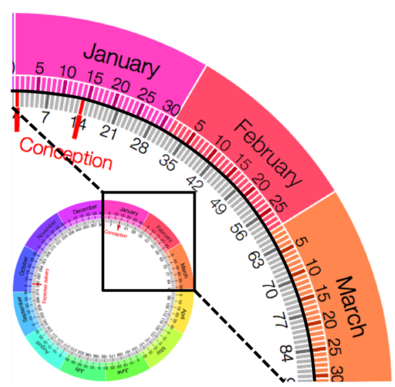

Figure 11: Printed output of the calendar year calculations tool from the lookup module (Section 5.2). The tool can be used by spinning the inner, grey circle so that the red dash lines up with the date of last menses and the conception and gestation markings will line up with the respective, estimated dates.

or decision tree.

System implementation. In the Papyr system, the user can specify the logic of the process in flowchart form. The flowchart is a directed, acyclic graph whose nodes are the "steps" or instructions the end user should follow and whose edges are "options" or logical connections from one step to another.

For example, if the user is looking to create a tool to help parents with the home treatment of fever in their children, the user would first create a step with the question of "How long has the child had a fever?" From this question, there would be two possible paths that can be taken. The user would create another step connected to the first step with the option "less than seven days" and the instruction to "bring the child to the nearest community health center." For the other possible answer to the question, the user would create another step that is connected to the first question with the option "more than seven days" and with the question "Does the child have any abnormal bleeding?". The user would then continue this process in specifying the answers to this question and continue until no questions remain and all paths end in instruction. This example is presented in Figure 12.

Then, the system converts this logic into a booklet. Each page of the booklet will present one question from the flowchart and the potential answer options associated with it as tabs below. The end-user can flip the tab over of the option that they select and continue with either the question or the instruction on the page.

Some of the challenges for this workflow in Papyr include figuring out the order of the steps and instructions. In order to incorporate the feedback from the needs assessment that there should be no blank pages, balanced with the need to show visible instructions, whether it is all possible options at a given time or a "STOP" instruction, our resulting algorithm for adapting the process logic from a flowchart to a booklet ended up being a depth first traversal that highlighted all nodes, or steps, that were accessed, even those that had been visited before. At each node, the algorithm would access the children of the node and append these options as tabs at the bottom of the page but if there were no children, append a "STOP". Another challenge was determining the best way to fit all of the instructions on a page, as per the "screen real estate" constraint of paper. The default presentation of information is using a fourth of an A4 sheet of paper. However, since there seemed to be varying preferences from the feedback, the user also has the option to adjust the size of each of the pages as well and our system uses this to parameterize the output.

6. DISCUSSION

In abstracting and developing the paper tools and the Papyr system, it was found that the design motivations, principles, and applications remain broadly consistent across all platforms—without considering technology, all the other design considerations remain the same. The same process was followed to test and tweak different iterations of a design and the same questions were asked about user engagement—the results were just slightly different. Therefore, while working within a given degree of computational or visual feedback required to solve a problem, we encourage a more rigorous and dynamic use of paper to resolve some of these problems, especially in low-resource settings.

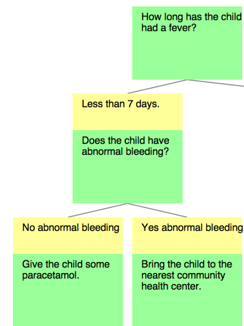

Figure 12: Example of user input of logic in flowchart format into the decision making module (Section 5.3).

We believe that the fervent drive to use ICTs to solve a broad range of problems could be scaled back an reconsidered. To avoid the risk of romanticizing paper, we recognize that paper's computational power cannot match that of a computer's. However, paper can certainly be improved over its existing, static uses by integrating more dynamic "smart" aspects to it, as we show specifically in the context of low-resource organizations in public health and microfinance. These tools and concepts can easily be abstracted to a host of other applications in the international development space. Papyr uses technology to support the development and creation of paper, unlike existing computing applications that reduce and remove paper's presence by mimicking its properties in a surrogate but "flashy" technology artifact. This preserves the affordances of paper for the end user while still being able to accomplish tasks such as progress tracking, information lookup, and decision making.

Papyr is also unique in its use of intermediaries, such as leaders of microfinance institutions or health officials in a hospital setting, to construct the tools for the end users in a way that is context-relevant. During our time in the field and through our interactions with different users, we discovered that their goals did not always align with the broader goals that we had envisioned for the paper tools. For instance, we assumed that users wanted more complete and precise results what the susu, or savings, tracker was providing them. However, in many cases, users were actually satisfied with or adapted their workflow to the current passbooks. They were able to estimate the approximate cumulative sum based on the number of pages that were filled out and at the time of a withdrawal, many simply asked to withdraw the entire sum of money saved, versus a certain amount. While some of this can be alleviated by retaining some of the original process or look-and-feel of the existing paper tool, as seen in the susu tracking example, this points to the balance between information need and tool ability as well as the general inertia towards the learning and implementation of new tools, paper or otherwise.

In addition to balancing the information needed versus the information that can be provided, there is a tradeoff between information gained and effort exerted. For instance, in the subtraction band, the scattered nature of the sticker sheets, the difficulty of adding and removing stickers, and trickiness associated with the shifting of the band may be disproportionate to the benefit receive, especially when the goal is not precision, but is instead a suitably accurate approximation.

This is especially difficult given the extended training of the tool and periodic evaluation and maintenance to ensure that individuals are using the tool properly. Therefore, it is valuable to push the limits of what paper can do, even beyond what we have explored in this paper, to provide the most marginal gain in information possible.

7. CONCLUSIONS AND FUTURE WORK

There are many ways this work can be extended with regards to the exploration of the capabilities of paper. There are various primitive actions that can be done onto paper that were not included in this study, including, but not limited to, ripping, stacking, layering, or complex folding (origami) with paper. This could result in understanding how layering could help figure out clustering of disease incidence across households in a community or incremental folding of different shapes could tracking. Looking at other low-cost materials, it would be interesting to explore the properties of these items as well or look at ways to create composites with paper to explore more of the spectrum between paper and technology.

Furthermore, there are many ways the project can be extended with the development of the Papyr system including improvements to specific modules or expansion of the overall capabilities. Future iterations can include more specialized tools such as maps for geospatial events in progress tracking or editable calendars for information lookup. Another step would include the support for uploading images or different languages to help adjust the application to be more inclusive over different languages and literacy-levels. We plan to provide Papyr as a free open-source platform for immediate use by low-resource organizations.

This paper describes the an exploration into the design of "smart" paper tools in the context of developing regions. We described the process of brainstorming, designing, assessing, and developing a paper-technology infrastructure that automates the production and distribution of smart paper tools. We explored existing paper tool use in healthcare and microfinance in Ghana to understand how paper is currently being used by low-resource organizations to track and disseminate information. From our needs assessment we iterated on several potential designs of enhanced paper-based tools to push the boundaries of paper. We designed a smart paper generation tool that allows intermediaries to specify tasks to quickly and automatically construct potential paper-based solutions that do not require ICTs at the point of use. We describe the design and implementation of our "smart paper" prototype, Papyr and demonstrate how it can be used to produce smart paper outputs that preserve the affordances of paper for the end user.

The motivation driving this study is the fact that paper is abundant, affordable, deeply embedded in existing workflow practices and personal spaces, and familiar, especially when compared to digital devices that are yet to achieve the same level of adoption and use in the developing world. Furthermore, as we demonstrate in this work, paper is capable of providing augmented computational and visual feedback to achieve some of the everyday tasks that computers currently do. Smart paper can perform basic arithmetic tasks, provide regularity and frequency information through visual feedback, and streamline information dissemination.

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