# Evaluation of Policy and Research Interventions in Science and Technology: *Consequence Assessment of Regulatory and Technology Transfer Programs*

Submitted in Partial Fulfillment of the Requirements for

the Degree of

Doctor of Philosophy

in

Engineering and Public Policy


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August 2011

# Dedication

"I prefer to be true to myself, even at the hazard of incurring the ridicule of others, rather than to be false, and to incur my own abhorrence."

~ Frederick Douglass

*This thesis is dedicated to my wonderful husband and partner in life, Matt,*

*who inspires and encourages me to be the best version of me.*

*He brings balance and happiness into my life.*

*I am forever grateful for the gift of his love.*

## Acknowledgements

This Ph.D. research was sponsored by grants from the Richard A. Lounsbery, and John D. and Katherine T. MacArthur Foundations, as well as the Qatar National Research Fund through grant number NPRP 30-6-7-91 of the National Priorities Research Program. The opinions expressed in this thesis are solely those of the author and do not necessarily represent the views of the sponsors. I am grateful to these institutions for their financial support during my tenure as a graduate student.

I also want to acknowledge the members of my thesis committee who have advised me through this PhD: Dr. Elizabeth A. Casman (chair), Dr. David J. Dausey, Dr. Mitchell J. Small, Dr. Faheem Hussain, and Dr. M. Bernardine Dias.

Liz, you have always made time to meet with me when I needed and read through every single thing I've written. Thank you for being such an attentive advisor. I knew we would hit it off after I discovered our mutual love for the Big Lebowski and what have you. It has been fun. You've always challenged me to do better research and write better papers. Thank you for that. I know that whenever I write anything in the future, your voice will be in my head telling me not to say "I did this, then that, etc." I am really grateful for all the advice.

David, it has been such a pleasure to work with you during the past couple of years. Thank you for encouraging and guiding me through this crazy PhD process. I have learned so much from you and am inspired by the work you do. You are a great teacher and a wonderful advisor. I am very grateful for all the times you met with me to make sure that I had everything I needed to finish this PhD.

Mitch, thank you for always making the time to meet with me when I needed to run things by you. You are a great sounding board for ideas and have continually encouraged me when I was afraid that I was going to fail. I am really grateful for your advice and kindness.

Faheem, you're the only advisor I know who will stay up till 3AM to have a Skype call with his student. Thank you for always giving me the better meeting time slot given the time difference we worked with. Your advice really helped shape my work and I thank you for taking the time to read through my drafts in spite of your very busy schedule.

Bernardine, you are truly an inspiring person. I cannot thank you enough for enabling me to pursue a line of research that really meant something to me. As my sister you have always looked out for me, and as my advisor you have challenged and encouraged me when needed. I don't know how you are able to balance these different roles, but I am so grateful to you for doing so. The work you do really makes a difference in the world, and I feel very fortunate to have been a part of these efforts through TechBridgeWorld. Thank you so much for giving me the opportunity to work with you, and for advising and supporting me through this PhD.

My work in Chapter 1 could not have been accomplished without the help of Professor Francisco Veloso and Leonardo Reyes-Gonzalez. Thank you both for your collaboration on this work. I would especially like to thank Francisco for guiding me through my qualifiers and teaching me everything I know about logistic regressions! Thank you also to all the researchers who volunteered to be interviewed by me for this project.

I must also thank my TechBridgeWorld family, especially, Freddie, Ermine and Sarah. Without their support I would not have been able to complete Chapters 2 through 4 of this dissertation.

Thank you to my 2009 fellow iSTEP interns who worked with me on the study in Chapter 2 and provided me with some great memories of our adventures in Tanzania. Asante sana sana sana… I would like to also thank the University Computing Centre (UCC), in Dar es Salaam, especially Eric Beda Mutagahywa, the Institute of Social Work (ISW), and the Department for Social Welfare (DSW) for their help with our project in Tanzania. Special thanks go out to Dr. Theresa Kaijage, Bernard Sefu, Leah Omari, the Para-Social Workers from ISW, and Sesil Charles Latemba from the DSW for their help. I also thank members of the Tandika village for welcoming us into their community and their involvement with the project.

I'd like to thank all the ICTD researchers and practitioners who provided me with valuable feedback on the PREval framework described in Chapter 3. Also, thank you to Brett for sharing his expertise in this project.

The work in Chapter 4 would not have been possible without the support of the Mathru School for the Blind in Bangalore, India. I am truly grateful especially to Ms. Muktha who helped me through every step in the process of conducting the field research for this project. She is an amazing person and I am grateful to have had the opportunity to get to know her and her wonderful Mathru School. Thank you also to Teju and Sujatha who helped me with all the interviews, Pushpa who cooked amazing food for me, and all the teachers, staff and students at the Mathru School. Also, this project was made possible only with the help and support of my colleague and friend Ermine Teves who travelled to India with me and assisted me with collecting data and other aspects of the work. I must also thank Freddie who met with me on several occasions to provide me with all the data I needed for this work. Also, thank you to Samitha and Sarjoun for sharing their expertise in this project.

On a personal level, I would like to thank my husband, Matt, who has supported me through this PhD process without complaint. He is my rock. I would not have been able to complete this dissertation without his continuous encouragement. He made sure I had something to eat everyday and took care of the house, while I was lost in the maze of my own thoughts and the words on these pages. I love you babe.

My family has been there for me through every occasion in my life. I could not have asked for more of a supportive and loving family. My parents have always encouraged me to be the best I can be and to them I owe everything. Thank you Mama and Papa! I've also been blessed to have so many wonderful siblings who have helped me get through many challenges in life and also shared in my joyous moments. They inspire me to achieve all I can and I am so grateful for their love and support throughout the years.

Last but not least, I'd like to thank my friends who have always been a source of support to me. I would not have survived this PhD without them. I must especially thank my dude Anu for being such an amazing friend to me. Thank you!

## Abstract

This research contributes to efforts in assessment studies related to science and technology interventions. The work presented in this thesis focuses on understanding the effects of policies that influence science and technology interventions, and determining the impact of science and technology interventions themselves.

Chapter 1 explores how the USA PATRIOT and Bioterrorism Preparedness Acts affected scientific progress. Regulations and guidance stemming from these pieces of legislation placed restrictions on microbiological research involving certain dangerous pathogens, including B. anthracis and Ebola virus. On a macro level, results indicated that research involving virulent strains of these organisms was not inhibited by the biosecurity laws. The most striking negative effect was a loss of efficiency.

Chapter 2 examines a pilot research intervention in information and communication technology for development (ICTD). Initial assessments in the field indicated that technology has the potential to be successfully implemented in an underserved community. Researchers' experience in the field also identified the challenges and rewards of conducting field research in ICTD.

Chapter 3 presents the PREval (Pilot Research Evaluation) framework, which was developed to address the specific needs and challenges of ICTD field researchers. This framework draws from established evaluation techniques and other available resources on project assessment, but offers instructions customized for ICTD pilot research interventions. Initial testing of the concept behind PREval indicated that it can be feasibly applied to a range of ICTD projects and has the potential to add value to ICTD pilot project evaluations.

Chapter 4 demonstrates the potential for an assistive technology tool to impact a developing community in the long term. This study examined whether the use of the Braille Writing Tutor could be sustained within the Mathru School for the Blind in India. Sustainability was explored at the micro level based on three dimensions: financial, technological and social. Findings suggest that this assistive technology is financially and socially sustainable given the current conditions at the Mathru School. However, the technology can be modified to render it more technologically sustainable at this location.

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# Introduction

Significant amounts of resources are expended on scientific and technological endeavors each year; for example in 2007, the U.S. federal government spent over 60 billion USD on Science and Technology (S&T) line items [1]. Assessing the impact and consequences of these ventures is challenging and currently not done routinely. The work presented in this thesis contributes to efforts in assessment studies directed towards understanding the effects of policies that affect S&T interventions, and determining the impact of S&T interventions themselves.

In Chapter 1 the effects of a particular set of legislation on scientific research are explored. The USA PATRIOT and Bioterrorism Preparedness Acts were signed into law in 2001 and 2002, respectively. Regulations and guidance stemming from these pieces of legislation placed restrictions on microbiological research involving certain dangerous pathogens. While these pathogens pose health and security risks to people, studying these organisms can provide valuable information to help mitigate their devastating impact. Therefore, continuing research on such pathogens is important. This chapter explores how these regulatory changes affected scientific progress.

Chapter 2 concerns the field of Information and Communication Technology for Development (ICTD), which considers how technology can play a role in addressing the needs of under-served communities. This chapter assesses the success and sustainability of a pilot study that employed mobile phone technology to facilitate data collection and transfer among a community of social workers in Dar es Salaam, Tanzania. Additionally, this work provides insight into the challenges associated with field research in ICTD.

In Chapter 3 approaches to incorporating structured evaluation into the design of ICTD pilot field research projects are examined. This is a challenging problem because of the many unknowns associated with field research in general and the particular complexities involved in ICTD field work. However, there is a need for well thought out project assessment in this area of study, because findings from such evaluations are crucial in shaping future work in the field. This chapter focuses on creating a set of guidelines that researchers can follow to successfully plan and execute structured pilot project evaluations in ICTD.

Finally, Chapter 4 assesses a specific technology intervention in ICTD. This work examines TechBridgeWorld's Braille Writing Tutor, which is an assistive technology tool designed to teach visually impaired students to write in braille using a slate and stylus [2]. This chapter seeks to understand the sustainability of the Braille Writing Tutor, in terms of its cost, technical durability and applicability within a developing community setting.

# <u>Chapter 1</u>: Effects of the USA PATRIOT Act and the 2002 Bioterrorism Preparedness Act on select agent research in the United States

## Abstract

A bibliometric analysis of the *Bacillus anthracis* and Ebola virus archival literature was conducted to determine whether negative consequences of the USA PATRIOT Act and the 2002 Bioterrorism Preparedness Act on US select agent research could be discerned. Indicators of the health of the field, such as number of papers published per year, number of researchers authoring papers, and influx rate of new authors, indicated an overall stimulus to the field after 2002. As measured by inter-organizational co-authorships, both *B. anthracis* and Ebola virus research networks expanded after 2002 in terms of the number of organizations and the degree of collaboration. Co-authorship between US and non US scientists also grew for Ebola virus but contracted for the subset of *B. anthracis* research that did not involve possession of viable, virulent bacteria. Some non-US institutions were dropped, and collaborations with others intensified. Contrary to expectations, research did not become centralized around a few gatekeeper institutions. Two negative effects were detected. There was an increased turnover rate of authors in the select agent community that was not observed in the control organism (*Klebsiella pneumoniae*) research community. However, the most striking effect observed was not associated with individual authors or institutions; it was a loss of efficiency, with an approximate 2- to 5-fold increase in the cost of doing select agent research as measured by the number of research papers published per millions of US research dollars awarded.

## 1. Introduction

In October 2001, President Bush signed the "Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism" Act, otherwise known as the USA PATRIOT Act [3]. It was followed in June 2002 by the Public Health Security and Bioterrorism Preparedness and Response Act, otherwise known as the 2002 Bioterrorism Preparedness Act. Sections of these laws deal with research on select agents (pathogens and toxins listed by the US government that pose a severe threat to public health and safety) in the US, and include procedures for registration, inventory and transfer of these organisms and toxins, and the physical security required for facilities where research is performed. Regulations implementing these laws require US laboratories that possess, use, or transport select agents to register with the Department of Health and Human Services [4].[1] Federal Bureau of Investigation (FBI) background checks were required of all personnel with access to select agents. Research facilities had to meet stringent security standards. Mandatory protocols for select agent transfer and inventory; safety and security training and inspections; notification after theft, loss, or release of a listed agent; and record maintenance were instituted. Certain ex-criminals, drug abusers, illegal aliens, mentally ill people, citizens from the Attorney General's list of terrorist nations, and suspected national or international terrorists were prohibited from working with select agents.[2] Violations of the regulations result in penalties as severe as incarceration [5].

A 2002 Congressional Research Service report warned of potential negative impacts of these laws, including additional financial costs associated with high security and tracking, inhibited

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[1] Associated rules found in 42 CFR 73, 9 CFR 121, and 7 CFR 331; HHS and USDA Select Agents and Toxins, 7 CFR Part 331, 9 CFR Part 121, and 42 CFR Part 73. http://www.cdc.gov/od/sap/docs/salist.pdf and http://www.cdc.gov/od/sap/. Interim rules were first issued in 2003, and final rules came into effect in 2005.

[2] The list of categories of excluded individuals is in actuality much broader by virtue of the databases that the FBI consults for its security risk assessments of personnel.

scientific information exchange and scientific inquiry, and the loss of skilled foreign technical workers [6]. Over 20% of select agent researchers surveyed in 2004 and 2005 noted that the regulation was affecting their ability to collaborate domestically and internationally, and about 40% claimed that they had to use research funding to make security upgrades [7]. A 2006 Stimson Center survey found the main complaints of select agent researchers to be monetary and time costs of security upgrades and procedures, bureaucratic time sinks, the tedium of inventorying samples, and barriers to international collaboration [8]. Researchers have turned down Department of Homeland Security funding because of the bureaucratic overhead of the compliance review [9]. A group of members of the National Science Advisory Board for Biosecurity recently lamented the unmeasurable cost of select agent research that was not done, suggesting that unnecessary inhibition of this science amounts to a national security and public health threat [10].

A National Research Council panel has been tasked with evaluating the safety measures at biosecurity laboratories and the impact of biosecurity policies and regulations on the ability of the scientific community to conduct select agent research [11]. A recent report of the US Commission on the Prevention of Weapons of Mass Destruction Proliferation and Terrorism called for tightening government oversight of high-containment laboratories [12]. Governments across the globe are grappling with the problem of how best to secure dangerous pathogens, and there is an acute need for quantitative measurements of the impacts of the existing oversight before decisions are made to strengthen or relax biosecurity rules.

If the counter bioterrorism laws have had detrimental effects on select agent research, the impacts should be detectable in the published literature, the output by which scientific production is judged. Previous studies addressing the impacts of the biosecurity laws and regulations have relied entirely on expert opinion and surveys. This chapter analyzes the archival experimental research record for evidence of impacts on select agent research.

## 2. Methods

### *2.1 Data Sources*

Two representative select agents were chosen for this study: the bacterium that causes anthrax, *B. anthracis*, and Ebola virus, both CDC "Category A" select agents. *K. pneumoniae*, a common pathogenic bacterium, was chosen as a control organism.

Peer-reviewed research publication records dealing with these three organisms from 1992 through 2007 were retrieved from the Institute for Scientific Information (ISI) Web of Knowledge.[3] Only the subset of papers that would be subject to the biosecurity laws, namely research involving manipulation of viable virulent strains and certain genetic materials conducted in the United States, were retained. This excluded reviews, editorials, letters, *in silico* studies, numerical modeling, meta-analyses, articles that did not list any US authors, and most clinical reports.

The remaining articles were manually classified as "live-pathogen" if the research required possession of viable, virulent organisms or as "non-pathogen" if the research involved only avirulent strains or subcellular fractions of virulent strains obtained without possession of the pathogen (Appendix A, Table A4 and Table A5). Publication data for the control microorganism were identically classified, that is, as if *K. pneumoniae* were a select agent.

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[3] ISI Web of Knowledge, Web of Science, Copyright © 2008 The Thomson Corporation: http://portal.isiknowledge.com/portal.cgi?DestApp=WOS&Func=Frame.

At the time of this study, two searchable sources of annual US funding were available on the web: the NIH CRISP database, which covered only NIH grants and did not include the award amounts, and the RAND Corporation's RaDiUS database, which compiled estimated average annual US research funding data over all federal agencies. The results from using either of the databases were comparable, so for this chapter we reported results derived from the RAND database because it was more comprehensive and reported dollars spent rather than number of grants (Appendix A, Table A6).

Using the microbe names as keywords, yearly funding data for research on each of the three microorganisms were downloaded [13]. Most of the research records included abstracts so it was possible to remove nonresearch grants (e.g., funding for building construction or certain training grants) manually, but it was not possible to reliably sort the funded research into "live-pathogen" and "non-pathogen" categories from the information provided.

It is important to note that the data above naturally excluded classified and forensic research and funding, which might be non-negligible. Yet we believe that classified research has a different nature and objectives and is therefore beyond the scope of this work.

### *2.2 Data Classification*

Determining which years of data to consider having occurred after the laws were enacted and which years before was not trivial because all possible solutions introduce some error. The laws were passed at the end of 2001 and in the middle of 2002, but the regulations implementing them continued to be issued for the next 3 years and are still being scrutinized. Sensitivity analysis supported the decision to define 2002, the first year in which both laws were in effect, as the boundary year and to discard all papers with a 2002 publication date (Appendix A, Table A7).

All papers published from 1992 to 2001 were considered to be written before the laws were enacted and those published from 2003 to 2007 as after the laws took effect.

Paper publication dates also need to be linked to funding dates, that is, to possible one-or multiyear lags between the funding award and the publication of results from the supported research. We conducted a sensitivity analysis on the length of the lag between funding award and publication and determined that 1- and 2-year lags are good predictors of future publications, with the key results consistent regardless of the lag used. All results in this chapter are reported with a 1-year lag. Results with other lags are presented in Table A7 of Appendix A.

### *2.3 Data Analysis*

Binary logistic regressions were performed using STATA data analysis and statistical software (STATA http://www.stata.com/). Equation 1 represents the regression model used to analyze whether there was a shift from "live-pathogen" research to "non-pathogen" research after 2002:

$$P(LivePathogen_{it} = 1) = \frac{EXP(\alpha_0 + \alpha_1 Funding_{t-1} + \alpha_2 Law_t + \varepsilon_{it})}{1 + [EXP(\alpha_0 + \alpha_1 Funding_{t-1} + \alpha_2 Law_t + \varepsilon_{it})]} \quad \textbf{(1)}$$

where $i$ = 1, 2, …, n papers; $t$ = 1992, 1993, …, 2007; $\begin{bmatrix} \mathrm{t} \geq 2003 \\ \mathrm{t} < 2002 \end{bmatrix} = \begin{bmatrix} Law_t = 1 \\ Law_t = 0 \end{bmatrix}$ and

$$\begin{bmatrix} LivePathogen = 1 \\ LivePathogen = 0 \end{bmatrix} = \begin{bmatrix} \text{research with live pathogens} \\ \text{otherwise} \end{bmatrix}$$

In the model represented by Equation 1, if $\alpha_2$ is significantly different from zero, the propensity to publish on "live-pathogen" research was sensitive to the timing of the biosecurity laws. The odds ratio of publishing a paper on "live pathogen" research after 2002 (compared to before

2002) is exp($\alpha_2$). An odds ratio of less than one means that, controlling for funding, papers after 2002 were more likely to describe "non-pathogen" studies.

The model for determining if the laws influenced whether scientists entered select agent research predicts the probability that a given author entered in a given year, P($Entry_{jt}$ = 1), where $Entry_{jt}$ = 1 indicates that author *j* appeared in the dataset in year *t* (Equation 2). As in Equation 1, the model controls for funding level for the previous year and whether the biosecurity laws were in effect at the time of publication. The exit model is identical to the entry model except that it predicts P($Exit_{jt}$ = 1) for author-year pairs:

$$P(Entry_{jt} = 1) = \frac{EXP(\beta_0 + \beta_1 Funding_{t-1} + \beta_2 Law_t + \varepsilon_{jt})}{1 + [EXP(\beta_0 + \beta_1 Funding_{t-1} + \beta_2 Law_t + \varepsilon_{jt})]} \;, \qquad \textbf{(2)}$$

Where:

$j = 1, 2, \ldots, m$ *authors*, $t = 1992, 1993, \ldots, 2007$

and

$$\begin{bmatrix} \mathrm{t} \geq 2003 \\ \mathrm{t} < 2002 \end{bmatrix} = \begin{bmatrix} Law_t = 1 \\ Law_t = 0 \end{bmatrix}; \begin{bmatrix} t \text{ is the entrance year for author } j \\ \text{otherwise} \end{bmatrix} = \begin{bmatrix} Entry_{jt} = 1 \\ Entry_{jt} = 0 \end{bmatrix}$$

Network statistics and figures were generated in UCINET 6 [14]. For institutional level analyses, variants in workplace names were harmonized and classified by institutional type manually.

## 3. Results

The archival laboratory research literature concerning two select agents, the bacterium *Bacillus anthracis* and the Ebola virus,[4] and one control pathogen, *Klebsiella pneumoniae*, was examined in this study. After removing papers that would not be subject to the biosecurity laws (e.g., review articles), the remaining papers were sorted by whether they entailed the possession of viable, virulent microbes. This was done to determine whether the choice of research methods responded to the passage of the laws.

### *3.1 Was the Volume of Select Agent Research Reduced After the Laws Were Passed?*

Although the number of annual publications increased, there was a steep decline in the number of papers per million dollars of US funding for the select agents. This was not observed with the control organism (Figure 1). Before 2002, the average number of *B. anthracis* research papers published per million dollars was 17. After 2002, the average number was only 3. For Ebola virus, before 2002 the average number of papers was 14, which subsequently fell to 6 per million dollars. In contrast, the average number of papers per million dollars for the control organism declined from 26 to 17. Admittedly, the funding data cannot be directly matched to specific research papers, and errors may have been introduced by the data cleaning process. Nevertheless, there should be no particular difference in errors introduced before and after 2002. Therefore, although we recognize that these figures are soft, they clearly indicate that the efficiency of select agent research fell sharply after the passage of the laws, perhaps by factors in the vicinity of 2- to 5-fold.

[4] These select agents were chosen in an attempt to cover a range of regulatory conditions because *B. anthracis* can be studied in BLS 2+ and BLS 3 labs, whereas Ebola virus work has always been conducted with the highest level of biosecurity.

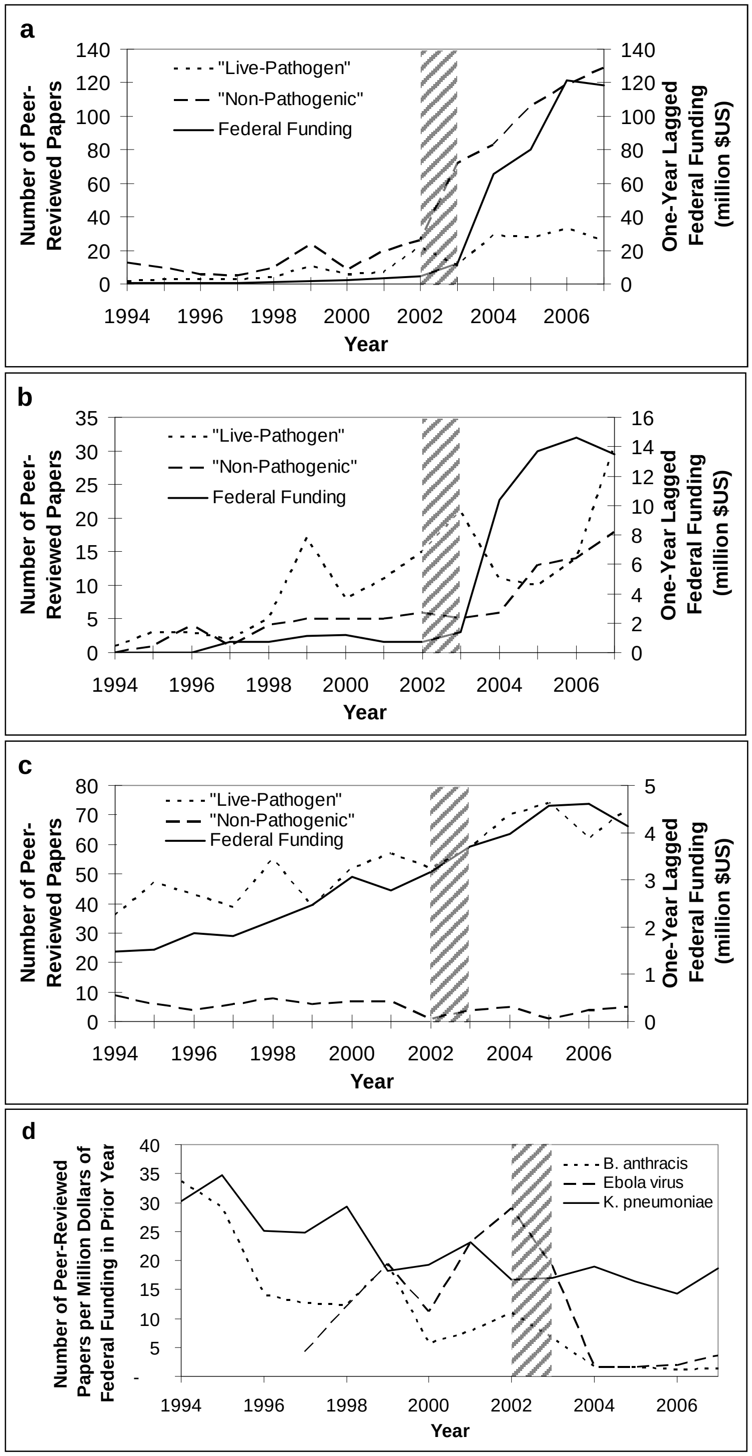


**Figure 1:** Annual peer-reviewed research publications and US funding time series for (a) *B. anthracis*, (b) Ebola virus, and (c) *K. pneumoniae*. (d) Annual number of papers per million dollars of US funding in the previous year. The vertical bar indicates an approximate boundary between pre- and post-biosecurity law eras.

### *3.2 Did the Laws Accelerate a Switch from Research Involving Live Select Agents to Methods Involving Avirulent or Subcellular Fractions of the Organisms?*

One way for researchers to continue working on select agents without having to comply with the most stringent new regulations would be to switch to non-pathogenic strains or to research on subcellular components of the select agents. Using a binary logistic regression to assess whether scientists turned away from research in the more regulated "live-pathogen" category after the laws were passed, we find mixed results (Table 1). After 2002, the propensity to publish research involving viable, virulent *B. anthracis* decreased compared to research involving subcellular fractions or non-pathogenic strains. The same was not true for Ebola virus or *K. pneumoniae* research. The mixed results for the two select agents suggest that the choice of methods was not influenced by the biosecurity laws.

**Table 1:** Ratio of the odds of "live-pathogen" research before and after 2002

| Organism | Odds Ratio |
|---|---|
| *B. anthracis* | 0.54 * |
| Ebola virus | 2.25 |
| *K. pneumoniae* | 1.57 |

* $p \leq 0.10$

### *3.3 Was There a Detectable Exodus of Expertise or Were Fewer Researchers Attracted to Working with Restricted Organisms?*

In the wake of the biosecurity laws, more than one high-profile scientist announced publicly that they had abandoned select agent study rather than fulfill the legal requirements [15]. To determine whether this phenomenon was widespread among scientists doing "live-pathogen" research on *B. anthracis* and Ebola virus, and to understand whether these fields have become less attractive to scientists, we developed logistic regression models for estimating the likelihood of author entry and exit. Authors were said to "enter" the field in the first year in which they published between 1992 and 2007 and to "exit" the year after their last publication within this time period.

Results of these regressions are presented separately for "all scientists" and "career scientists," the latter being defined as those publishing in two or more years within the 16-year period of our study (Table 2). This distinction was made to highlight any effects on the core research communities. Interestingly, less than one third of the authors in the database met the career scientist criterion.

**Table 2:** Effect of the biosecurity laws on the odds of US author entry and exit of the "live-pathogen" research field

| **Odds Ratio of Author "Entry" After 2002** | | | |
|---|---|---|---|
| **Author Type** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| Career Scientists | 3.91 *** | 2.42 *** | 0.71 |
| All Scientists | 9.63 *** | 4.41 *** | 1.11 |
| **Odds Ratio of Author "Exit" After 2002** | | | |
| **Author Type** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| Career Scientists | 0.82 | 4.81 *** | 1.12 |
| All Scientists | 1.87 *** | 1.69 ** | 0.97 |

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$

Controlling for funding, an increased propensity for US authors to enter "live-pathogen" select agent research after the laws were passed was detected. This propensity to enter the field was not observed among control organism researchers. We also observed increased odds of Ebola virus career scientists leaving the field after 2002, which were twice their odds of entering the field.

### *3.4 Did the Patterns of Collaboration Change?*

Institutional collaboration networks for "live-pathogen" *B. anthracis* and Ebola virus research are diagrammed in Figure 2 and Figure A1 of Appendix A, respectively. Changes in the research networks in the 5 years preceding and following the passage of the biosecurity laws reveal some key features of how these communities reacted to the laws. For visual clarity, instead of author names, we plot the names of the authors' home institutions. A link between two nodes represents papers coauthored by members of those institutions.

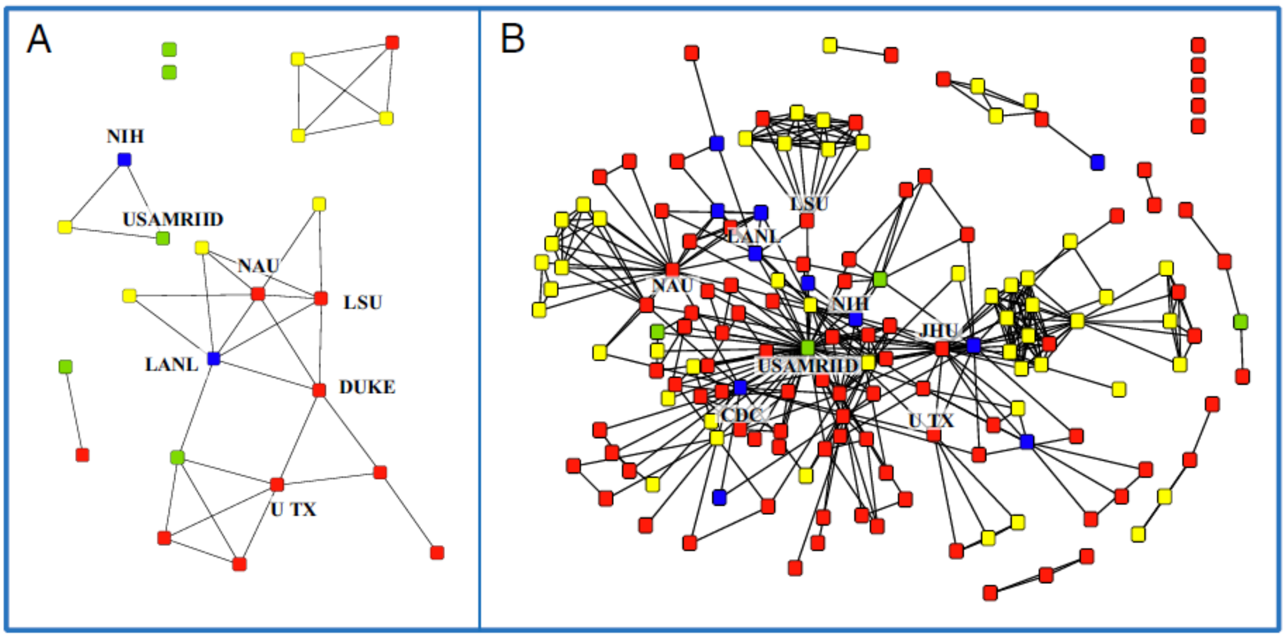


**Figure 2:** Schematic of the collaboration networks of research organizations working with live *B. anthracis*. A link between two nodes indicates a coauthorship involving members of the institutions. (A) Publication network 1997–2001. (B) Publication network 2003–2007. Red nodes indicate US educational or research institutions; blue, US government; green, US military; and yellow, foreign institutions collaborating with US institutions. CDC: Centers for Disease Control and Prevention; DUKE: Duke University; JHU: Johns Hopkins University, LANL: Los Alamos National Lab; LSU: Louisiana State University; NAU: Northern Arizona University; NIH: National Institutes of Health; USAMRIID: United States Army Medical Research Institute for Infectious Diseases; U TX: University of Texas.

Both *B. anthracis* and Ebola virus "live-pathogen" research networks expanded over the study period in terms of number of organizations, with the *B. anthracis* network expanding by a factor of more than 6 and the Ebola virus network by a factor of almost 3. In contrast, the number of institutions involved in *K. pneumoniae* "live-pathogen" research grew by just 30% (Table 3).

**Table 3:** Indicators of changes in the research collaboration networks

| | **Live-pathogen** | | | **Non-pathogenic** | | |
|---|---|---|---|---|---|---|
| | 1997 – 2001 | 2003 - 2007 | Change | 1997 - 2001 | 2003 - 2007 | Change |
| **Total number of institutions in network** | | | | | | |
| ***B. anthracis*** | 24 | 163 | 579% | 54 | 281 | 420% |
| **Ebola virus** | 29 | 82 | 183% | 22 | 59 | 168% |
| ***K. pneumoniae*** | 268 | 347 | 29% | 28 | 30 | 7% |
| **Fraction of institutions belonging to the largest sub-graph** | | | | | | |
| ***B. anthracis*** | 54% | 84% | 56% *** | 43% | 84% | 95% *** |
| **Ebola virus** | 93% | 96% | 3% | 73% | 75% | 3% |
| ***K. pneumoniae*** | 69% | 73% | 6% | 94% | 93% | -1% |
| **Share of papers involving only one U.S. institution** | | | | | | |
| ***B. anthracis*** | 45% | 24% | -48% ** | 54% | 49% | -10% |
| **Ebola virus** | 35% | 18% | -47% ** | 5% | 36% | 614% † |
| ***K. pneumoniae*** | 43% | 37% | -15% | 56% | 42% | -25% |
| **Network Centralization** | | | | | | |
| ***B. anthracis*** | 9% | 7% | -20% | 12% | 5% | -60% |
| **Ebola virus** | 20% | 5% | -78% | 14% | 5% | -69% |
| ***K. pneumoniae*** | 5% | 1% | -74% | 21% | 5% | -74% |

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$, † Significance test impossible due to small sample size

The overall level of connectivity in the select agent research communities as measured by the fraction of institutions belonging to the largest subgraph (a connected group of nodes), increased significantly for *B. anthracis* research after the laws, but not for the other two organisms. This is true for both "live-pathogen" and "non-pathogen" research networks. The Ebola "live-pathogen" research network was already highly connected before the laws and remained so afterward.

There were fewer single-institution papers on "live-pathogen" select agent research after the laws, but no significant change in the control group.

### *3.5 Was US–International Collaboration Inhibited?*

As measured by the fraction of papers coauthored by US and international partners, international collaboration in research on viable *B. anthracis* and *K. pneumoniae* held roughly steady over the study period (Table 4). The international fraction of "live-pathogen" Ebola virus papers actually increased after 2002. Because many of these papers dealt with outbreaks around the world, it is not surprising to see international collaboration. In addition, the importation of *B. anthracis* strains became exceedingly difficult post-2002, so many international collaborations became virtual rather than physical.

Perhaps more interesting is the decline in international "non-pathogen" select agent work. Avirulent and subcellular *B. anthracis* research papers outnumbered "live-pathogen" papers by a factor of more than 3 to 1, so the statistically significant decline here is an important indicator of the state of the broader field. The control organism did not demonstrate a similar decline in international cooperation. Coupling this observation with the increased fraction of exclusively US papers on *B. anthracis*, a pattern of decline in international collaboration on *B. anthracis* research emerges.

**Table 4:** Indicators of international collaboration

| | **"Live-pathogen"** | | | **"Non-pathogenic"** | | |
|---|---|---|---|---|---|---|
| | 1997 - 2001 | 2003 - 2007 | Change | 1997 - 2001 | 2003 - 2007 | Change |
| **Fraction of papers involving at least one U.S. and one non-U.S. institution** | | | | | | |
| *B. anthracis* | 16% | 20% | 22% | 21% | 11% | -48% ** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ebola virus | 23% | 38% | 63% * | 50% | 36% | -29% |
| *K. pneumoniae* | 26% | 33% | 25% * | 24% | 53% | 124% ** |
| **Share of degree centrality of all non-U.S. institutions** | | | | | | |
| *B. anthracis* | 18% | 26% | 44% | 26% | 26% | 0% |
| Ebola virus | 32% | 28% | -13% | 24% | 39% | 63% |
| *K. pneumoniae* | 37% | 39% | 6% | NC | 50 | NC |
| **Share of papers involving exclusively U.S. collaborations** | | | | | | |
| *B. anthracis* | 39% | 57% | 46% * | 25% | 40% | 62% *** |
| Ebola virus | 42% | 44% | 4% | 45% | 29% | -37% |
| *K. pneumoniae* | 30% | 30% | -1% | 21% | 5% | -74% † |

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$, † Significance test impossible due to small sample size
NC: Insufficient number of institutions to calculate share of degree centrality

Another measure of international collaboration in network terms is the share of degree centrality (DC) of the coauthorship graph attributed to non-US institutions. The *degree centrality* of a single node in a network is measured by the number of links emanating from it. The *share of degree centrality* for a class of nodes is the proportion of the total number of links in a network emanating from all members of that class of nodes [14]. Changes in the share of DC for non-US institutions after 2002 appear to be minimal (Table 4). For Ebola virus, the share of papers resulting from international collaborations on "live-pathogen" work increased whereas their share of degree centrality decreased. This does not necessarily imply any contradiction because only the latter is scaled to the network in Figure A1 of Appendix A, which is composed of links between institutions. The fraction of international inter-institutional collaborations in the Ebola virus network decreased even though the fraction of all papers with international collaborators increased. This indicates a winnowing of non-US institutions. Collaborations with some non-US groups were dropped whereas others intensified (Table 4 and Table A1 of Appendix A).

### *3.6 Did Select Agent Research Networks Become Centered on a Few Institutions?*

Another concern was that the research communities would become dependent on a few gatekeeper institutions. Such a change would be captured by *network centralization* [16]. This measure compares the actual network to a "star" network of equivalent size in which one central node is connected to all other nodes (the extreme case of centralization). Network centralization decreased over the study period for "live-pathogen" research on both select agents. The same pattern was seen in *K. pneumoniae* research and in non-pathogen research on the select agents (Table 3). This suggests that the observed decentralization was a secular trend unrelated to the passage of the biosecurity laws.

A similar question can be asked for institution type: Did military or governmental institutions become more central in the network? We calculated the share of degree centrality for four categories of institutions: US government, US military, US academic and commercial,[5] and non-US institutions (Appendix A, Table A1). The most striking observation is a significant increase in the role of the military laboratories in "live-pathogen" select agent research and the relative decline in the centrality of the civilian government laboratories. In contrast, the participation of academic institutions and foreign collaborators remained remarkably unchanged. Thus, although the select agent networks became less centralized after the laws were enacted, military institutions became more collaborative in "live-pathogen" *B. anthracis* and Ebola virus research.

[5] Universities, hospitals, nonprofit institutes, and commercial laboratories are included in this category—i.e., all institutions not falling in the military or government categories.

### *3.7 Did the Key Institutions Change After the Legislation?*

In terms of the numbers of papers published, the top two institutions retained their positions throughout the study period, although there was a shift in the later period to institutions with higher biosecurity-level laboratories and government agencies such as the Centers for Disease Control and Prevention (CDC) and the Food and Drug Administration (FDA) (Appendix A, Table A2).

Regarding "live-pathogen" *B. anthracis* research, before the laws, the institutions with the most coauthorships with other institutions were Northern Arizona University (NAU), Louisiana State University (LSU), and the Los Alamos National Laboratory (LANL). After the laws, NAU remained a key player, and the US Army Medical Research Institute for Infectious Diseases (USAMRIID) attained the highest share of DC (Appendix A, Table A3). In contrast, USAMRIID was not even a member of the main *B. anthracis* subgraph during 1997–2001, its researchers being prolific but not very collaborative.

The Centers for Disease Control and Prevention (CDC) and the National Institutes of Health (NIH) were key players in "live-pathogen" Ebola virus research both before and after the laws (Appendix A, Table A2). In the period 2003–2007, CDC collaborations declined from accounting for nearly 19% of the degree centrality of the network to 6%, whereas USAMRIID and the NIH became more central (Appendix A, Table A3). Furthermore, USAMRIID ranked highest in terms of productivity (for "live-pathogen" research on both select agents) after 2002, as measured by the number of papers involving researchers from that institution (Appendix A, Table A2). Thus, USAMRIID saw the most growth in prominence for "live-pathogen" work on the two select agents after the laws came into force.

### *3.8 Were Detected Trends Consistent with Individual Experience?*

Phone interviews were conducted with 13 authors to determine whether our findings were consistent with their individual experiences. Eleven of the scientists were selected because they had a large number of publications in the cleaned dataset. Two worked with select agents other than *B. anthracis* and Ebola virus. All agreed to be interviewed after reading the list of Institutional Review Board-approved questions. Their responses were not statistically analyzed because the purpose of the interviews was to provide anecdotal information (Appendix A).

The group did not report witnessing an exodus of select agent scientists. To the contrary, several mentioned that the increased US funding led to an influx of new scientists to the select agent field, but that many did not stay. None of the scientists reported having to sacrifice research partnerships, and most of them perceived increased collaboration and diversity of expertise within the field after 2002. However, they pointed out that the process of collaborating was made significantly slower and more tedious due to the restrictions placed on organism transfer and laboratory access. Most of the scientists with whom we spoke did not work with foreign partners, and those who did alluded to difficulties in sharing cultures. Nearly all authors complained of the increased paperwork that they were legally obligated to fill out, one of them estimating that it took twice as long to complete any project as a direct result of the bureaucratic overhead. One author commented that the FBI background checks took so long that they interfered with hiring students and technicians, especially non-US citizens. In general, the interviews confirmed the bibliometric findings.

## 4. Discussion

Over the study period there were major changes not only in the biosecurity laws, but also in the size of the research communities in question and in the funding that they received. On a macro level, research involving viable virulent *B. anthracis* and Ebola virus does not appear to have been inhibited by the biosecurity laws, although research became less efficient. After the passage of the laws, US scientists published more papers on *B. anthracis* and Ebola virus research, and more scientists entered the field. Although dramatic funding increases surely influenced these phenomena, they do not completely explain them. Research collaboration increased after the laws, and US military research laboratories became more central to the research community. International partnerships with a select group of foreign institutions increased, although not necessarily physical collaborations.

This work is subject to a number of limitations. We can make no claims that the trends detected were caused by the anti-bioterrorism laws—only whether the observations were consistent with hypothesized effects. Changes not tied to the laws were certainly operative during the study period, and random effects in the early period, when research communities were very small (e.g., the retirement of a senior researcher), may have exerted a disproportionate influence. The funding and publication data were not individually linked, which added to the noise introduced by any errors in the data sorting procedures. Finally, classified research and funding are not considered in this study.

*Note that this work was a collaborative effort between M. Beatrice Dias, Leonardo Reyes-Gonzaleza, Francisco M. Veloso and Elizabeth A. Casman. This research was funded by grants from the Richard A. Lounsbery Foundation, the John D. and Katherine T. MacArthur Foundation, Consejo Nacional de Ciencia y Technología (Mexico) Fellowship 168868, and National Science Foundation Grant NSF-SBE-0738182. A paper resulting from this work was published in the PNAS journal in 2010: Dias, M. Beatrice et al. "Effects of the USA PATRIOT Act and the 2002*

*Bioterrorism Preparedness Act on select agent research in the United States." PNAS 107.21 (2010): 9556-9561.*

*http://www.pnas.org/content/107/21/9556*

# <u>Chapter 2</u>: A Pilot Field Research Project in Information and Communication Technology for Development (ICTD) – *Using Mobile Phone Technology to Empower Social Workers in Tanzania*


## Abstract

The growing field of information and communication technology for development (ICTD) has produced many pilot-stage projects in recent years. Lessons learned from these studies contribute important knowledge to further this relatively new field of study. The work presented here is a pilot stage ICTD project conducted in Dar es Salaam Tanzania with a group of para-social workers. Although para-social workers carry the primary responsibility of providing essential services to the growing population of orphans and vulnerable children in Tanzania, they are often not paid for this work. Moreover, these para-social workers are unable to access governmental resources due to the lack of an efficient means of reporting their needs to relevant government officials in a timely manner. This chapter describes a text message (Short Message Service, or SMS) based solution that harnesses the prevalence of mobile phones coupled with several open source data management tools to empower these para-social workers. In this study, researchers built a more efficient mechanism for reporting summary data on orphans and vulnerable children to relevant government officials in a cost-effective and efficient manner. This chapter presents details of the needs assessment process, reviews related work, describes the application and testing the proof of concept of the prototype technology solution, and concludes with a discussion of possible future work.

# 1. Introduction

Information and Communication Technology for Development (ICTD) is a relatively new field of research that crosses many different disciplines, including computer science, development studies and information systems. Those working in ICTD strive to channel the power and potential applications of information and communication technologies (ICTs) towards addressing the numerous challenges in developing communities across the world [17].

Richard Heeks categorized the evolution of ICTD as moving from ICTD 1.0 to its current phase ICTD 2.0: "Where 1.0 imposed preexisting designs and expected the poor to adapt to them, 2.0 designs around the poor's specific resources, capacities, and demands" [18]. Internet kiosks were popular during the ICTD 1.0 phase, of which the Lincos (Little Intelligent Communities) project is a good example. This project was initiated by the NGO Entebbe in collaboration with a group of commercial and academic institutions (including Microsoft, MIT, HP, and Harvard University) and sought to distribute multi-application ICT centers to marginalized regions, with the centers themselves housed in industrial shipping containers [19]. However, the metal containers accommodating these centers did not provide a hospitable environment for the user or the technology due to the heat and lack of ventilation. Thus, Lincos kiosks failed to inspire any change in these communities because people did not want to use them. ICTD 2.0 involves a more participatory approach to designing and implementing technology solutions to address development problems. A good example of an outcome of this phase of ICTD is the Braille Writing Tutor developed by the TechBridgeWorld research group at Carnegie Mellon University. Following a participatory and iterative approach, the Braille Writing Tutor was cooperatively designed to address challenges faced by visually impaired people in developing communities, specifically the difficulty of learning braille using the slate and stylus method [20]. As such, it was more successfully accepted and utilized by the targeted population.

Regardless of the positive changes and steady increase in ICTD research, critics posit that when tackling the adverse conditions of the developing world, it is unclear whether employing information and communication technology is the most appropriate approach to addressing major social issues such as poverty, illness, hunger and discrimination [21]. While technology alone is insufficient to address these problems, those working in ICTD expect to creatively adapt and revamp the design, function and applications of ICTs so as to best meet the numerous challenges in developing communities [17]. ICTD is growing as a field and tackles problems in a variety of areas including education [22], healthcare [23], economics [24] and government [25].

The study described in this chapter was conducted as part of TechBridgeWorld's inaugural innovative Student Technology ExPerience (iSTEP) internship program in Dar es Salaam, Tanzania. This project exemplifies the features of a typical pilot ICTD project in that time and resources were limited, the project's target audience was a developing community facing numerous challenges, and the field research team conducting the study was inter-disciplinary. The specific focus of this research endeavor was to investigate potential technology applications that could facilitate the responsibilities of para-social workers in Tanzania. Researchers utilized mobile phone technology and open source data management tools to create a feasible solution to the problems para-social workers face with data transfer. Lessons learned from this project provide insight into the challenges of ICTD field research, particularly at the pilot stage. Additionally, this work demonstrates that creating or adapting the technology output is merely one stage of an ICTD project. The successful transfer and implementation of the technology requires further planning and coordination with the local community. Therefore, the pilot project presented here not only affects the Tanzanian para-social worker community, but also provides knowledge to advance the field of ICTD.

## 2. Project Background

The goal of this work is to explore the role technology can play in alleviating some of the data management burden placed on social workers and para-social workers who are attempting to serve the millions of orphans and vulnerable children (OVC) across Tanzania [26]. Specifically, this study investigates the use of SMS (Short Message Service or text messaging) to improve the cost, regularity, and timeliness of reporting data to the relevant government database so that resource distribution can be better informed and the service provision to OVC can be enhanced.

### *2.1 HIV/AIDS in Tanzania*

As of 2007, an estimated 33 million people across the globe were infected with HIV [27]. Prevalence of HIV among adults in Tanzania in 2009 was estimated to be 5.6%; that was an order of magnitude greater than prevalence in the United States (0.6%) [28]. In 2007 alone, Tanzania reported approximately 96,000 deaths due to HIV/AIDS. Furthermore, Tanzanians are at a high risk of contracting other infectious diseases such as Hepatitis A, Typhoid Fever, and Bacterial Diarrhea. Adult mortality in Tanzania has left approximately one million children (aged 0 to 17) parentless and in a vulnerable position [29]. The HIV/AIDS Twinning Center estimates this number is even higher and reports that there are close to 2.5 million OVC in Tanzania due to the HIV/AIDS epidemic [30].

According to the World Bank, in 2007 over 33% of the Tanzanian population fell below the national poverty line [31]. Economic hardships exacerbate the HIV/AIDS epidemic by limiting the healthcare resources accessible to patients. The social stigma concerning HIV/AIDS is an added burden borne by Tanzanians who contract the disease, and this stigma often extends to the relatives and associates of HIV infected persons. Hence, fear of being ostracized deters many Tanzanians from getting tested for HIV and contributes to the continued spread of the disease.

Tanzania faces a severe shortage of trained social workers to provide services to affected individuals. Some of the factors escalating the need for social workers in Tanzania are the increasing number of HIV/AIDS adult deaths, the concurrently rising number of OVC, and the breakdown in family support structures due to greater migration from rural areas to cities [32].

### *2.2 Para-Social Workers*

Tanzania needs at least 8,000 additional social workers, according to the country's Institute of Social Work (ISW), to meet the current demand for services. To address this challenge, several groups in Tanzania are training thousands of para-social workers (PSWs) to provide services to HIV/AIDS victims and their families; especially to OVC. Many of these PSWs are already community development officers or representatives of community-based organizations [32].

An estimated two-thirds of Tanzania's 127 districts are left with no social welfare support due to a lack of trained welfare workers [32]. Thus, in 2007, the HIV/AIDS Twinning Center joined with ISW, the University of Illinois at Chicago's Jane Addams College of Social Work, and the Midwest AIDS Training and Education Center to launch their Para-Social Worker Training Program. This program was created to equip community-based caregivers with the necessary skills to help alleviate the plight of OVC [33]. Through their efforts, these organizations trained 516 PSWs, 40 district social workers, and 55 master trainers in Tanzania, and "the newly trained PSWs are identifying new children and families in need and connecting them with critical support and assistance" [33]. Home visits are conducted to gather information on the children and their current situation.

### *2.3 Supporting Efforts*

In addition to the ongoing work by PSWs, social welfare organizations such as HUYAWA, the Institute of Social Work, and WAMATA provide OVC and their families with school supplies, counseling services, and advice on a range of life skills such as caring for family, managing with a small budget, as well as family planning and HIV/AIDS prevention [32]. Furthermore, there is a national effort to monitor and evaluate HIV/AIDS data in Tanzania by way of the Tanzania Output Monitoring System for HIV&AIDS (TOMSHA). This national system is dedicated to collecting information on the impact of the disease in Tanzania, which includes data on OVC. The Department of Social Welfare (DSW), a governmental organization, maintains a database specifically on OVC. The goal for this database is to enable leaders to make more informed decisions on how to combat the spread of HIV/AIDS in the country, and to allocate limited resources more effectively. However, PSWs do not have many incentives to collect or submit high quality data to the DSW database, because they are not privy to how this information is used and are often not compensated for their work.

In summary, while PSWs carry the primary responsibility of providing essential services to the growing population of OVC in Tanzania, they do not receive sufficient support for this work. Additionally, PSWs are unable to access governmental resources due to the lack of an effective means of reporting information to the national database in a timely manner. A team of Carnegie Mellon University students associated with TechBridgeWorld[6] worked with several relevant

[6] TechBridgeWorld (http://www.techbridgeworld.org/) is a research group at Carnegie Mellon University conducting work in the field of ICTD.

groups in Tanzania to understand the needs of this community. Based on these assessed needs, a SMS-based solution was proposed to address the reporting challenges faced by the PSWs. This chapter reports on the needs assessment process, reviews related work, describes the application and testing the proof of concept of the prototype solution, and concludes with a discussion of future work that could further enhance this solution.

## 3. Needs Assessment

The needs assessment process identified the challenges faced by the para-social worker community in Tanzania, their desired solutions, and the existing infrastructure that has been created by associated organizations to support them. Two community partners were consulted for this work, the Institute of Social Work (ISW), an academic institution that trains social workers and PSWs throughout Tanzania, and the Department of Social Welfare (DSW), a governmental office that currently maintains the national OVC database.

Initial meetings were held with several local organizations that conduct or oversee social work. ISW houses a program for supporting OVC, which started in October 2006 and is sponsored by USAID. At the inception of the program, they trained community members who already work with OVC in order to empower and motivate them to continue to provide services to the OVC. After a social worker symposium, a curriculum was developed for training supervisors who then go on to train PSWs. ISW partnered with the Jane Addams College of Social Work at the University of Illinois at Chicago in the United States to deploy the “Train the Trainer” approach. Through this partnership, ISW has been able to train several hundred PSWs under the new curriculum. The PSWs are all trained in their respective districts with an emphasis on methods for identifying OVC and a standard process for collecting data and providing services.

WAMATA, a non-profit organization that was the first HIV/AIDS support organization of its kind, reported that keeping records and tracking the OVC is a major challenge. The OVC Data Management Specialist at DSW stated the major issues that their institution faces with data collection for OVC was incompleteness of and inaccuracies in the data. As of 2009, out of a total of 132 recognized districts, only 81 reported to the national database while 51 did not submit any information, and even submitted reports were often incomplete. Data verification occurs through a manual checking process conducted twice a year. If the national database received information electronically and more frequently than every three months, the entire process of data collection and verification could be streamlined.

### *3.1 PSW Interviews and Observations*

Five PSWs were interviewed, all from the Dar es Salaam region, which contains three districts – Kinondoni, Ilala, and Temeke. Many of these workers are involved with the village or ward committees that provide data on OVC to the national database, and would therefore be the end users of the proposed technology solution. The research team also conducted a site visit to Tandika village, which is located in the Temeke District, to obtain a firsthand view of the problems that the village members (including PSWs and OVC) face on a regular basis.

The interviews with the PSWs revealed that lack of resources and incentives were major obstacles to comprehensive data collection. The PSWs were able to give us a grassroots perspective as to why the information does not get to the various levels of government as fast as needed. PSWs focus on meeting the day-to-day needs (e.g. food, health care, school supplies, and clothing) of the OVC and other community members and often do not have the time or resources to submit paper reports. They also find that sending in reports to the district level governing body yields little in terms of support or resources. Apart from this, printing, photocopying, and travel expenses required for preparing and submitting reports are costly, and they are typically not compensated for these costs. Furthermore, there is no official at the district level who advocates for providing funds and resources for social welfare-related work. Finally, although the PSWs receive some training, they often do not receive support beyond that initial instruction. Many of them are not paid for the social work services they provide. They perform social work on a voluntary basis and maintain other jobs to earn a living. The interviewees were schoolteachers, cooks, electricians, program coordinators at non-governmental organizations, and chairmen of their village committees.

### *3.2 Identified Data Collection Challenges and Needs*

Data transfer from the ward level to the district level is very slow. The DSW in Tanzania collects data from village, ward, and district level committees. Currently, this data collection occurs via paper forms, and as such, can take up a significant amount time (on the order of months) for the forms to reach their final destination, the national database. More specifically, reporting is a multi-step process involving paper forms sent to the district where they are digitized and forwarded to the national database (Figure 3).

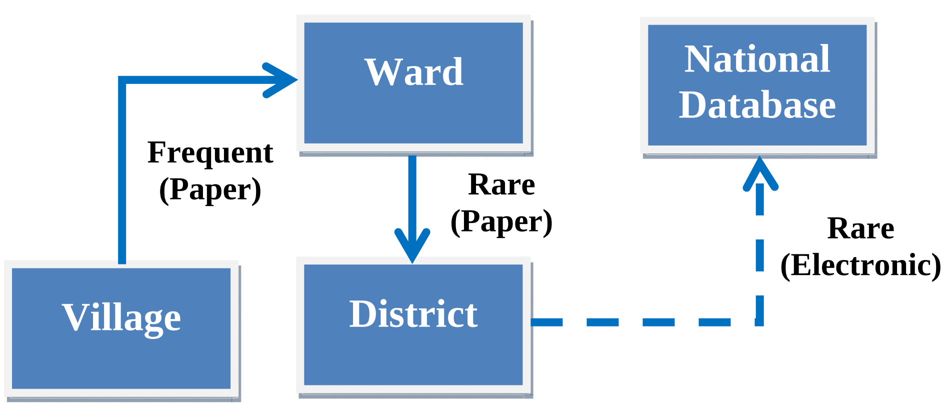


**Figure 3:** Flow of reports on OVC from village level to the national database.

PSWs predominantly operate at the village level. Their efforts are concentrated on serving villages and the paper reports they construct are brought to a ward. A ward is a collection of approximately three villages, where social workers can meet and interact, as visits to the ward happen very frequently, if not daily. At the ward level, these paper reports are collected and then are taken to the district level. This process is expensive and infrequently completed. The bus ride into the district can take hours and is often uncomfortable and costly. At the district level, the forms are digitized and submitted to the national database once every three months. However, the many difficulties of ward-to-district transportation can cause the forms to be delayed anywhere from a couple of months to a year, in addition to some forms being lost entirely. This in turn leads to the national database containing out-of-date and incomplete information.

There are two main issues with this data transfer: 1) lag time to transport the paperwork and 2) misplaced or lost documents during this transfer. Approximately 60% of districts send in reports to the national database, and only a handful of those reports are complete. The omissions and flaws in the reporting process hinder the flow of communication. Government officials and donors use this information to make critical funding and policy decisions. Therefore, it is important to obtain accurate data so that adequate resources can be provided to support OVC.

### *3.3 Proposed Technology Solution*

Based on the findings of the needs assessment a technology solution was proposed to help address the reporting needs of the local social worker community. This solution was iteratively developed utilizing feedback from community partners and led to the production of a SMS-based data transfer and management application. The scope of this project was to test this prototype by ascertaining its potential to be adopted and deployed in Tanzania. To this end, relevant user feedback was obtained and a deployment strategy was proposed.

# 4. Related Work

The problem of exchanging information without advanced infrastructure such as Internet access, stable mobile phone connections, or landline telephone service is a problem encountered in many different ICTD projects. Due to the prevalence of this problem, a variety of research groups and other organizations are working to improve information exchange in rural areas.

## *4.1 Voice-Based Solutions*

Several research efforts have explored voice-based information retrieval systems relevant to developing community settings. One example is HealthLine, which is a speech-based system that allows users to access information from a database via a phone call [34]. There are several advantages to a speech-based solution. First, such systems do not require high levels of literacy or technical skill. Moreover, all data processing and custom software is server-side, eliminating the need for any installation on users' phones. However, speech-based solutions do not address data entry [35], which is an essential component of this project since it focuses on reporting rather than retrieving information. Voice based data entry can be prohibitively expensive for our target users.

Similarly, the TRACnet system in Rwanda was designed to collect, store, retrieve, and disseminate a variety of information related to HIV/AIDS care and treatment [36]. The Ministry of Health and the Treatment Research and AIDS Centre (TRAC) joined forces to deploy TRACnet to increase the efficiency of Rwanda's HIV/AIDS program management and enhance the quality of patient care. TRACnet has been deployed nationwide to connect every health facility providing HIV/AIDS treatment and related services. The primary mode of information exchange in TRACnet is a bilingual English and French telephone and web interface. The backend of TRACnet is a central information repository. The system has reportedly transformed a largely paper-based one-way information flow that took several weeks, into a bi-directional data exchange completed in seconds. Hence, it allows decision-makers and supervisors to quickly analyze and respond to program information. Uganda's Rakai Center and others are utilizing similar systems to enhance information management and treatment provided to HIV/AIDS patients [37]. However, none of these systems have explored methods for reporting information in settings where phone calls are cost-prohibitive. In working with PSWs in Tanzania who have very limited income and are unable to afford phone calls or internet access for regular reporting of OVC data, alternative solutions needed to be explored.

Patnaik, Brunskill, and Thies presented a review of accuracy rates of different data collection mechanisms using mobile phones [38]. Their study compared three different methods, utilizing a Java application to enter data into a form, sending a coded SMS message, and verbally reporting information to a human operator via a phone call. In comparing these three methods, they tracked mistakes that workers made as well as the duration of the interaction. Results showed that the SMS and Java application methods had a comparable error rate (under 5%). The voice solution, however, produced errors less than 0.5% of the time. The duration of an interaction using SMS and the Java application was also close, while interactions on the phone took almost one minute longer.

### *4.2 SMS Solutions*

FrontlineSMS is a project that was developed to encourage stronger communication for non-governmental organizations and their workers [39]. The system provides a suite of tools that only require a computer and a mobile phone. It can then arrange text messages such that they can be sent either to individuals or to large groups, and conversations can be organized. It has been used in a variety of projects, including in a hospital in Malawi where it was able to track patients, respond to requests for care, and answer health worker's queries for dosage information [40]. The goal of the project described in this chapter was to automate data entry, and provide confirmation that the reported data reached the database. However, FrontlineSMS does not allow users to export and automate the data processing. Also, FrontlineSMS is not open source and is better suited for connecting and tracking field work.

Texas A&M University implemented the LINKS project in 2004 in Kenya and Ethiopia. LINKS, which stands for Livestock Information Network and Knowledge System, allows users to send coded SMS messages to a central server [41]. These SMS messages contain data such as livestock type, age and condition, and the server replies with a SMS message containing the prices a farmer could receive for such an animal in different nearby markets. This enables farmers to maximize their profits and thereby improve their livelihood. The LINKS study emphasized that using coded text messages is a feasible way of interacting with a system in the context of ICTD work. This system was the most promising solution that could work within the constraints of our target user group, and hence the LINKS protocol informed several aspects of the solution design.

### *4.3 Other Relevant Tools*

The OpenRosa consortium is a group of developers working to create open source protocols for data collection on mobile devices. Through projects such as JavaROSA [42], OpenRosa's standards have been used to develop mobile phone applications in developing communities [43]. Projects using the JavaROSA platform can be run on most Java-enabled phones, including the Nokia 3110c and 6085, which are readily available in low-income regions [44]. However, despite being available, Java compatibility is neither universal nor cheap. Since mobile phone customization is relatively uncommon in Tanzania, this may lead to a number of issues, especially concerning usability, as the PSWs did not demonstrate knowledge on how to use Java applications. In contrast, PSWs were very familiar with the use of SMS.

Epihandy is a suite of tools constructed with OpenRosa for data aggregation on mobile phones [45]. It includes a wealth of already developed tools both user- and server-side to run on smart and Java-enabled phones that would minimize the need to re-implement basic data collection functionality. Epihandy includes tools to design user interfaces that make data entry more user friendly [46], but also requires a consistent connection for data collection [47]. Additionally, storage of data on memory cards to ensure it is not lost before it is transmitted raises the cost, and violation of privacy becomes a concern in the event that a mobile phone is lost or stolen.

CAMBrowser is a solution that targets form-based data entry. Utilizing cameras that are becoming more prevalent in mobile phones, CAMBrowser's developers hope to make data entry more efficient. To enter data, users are provided a form listing all the fields and a corresponding bar code for each field. To enter data into a particular field, they take a picture of the bar code and CAMBrowser is able to decode the image to ascertain the type of data the user is entering, thus ending the need to navigate through menus [48]. CAMBrowser is appropriate for low-literacy users since it offers an alternative to cumbersome navigation menus or text coding. However, the PSW user group in this study was literate, and given the complexity of implementing CAMBrowser, it was decided that the cost outweighed the benefits. Additionally, mobile phone cameras are not universal and hence an application that requires a camera would limit the number of users that could be served.

None of the related work surveyed addressed the need for effective processing of reports at the ward level as well as the need for the application to be inexpensive and easily deployed on a variety of mobile devices. Thus, in this project an application was developed specifically for enabling PSWs in Tanzania to report vital information on OVC more easily and quickly.

# 5. Applying the Proposed Technology Solution

The needs assessment process revealed that the PSWs required a less complicated and less costly method for submitting reports if they were to submit data more frequently and consistently. All of the PSWs owned basic mobile phones (mostly Nokia brand) and used their phones on a regular basis; typically every day. In contrast, none of them had easy access to a computer. In Tanzania SMS is much more affordable than phone calls. The cost of a mobile phone call per minute can be as much as five or six times the cost of sending one text message [49]. Therefore, a SMS-based solution would be a less cost prohibitive mode for transmitting data. SMS technology is limited by the character allowance in a text message, but community partners were able to identify the following key pieces of information that can be submitted in aggregate form:

- Number of OVC
- Gender and age breakdown of OVC
- Location of OVC
- Needs of OVC and services provided to them (to match and determine which needs are still unmet)

## *5.1 Information Flow*

Informed by the assessed needs of the PSWs, the primary goal of this project was to digitize information at the ward level and streamline the process of data transfer out of the ward directly to the national database. In doing so, the lengthy and arduous task of transporting a large number of backlogged paper forms to the district level at uncertain intervals could be minimized and the national database could be updated directly from the ward level. This will significantly simplify the data transfer process outlined in Figure 3. Due to the limitations in the volume of data that can be transferred over SMS, it is infeasible to digitize all data at the ward level using the proposed approach. Hence, this system does not entirely eradicate the need for paper forms. However, it does allow the national database to be updated with key information at more frequent intervals.

### *5.2 SMS Solution Tradeoffs*

SMS is a low-cost, low-bandwidth method of transmitting data that is supported by most mobile phones. In particular, a SMS-based solution was most appropriate because many users already owned mobile phones, and the cost of an individual SMS is very low (somewhere between US$.03 and US$.05 in Tanzania in 2009). Additionally, owing to the fact that SMS is considerably less expensive than standard voice communication, many Tanzanian mobile phone users are already familiar with SMS.

Several other options were explored before ultimately settling on a SMS-based solution. A voice-based system, where users dial in to a call center and speak to a live operator, who then enters the relevant data, is highly robust. This method limits the possibility of mistyped data, and allows for instant clarification of information and collection of a greater volume of data. Additionally, a voice-based option was shown to have lower error rates than SMS and mobile phone applications [38]. However, the high cost of “airtime” (time spent on a phone call) compared to SMS, as well as the additional cost imposed, and time required to train and employ phone operators disqualified this solution path.

The possibility of using a mobile phone application to help users format their responses properly and decrease error rates by making data entry more intuitive was also investigated. However, previous studies have shown that error rates were not significantly different between data entered with the aid of a Java application and hand-formatted SMS [38]. Each of the application formats considered posed significant barriers to wide-spread deployment: Java applications tend to only run on higher-end mobile phones, and SIM card applications require approval from network operators (which is extremely difficult to obtain). Therefore, a system that uses hand-formatted SMS messages to transmit data was designed.

### *5.3 System Components*

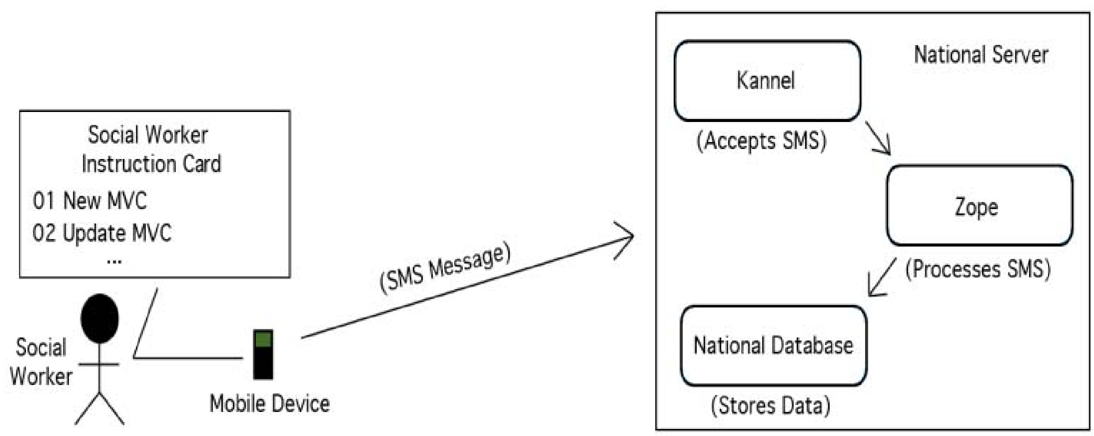


**Figure 4:** Overview of components in the designed SMS-based data transfer and management system

A key code style format SMS message similar to the one used by LINKS [41] was chosen. As illustrated in Figure 4, social workers were given a small card, which contained all of the codes to be used in the SMS message. This SMS message was then sent to a central server, which received the information, processed it, and finally transferred the data into the national database.

The server was implemented using several open source technologies: Kannel, Python, and Zope. Kannel [50] is a SMS gateway, which serves as the connection between the mobile phone networks and the server, connecting one or more GSM modems to Zope. Zope is a web framework written primarily in Python. Zope facilitated the design of a simple and intuitive administrative interface that worked well together with Kannel and external databases. For database connectivity, SQL Alchemy [51] was used. This is an object relational manager for Python, which easily plugs into various back-ends. The prototype version of the server runs using SQLite. However, for larger scale deployment a better choice would be a production quality database, such as MySQL or PostgreSQL.

The designed system receives text messages through the SMS gateway, Kannel. By connecting a phone or GSM modem to a computer, Kannel receives SMS messages from the phone, processes the information into an XML file, and sends it to a Zope application. Zope is a content management system that has been in development since 1995 [52]. Using an array of Zope modules, an application was developed to store the received SMS messages in SQL by parsing the XML file for the required fields. If the Zope application finds the message to be improperly formatted or to have anomalous values, Zope returns an error to Kannel, which replies the user with the problem Zope encountered. Following this process, the user can remedy the error and resend the information, which can then be submitted to the national database. In this solution design, users are given instructions on how to format a SMS containing data they have collected in their work with OVC. Shortly after a user sends this SMS to the supplied number—a phone number that would be owned by the server operator—the server receives, parses, and automatically enters it into a database. The server is also able to determine, from the SMS, which user sent the data and the region where he or she works. Server administrators can then export and analyze the submitted data.

### *5.3.1 User-Side*

Data flow begins with the users—in this case the PSW or social worker. Users are instructed via cue cards to submit data by sending a specially formatted SMS. Such cue card instructions have been shown to be effective [38]. Despite its many advantages SMS has its drawbacks. A SMS is limited to 160 characters, and the lack of a full keyboard on most phones makes typing large amounts of data cumbersome, and error-prone. Thus, it is reasonable to expect users to be able to accurately enter no more than a small amount of numerical data—a total of approximately 10 to 20 characters. Based on discussions with partner organizations, it was determined that the most useful data would be summary data, such as the number of OVC identified in a village, their gender breakdown, their age range, as well as which services are currently provided and which services are most needed (enumerated using an existing coding system). This data is expected to allow an administrator to identify meaningful trends in social work across the nation and enhance the input of data to the national database.

Each SMS begins with a personal identification number (PIN) that uniquely identifies the user. Combined with user registrations in the database, the PIN also allows the server to identify where the data are coming from, as each PIN is tied to a specific village. Users can either register via SMS or can be manually entered into the database by an administrator.

### *5.3.2 Server-Side*

Within minutes, if not seconds, of a user submitting a SMS, the server receives the message. This is accomplished using Kannel in conjunction with a GSM modem. Since the format specified by the cue cards is machine-readable, as soon as the server receives a SMS, it is parsed and entered into the database. In the event that the server receives an incorrectly formatted message, or one with clearly incorrect data (e.g. a report of a thousand OVC in a given village), instead of entering incorrect data into the database, the system flags the message for review by a human operator. In particular, messages that cannot be properly parsed are flagged, and depending on the data, range-validation could be implemented so that only specified, reasonable ranges of values for different fields will be accepted. This system combines the benefits of the robustness of a human operator when needed with those of digitization.

## 6. Testing Proof of Concept of the Technology Prototype

After developing a prototype technology and cue card system, an initial evaluation was conducted to gauge the usability and feasibility of the proposed technology. This was done in two stages:

- Stage 1: Determining deployment potential of the mobile phone application by demonstrating the solution prototype to partner organizations to obtain their feedback.
- Stage 2: Assessing feasibility of cue card instructions with a village OVC committee to understand the degree to which they can follow the instructions to send SMS in the required format.

### *6.1 Stage 1 Prototype Assessment - Feedback on Technology Demonstration*

Users provided the following feedback:

- Highlighting errors in data records for human intervention is very useful.
- The limitation on the amount of data that can be sent via SMS is a concern. Currently, they use paper forms to send a lot more text-intensive data such as comments on

particular children and other problems in the community. It is not feasible to send such data in one SMS message.

- Training people to send data using this technology could be challenging because many people in villages and wards (outside of Dar es Salaam) have limited exposure to technology and some do not even own or use mobile phones.
- Lack of mobile phone network coverage in certain areas of the country will be an issue for a SMS-based solution.
- Since there are up to 12,000 villages in Tanzania, it is important to ensure that a corresponding number of unique PIN codes exist to distinctively identify data senders at different locations.

Apart from the character limitation of a SMS-based system, the feedback about the technology itself (in terms of its function and design) was positive. Therefore, the demonstrations did not lead to further modifications of the solution at this stage. However, this feedback did help shape the design of the instructional cue cards as well as the deployment strategy for this project.

### *6.2 Stage 2 Prototype Assessment – PSW Feedback on Instructional Cue Card System*

The instructional cue cards designed for data senders (i.e. PSWs or social workers) were tested with five village committee members (one woman and four men, who help support village OVC) from Tandika village. For this testing, we provided each of them with a cue card, which contained instructions translated into the locally spoken language, Kiswahili (see Figure 5).

We asked the PSWs to imagine they had 11 OVC in total, of whom six were female and five were male. Equipped with this information and their mobile phones, we asked them to try to follow the instructions and transmit the data provided. The mobile phone on the receiving end of the SMS data was one of the researchers' personal phones. This made it possible to verify the accuracy with which the PSWs formatted and submitted the given data. There were several useful observations that resulted from this trial:

- Participants had a difficult time understanding step #2 of the cue card instructions. They asked for some guidance on this, and were subsequently able to send the SMS in the required format.
- None of them knew what "numerical input mode" meant, so we needed to show them how to access it on their phones so they could follow the instructions.
- It was clear that three of the five OVC committee members were quite proficient in sending SMS with their phones, and mastered the instructions very quickly. The other two committee members struggled to get past instruction #2.
- One of the members had little to no experience with SMS and required guidance through the entire process.
- Correctly formatted messages were received from three of the members. A fourth member formatted it correctly, but did not wish to send the SMS. The fifth member did not successfully format or send a message.
- The participants said that the instructions were not difficult to follow, except for step #2. They also mentioned that they thought such an application will be useful to them in their work and that they would use it if it were available.

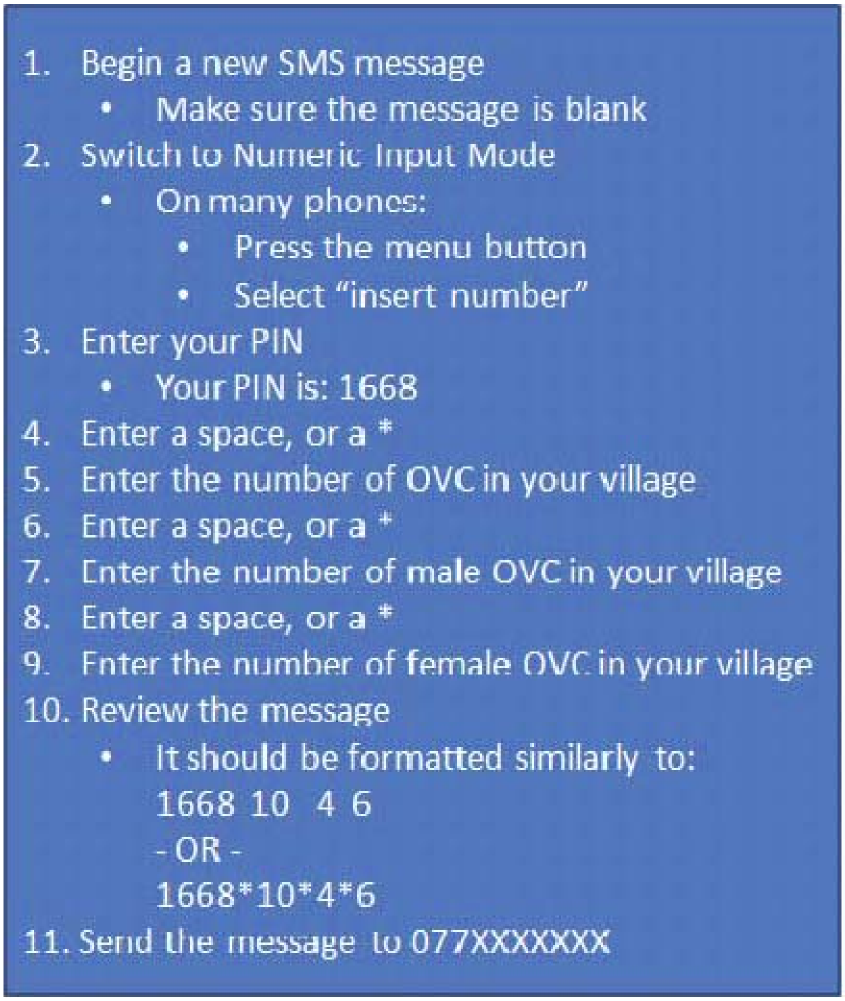


**Figure 5:** Cue card instructions for submitting data to the national database

### *6.3 Key Challenges and Limitations*

There are a number of challenges inherent to the problem of transmitting OVC data in Tanzania to the national database; chief among these is cost. However, once the server is set up, the cost per data submission will be just the cost of one SMS. In 2009 the cost of sending a SMS was roughly equivalent to the cost of making a photocopy, which is currently necessary for the PSWs to submit the paper-based forms. Additionally, even though the designed system would minimize the cost to PSWs for transporting paper forms, they would still be required to use their personal mobile phones and income to transmit and pay for the SMS data.

Although mobile phones can be an effective tool in a wide range of data transmission applications, including this one, there are a number of limitations to the platform worth noting. More remote areas in Tanzania, where data collection is already challenging, may have little or no mobile phone reception. Thus, the designed system will complement rather than replace the existing system of paper form transmission. However, the spread of mobile connectivity is likely to address this challenge in the near future. Furthermore, mobile phones are not designed as general-purpose data entry devices, and so they run into usability issues. Entering data via the keypad, particularly alphanumeric data, can be difficult and error prone.

### *6.4 Deployment Considerations*

During the last week of the field research in Tanzania, discussions were held with local partners on what the next steps of this project would be. The research team agreed to work with the DSW to transfer ownership of the application and plan for future deployment of the project. The sustainability of this project relies heavily on a local party taking on further ownership of the application and hosting it on their server. The ideal candidate for this role would be the DSW. Once ownership of the technology is undertaken by a local partner, we can work with that group to plan further testing as well as a long-term study to deploy, collect data, and evaluate the effectiveness of this technology solution.

## 7. Conclusions and Future Work

A SMS-based data transmission system can be feasibly implemented within the social worker community in Tanzania. However, several steps need to be taken to build the human resource and government advocacy infrastructure that would be necessary in order to successfully deploy this system. The SMS-based technology will help supplement the current paper form method for data collection within this community while improving the efficiency and timeliness of transmitted data. Additionally, the affordability of SMS compared with alternative avenues for information communication, render this approach more feasible to and adoptable by the end user, the PSWs at the ward or village level.

In addition to further testing and implementing this solution, there are two interrelated, interesting technical areas where this work could be extended, server-to-user communication and time-sensitive surveys. Server-to-user communication would allow server administrators to contact users via the same mobile phones they use to submit data. There are some issues with this, including the bandwidth limits of a GSM modem, the possibility that such communication is unwanted by its recipients, and of course additional costs. That said, by initiating two-way communication, valuable new possibilities emerge. One such possibility is a method for collecting time-sensitive surveys. A survey could be distributed via SMS and then collected via SMS, with a response time that would theoretically be in minutes. Again, there are challenges involved in implementing this, particularly regarding usability, but it could prove to be a versatile and useful tool. Some possible uses include tracking the spread of diseases or in disaster monitoring. The system designed in this project generally solves the problem of submitting data, especially location-tied information, to a central database. This has many possible applications beyond the scope of collecting data for social welfare in Tanzania.

Finally, the experience with this pilot ICTD project, offered many insights into the challenges and rewards of conducting field research in this discipline. One of the key learning points was the difficulty of evaluating such short term and under-resourced projects. Although limitations in the field diminished researchers' capability to carry out a rigorous project assessment, it was determined that with more advanced planning and preparation, a more thorough evaluation could have been made possible. Therefore, this project also paved the way for potential future investigations into the assessment of pilot stage ICTD projects, in general.

*Note that this work was a collaborative effort between M. Beatrice Dias, Daniel Nuffer, Anthony Velazquez, Ermine A. Teves, Hatem Alismail, Sarah Belousov, M. Freddie Dias, Rotimi Abimbola, Bradley Hall, and M. Bernardine Dias. This research was supported in part by discretionary gifts to the TechBridgeWorld research group at Carnegie Mellon University, by the Qatar Foundation for Education, Science, and Community Development, by the support of National Priorities Research Program grant #30-6-7-91 from the Qatar National Research Fund, by Carnegie Mellon University in Qatar, by the University Computing Centre, Ltd. Located at the University of Dar es Salaam Tanzania, and by the Holleran Scholars Fund.*

*A paper resulting from this work was published in the proceedings of the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development (London), December 2010. http://www.gg.rhul.ac.uk/ict4d/ictd2010/posters/ICTD2010%20Dias%20et%20al.pdf*

# <u>Chapter 3</u>: Evaluation of Pilot ICTD Field Research Interventions – *A Framework Approach*

## Abstract

Information and Communication Technology for Development (ICTD) is a relatively young field of study and as such much of the work being carried out is yet at the pilot stage. Although ICTD projects are now widespread, there is a particularly evident lack of structure concerning how such projects are evaluated, with many reports being anecdotal rather than analytical. Most currently employed evaluation methods do not address the unique aspects of ICTD. This chapter presents an ICTD-centric, practical framework for conducting comprehensive pilot project evaluations. Incorporating feedback from ICTD research practitioners as well as theorists, this study demonstrates the potential for this framework to establish a much needed foundation for evaluating pilot-stage ICTD projects in this emergent field.

## 1. Introduction

Information and communication technology for development (ICTD or ICT4D) is a burgeoning field that has attracted increasing interest from researchers, sponsors and policymakers in the last decade. Much of the work being carried out in this area is at the pilot stage, where researchers explore potential technology solutions to challenges in developing communities across the globe. ICTD projects are now widespread, but there is still little in the way of theory or standards established for this body of work. In terms of project outcomes, Heeks posits that "Most of the ICT4D research being produced is…descriptive not analytical" [53]. While there is a need for standards in many aspects of this field, there is a particularly evident lack of structure concerning how such projects are evaluated. The framework described in this chapter was created to offer a systemic approach to assessing pilot-stage field projects in ICTD.

Most currently employed evaluation methods in ICTD are borrowed from economic development and information systems projects and programs. Although these approaches are theoretically sound they do not address the unique aspects of ICTD, which combines development endeavors with efforts in technology innovation and adaptation. Furthermore, these methods typically focus on summative evaluations that examine end results, and neglect formative evaluations, which scrutinize processes that greatly influence results of a project. Additionally, existing evaluation techniques typically do not focus on assessing project output or in the case of ICTD, the technology itself. This is a significant omission since the technology innovation itself is a key ingredient in ICTD intervention research. Therefore, there is a need for an ICTD-centric, practical method for conducting comprehensive pilot project evaluations. To this end we designed a framework entitled 'The PREval (Pilot Research Evaluation) Framework', which provides ICTD field researchers with guidance on how to plan and execute a pilot ICTD project such that evaluation is part of the process. The PREval Framework is intended to promote more structured project assessments in the field. In the long term, the goals of this framework are to improve pilot ICTD studies, learn more from them and also make better decisions on how to scale them. Through application of the PREval framework, projects will generate analytical results that provide insight into project effectiveness. This could improve the overall quality of ICTD field work and better meet the needs of developing communities and project sponsors.

## 2. Obstacles Faced in Evaluating ICTD Pilot Projects

As field researchers, ICTD practitioners are challenged in very unique ways. Field research, in general, is rife with obstacles such as, limited time, bureaucratic barriers and an unpredictable environment. However, field researchers in ICTD encounter additional problems such as, working with limited information and communication technology (ICT) infrastructure and resources, and crossing cultural and language boundaries to create suitable products for different communities. Furthermore, the multitude of obstacles faced by developing communities can be overwhelming to ICTD field researchers; for example, they may be working with a school that does not even have enough benches to seat its students, let alone text books and teachers to educate them. ICT interventions cannot address all these problems within the scope of one project, so researchers are presented with the difficult task of picking an aspect of the community's needs that can be realistically addressed using ICT.

Given the many obstacles ICTD researchers face in the field, their ability to conduct a thorough project evaluation is often compromised. Although the value of planning for and incorporating evaluation into ICTD pilot projects is generally accepted as prudent, many practitioners resort to reporting stories from the field rather than conducting structured evaluations. For some projects evaluation is essentially an afterthought since the technology innovation is the primary focus and uses up the majority of researchers' time and resources. Recent ICTD publications have focused on conducting controlled trials [54][55]. These studies cite issues such as student cheating and absenteeism that hindered the data collection process and thus compromised the experiment. Therefore, although such experiments are considered the epitome of evaluation methods, they are not always realistic in field research where conditions are often beyond the control of researchers. In general, conducting any form of methodical evaluation can be challenging in ICTD field research.

### *2.1 Insufficient resources*

Financial, physical and human resources are the crucial inputs of any research endeavor. In ICTD work, typically the most expensive resources are the technology and technical personnel. With much of the focus on the technology component of ICTD, there is often little, if any, time or money available for evaluation.

### *2.2 Dearth of useful data*

Perhaps the most important element of any evaluation work is data. However, obtaining sufficient and credible data can be one of the most challenging aspects of field research. In developing communities, in particular, collecting and storing information may not be a priority. Records, if made, are often lost or fragmentary.

### *2.3 Limited access to research participants*

ICTD research is geared towards producing a beneficial impact within a developing community. Thus, to measure the effects of such projects, researchers need to study members of the society itself. However, obtaining people's consent to participate in a research study can be challenging, particularly if they have had unfavorable experiences with outside researchers in the past, such as being used only for a photo-op or promised outcomes that never materialized. Recruiting research participants is further complicated when working with young children, since consent needs to be obtained from a parent or legal guardian. Often, parents and guardians are unavailable, and in some cases it is not clear who the legal guardian of the child is since paperwork to support such claims may be non-existent. Additionally, language and cultural barriers render the task of explaining the research study to participants quite difficult. All these factors can significantly limit the study sample size and thus, restrict the rigor of any data analyses for evaluation purposes.

### *2.4 Volatile environment*

Difficulty controlling the environment may introduce confounding variables, and thus obstruct researchers' ability to accurately isolate the effects of a technology intervention. A primary objective of a typical evaluation is to establish a cause and effect relationship between the intervention and resulting outcomes. However, when there are many other events influencing the studied outcomes, the ability to identify the effects specific to the program being examined is diminished. In developing communities in particular, environmental, political, social and economic changes can be dramatic and have a significant impact on society. For example, students' home lives may be beset by problems related to poverty and disease, such as the HIV epidemic which can orphan children and leave them destitute [56]. Student performance in class will be greatly influenced by such experiences. Relative to such personal upheaval, the effect of a technology intervention on student performance may be undetectable.

## 3. Types of Evaluation

Evaluations are often divided into two broad categories:

1. Formative Evaluation – An evaluation designed to improve the performance of a project or program by examining whether and how well critical project activities and procedures are executed [57]. A widely used type of formative project assessment is process evaluation, which involves monitoring the implementation, development and quality of project or program activities [58].

2. Summative Evaluation – An evaluation that focuses on assessing the output and outcome of a project relative to expected results, so as to offer a summary judgment on its performance [57]. This is the more traditional form of evaluation that most people are familiar with.

These two types of evaluation work in tandem to inform decisions on how to improve a project or program and ascertain the extent to which the intervention achieved stated goals and objectives. Conducting a summative evaluation alone would provide information on the effectiveness of project output and outcomes, but does not offer much insight into how or why the project succeeded or failed. Therefore, neither a summative nor formative evaluation is as powerful when conducted in the absence of the other.

## 4. Existing Approaches to Evaluation in ICTD

Several different approaches to evaluation are currently employed in the field of ICTD [59][60][61][62]. These techniques can be applied to an array of projects from different disciplines, and outline a general approach to collecting, organizing and analyzing information for the purpose of evaluating a project or program. This section provides an overview of existing approaches to assessing ICTD projects.

### *4.1 Logical Framework Analysis (LFA)*

This planning and evaluation tool entails mapping out different components of a project such that there is a logical connection between project elements as well as external factors [59]. LFA can be applied during the planning as well as the execution stage of a project. "It makes the project logic explicit, provides the means for a thorough analysis of the needs of project beneficiaries and links project objectives, strategies, inputs, and activities to the specified needs. Furthermore, it indicates the means by which project achievement may be measured" [63]. Elements of a project matrix as outlined through LFA are given in Figure 6 [59].

| Sequence of Events | Indicators | Assumptions |
|---|---|---|
| GOAL<br>Overarching objective that the project is expected to accomplish | Specific measures to verify the extent to which the goal is fulfilled | If the necessary important events, conditions or decisions occur, the objectives will be sustained in the long term. |
| ↑ | | |
| PURPOSE<br>Effect that is expected to materialize as the result of the project | Specific measures to verify the extent to which the purpose is fulfilled | In the long run, achieving the project purpose will contribute to the fulfillment of the goal. |
| ↑ | | |
| OUTPUTS<br>Results that project management should be able to produce | Specific measures to verify the extent to which outputs are produced | If outputs are produced, then the purpose will be achieved. |
| ↑ | | |
| ACTIVITIES<br>Activities that need to be undertaken by the project in order to produce the outputs | | If activities are carried out, then outputs will be produced. |
| ↑ | | |
| INPUTS<br>Goods and services necessary to carry out activities | | If the inputs are available, then activities will be carried out. |

**Figure 6:** The Logical Framework Analysis Project Matrix [59]

LFA is implemented in two phases: designing the project and analyzing the situation. Project design involves constructing a project matrix with elements specific to the given endeavor. Situation analysis includes four steps:

i. Participation analysis, which is essentially a comprehensive look at project stakeholders.

ii. Problem analysis, where a 'problem tree' is constructed to map major problems with factors attributed to their cause.

iii. Objectives analysis, whereby potential solutions to identified problems are explored. In this step the problem tree is transformed into an objectives tree, such that causes are translated into means by which an end can be achieved; that end being the resolution of problems associated with those causes.

iv. Alternatives analysis, where the different means-end branches of the objectives tree are assessed to ascertain their feasibility [59].

LFA is a useful tool for organizing information in a manner that facilitates project planning, management and evaluation. However, LFA does not eliminate the need for conducting separate analyses to understand different aspects of a project, such as its target group, costs and benefits, and impact. Rather, LFA serves as one of many tools that project managers can utilize to plan, implement and evaluate a project [59].

### *4.2 Participatory Monitoring & Evaluation (PM&E)*

PM&E is a relatively new approach that advocates decentralized decision making within the context of a project or program. Applying this technique to project evaluation involves obtaining input from different stakeholders in designing and executing monitoring and evaluation. While stakeholder participation is important in project evaluation, the level of participation is often restricted by the dynamics of the groups involved, given that acquiring stakeholder participation for M&E involves negotiations in socio-cultural and political spaces [60]. Still, PM&E offers researchers an approach that has the potential to be useful in engaging stakeholders and managing projects more efficiently.

### *4.3 Most Significant Change (MSC) Technique*

This technique is a form of participatory monitoring and evaluation that involves obtaining qualitative measures of significant change on an ongoing basis during a project, with the participation of stakeholders. The measure of change utilized in the MSC technique is stories from the field. In essence, applying MSC involves gathering stories of significant change in the field, and designating a panel of stakeholders or project personnel to systematically decide which of these stories are the most significant [61]. The MSC technique can add value to project evaluation by capturing effects or impacts that would not be detectable through more traditional assessment measures.

### *4.4 Development-Focused Assessment Models*

These resources are primarily directed toward understanding how different interventions affect the economic development of project or program beneficiaries. Many of these methods focus on summative evaluations; i.e. the ultimate results of a project or program.

#### *4.4.1 Grassroots Development Framework (GDF)*

The Grassroots Development Framework was introduced by the Inter-American Foundation as a method to capture the wide array and multi-faceted development results at the grassroots level. This technique gives equal weight to tangible or quantifiable indicators and the more difficult to measure or intangible results. The GDF posits that "Sustainable development acts at three levels: 1) improving living conditions for participants; 2) strengthening community organizations and networks; and 3) addressing the policies, practices and attitudes that perpetuate poverty" [64]. In general, this approach is focused on capturing the broad range of factors that influence how a development project affects the standard of living of the community it serves. Participation, equity, empowerment and sustainability are core principles of the GDF [65].

### *4.4.2 Information-for-Development (I4D) Framework*

This framework was designed by the International Development Research Center (IDRC). It constitutes an information systems or information science approach to assessing the impact of ICTD research. The focus of this framework is on measuring the impact of information made available through ICTD projects. Its premise is that enhancing information provision is the major potential contribution of ICTD endeavors. An increased flow of information can in turn improve processes carried out and decisions made in development work, and thus facilitate the delivery of key development outcomes [62]. The I4D framework determines how information impacts different groups of stakeholders, and identifies measures that can be utilized to gauge the performance, effectiveness, cost-effectiveness, impact and cost-benefit of improved information provision through the project [62].

A variation of the I4D framework considers information failure to be a potential cause of development problems [66]. As such, ICTD projects would be considered successful if they mitigated such failures. Yet another variant of this framework highlights information provision as a component of ICTD projects, but not the sole input variable [67].

### *4.4.3 The Livelihoods Framework*

This approach looks at the impact of projects on livelihood assets such as political capital (e.g. empowerment), physical capital (e.g. laptops), financial capital (e.g. US $1 per day), as well as other factors affecting a person's livelihood (e.g. how information impacts decision making related to policies, strategies and processes) [62]. The backdrop for this framework is a context of vulnerability, whereby the framework recognizes that different factors affecting a person's livelihood can also determine how exposed or vulnerable they are to changes in circumstances or their environment, which are beyond their control.

Some variations or adaptations of the livelihoods framework are summarized below:

- The 12 Cs Framework – The United Nations Conference on Trade and Development (UNCTAD) introduced this approach to assess pro-poor ICT programs and policies. It identifies 12 Cs that are important in ICT related programs: Connectivity, Content, Community, Commerce, Capacity, Culture, Cooperation, Capital, Context, Control, Coherence, and Continuity. The purpose of the framework is "to help in the asking of questions and to focus on issues that are important to the poor, but not necessarily to prescribe particular actions" [68].
- The Diamond Alignment – This approach is designed to assess whether the conditions necessary for successful innovation and partnerships exist within a given project/program context. Elements investigated include: (a) Constituents' perceptions, goals, actions and resources; (b) Nature and maturity of the technology; (c) Governance; (d) Target constituents' perceptions and pursuits; (e) Nature of target problem; and (f) Interacting technologies/constituencies [68].
- The 8 Pillars – This method was developed to assess project or program sustainability. A list of success factors were compiled based on experience from a range of projects in developing countries. These factors were used to derive the 8 'pillars', which include: (1) Share costs appropriately; (2) Ensure equitable access; (3) Address diversity; (4) Provide a high proportion of local or appropriately localized content; (5) Build on existing systems; (6) Build capacity at the local level; (7) Use realistic technologies; and (8) Build knowledge partnerships between knowledge users [68].

The livelihoods framework approach, in general, is useful for long term projects focused on impacting development within a given community.

#### *4.4.4 Sen's Capabilities Framework*

Amartya Sen divides an individual's capabilities (freedoms to achieve) into five areas: (a) Economic, (b) Political, (c) Social, (d) Informational, and (e) Security. According to this approach, projects are assessed based on how they influence people's capability set. Sen recognizes that improving capabilities should not necessarily be the end goal since there is an added stage where people actually make use of their capabilities. This next stage is primarily driven by personal choice; e.g. using the internet to look up celebrity gossip versus researching a topic for a class essay [68].

### *4.5 General Project Evaluation Guidelines*

These documents are designed to offer assistance in general project or program evaluation. They were created by a variety of institutions that either manage or support different projects.

#### *4.5.1 W.K. Kellogg Foundation Evaluation Handbook*

This handbook is designed specifically for project directors who are assessing Kellogg Foundation funded projects and programs [69]. However, much of the information provided could be useful to project managers of a variety of other projects as well. The Kellogg handbook offers a useful blueprint on how to conduct evaluation at the project level. This blueprint entails a context evaluation, implementation evaluation and an outcome evaluation. Thus, it is one of the few resources that advocate a more comprehensive look at a project, as opposed to focusing solely on end results. In addition, the handbook outlines steps to plan and implement an evaluation, as well as utilize and communicate findings.

Instructions in this handbook are primarily presented as questions and factors to consider at different stages of the project and evaluation. The information is organized logically to facilitate more effective planning of project evaluations. This handbook offers valuable suggestions on how to approach each phase of a project assessment. Specifically, the worksheet on potential evaluation activities (Table 5) could be beneficial to project managers when constructing an evaluation strategy.

**Table 5:** Worksheet A from the Kellogg Foundation Evaluation Handbook [69]

| Project Phase | Possible Evaluation Activities at Project-Level |
|---|---|
| Pre-Project | > Assess target population/community needs and assets<br>> Define goals and objectives of planned services/activities<br>> Describe how planned services/activities will lead to goals<br>> Identify community resources that will be needed and how they can be obtained<br>> Determine extent to which project plans match community priorities<br>> Obtain stakeholder input<br>> Develop an overall evaluation strategy |
| Start-Up | > Determine underlying assumptions of program<br>> Develop a system for presenting information to and obtaining information from stakeholders<br>> Assess feasibility of procedures given actual staff and funds<br>> Assess data that can be gathered from routine project activities<br>> Develop a data-collection system (if doing so will answer desired questions)<br>> Collect baseline data on key outcome and implementation areas |
| Implementation and Modification | > Evaluate organizational processes or environmental factors that are inhibiting or promoting project success<br>> Describe project and assess reasons for deviating from original implementation plan<br>> Analyze staff and participant feedback about successes/failures and use this information to modify the project<br>> Provide information on short-term outcomes to stakeholders/decision makers<br>> Utilize short-term outcome data to improve the project<br>> Describe how short-term outcomes are expected to affect long-term outcomes<br>> Continue to collect data on short- and long-term outcomes<br>> Assess assumptions about how and why program works, and modify as needed |
| Maintenance and Sustainability | > Share findings with community and other projects<br>> Inform alternative funding sources about accomplishments<br>> Continue to use evaluation to enhance the project and monitor outcomes<br>> Continue to share information with different stakeholders<br>> Assess long-term impact and implementation lessons, and explain how and why program works |

| | |
|---|---|
| Replication and Policy | > Assess whether project suits other communities<br><br>> Determine critical elements of the project that are needed for success<br>> Highlight specific contextual factors that inhibited or facilitated project success<br>> Develop strategies for sharing information with policymakers to make relevant policy changes, as appropriate |

Arguably, the Kellogg Foundation has produced one of the most thorough handbooks to guide project level evaluation.

### *4.5.2 The NSF's 2002 User-Friendly Handbook for Project Evaluation*

This handbook was designed specifically for NSF project managers who are not experts in conducting evaluations [70]. In particular, this book recommends steps to take when conducting an evaluation, presents a thorough review of different data collection strategies, and offers guidance on carrying out a culturally responsive project assessment. The NSF handbook also advocates the use of logic models to assist in evaluation planning, as well as a combination of quantitative and qualitative methods to enhance data collection and analysis. Similar to the Kellogg Foundation handbook, the NSF guidelines can be applied to a variety of projects.

## *4.6 Guidelines for Evaluation of ICT-Related Projects*

The following documents were created with ICT projects in mind and are perhaps the most relevant to ICTD research.

### *4.6.1 Monitoring and Evaluation of ICT in Education Projects: A Handbook for Developing Countries*

This handbook was designed to assist in executing rigorous monitoring and evaluation (M&E) of information and communication technology in education (ICTE) projects, while taking into consideration the context of a developing country [71]. It is primarily targeted at program mangers or implementers, evaluation experts and policy makers. Although the book offers some practical guidance, the content is at an overarching level of instruction and thus assumes some *a priori* knowledge on the part of the reader/user. Executing an M&E plan recommended by this handbook would require significant resources dedicated to evaluation. The instructions offered are in line with established M&E theory, which is rigorous but sometimes difficult to execute in the field. To supplement this work in ICTE, Ng *et al.* present a toolkit on how to build capacity for large scale deployment and integration of ICT in education [72].

### *4.6.2 Framework for the assessment of ICT pilot projects: Beyond Monitoring and Evaluation to Applied Research*

This framework was produced by the research group *info*Dev specifically for *info*Dev task managers who are responsible for the assessment of pilot projects funded or managed by that organization [73]. The guidelines facilitate the decision-making process regarding how to proceed with a given project, from the perspective of donors and managing organizations. More specifically, the framework discusses forward-thinking research questions that should be posed early on in the project planning phase so that data/evidence can be collected in order to sufficiently address those inquiries.

## 5. Creating User-Friendly Guidelines

The goal of this study was to create an evaluation framework that would be easy to maneuver through. It was also important to strike a balance between providing a sufficient amount of guidance and not burdening researchers with an overwhelming number of tasks. Focusing on evaluation related activities can prove to be counter-productive if those tasks are carried out at the expense of other important project processes.

Mottur-Pilson recommends that user-friendly guidelines should (a) be written in language that is simple and clear, with little room for ambiguity; (b) be practical and relevant to the given field or practice; and (c) provide assistance in decision making related to the given field or practice [74].

Mahrani *et al.* investigated how people react to guidelines and why they might choose not to adhere to such instructions. Among reasons for not following guidelines, the majority of subjects cited that the guidelines were not comprehensive enough. In order to improve chances of the guidelines being utilized by intended users, the authors stressed the importance of customizing instructions to suit the setting and views of users rather than rigidly prescribing practice [75]. They recommend that user-friendly guidelines should be in summary form and make use of bullet points as opposed to detailed paragraphs. Black *et al.* echo this last point in their work, which found that shortening the instruction guidelines in a fairly mechanical fashion can improve learning by the user or reader [76].

# 6. An Evaluation Framework for Pilot ICTD Research Interventions

In this study an evaluation framework that can be applied to pilot ICTD research interventions was created by drawing from existing evaluation manuals, handbooks and techniques mentioned above. The primary goal was to enable even amateur evaluators to plan and conduct a structured project assessment in the field.

## *6.1 Guidance for Amateur Evaluators*

Target users for this framework are novice ICTD field researchers who have little to no experience conducting project evaluations. The framework offers more detailed instructions, compared with the guidelines discussed above, on how to plan each phase of an evaluation and also execute that plan once in the field. In ICTD it is common practice that the field researchers themselves will be responsible for not only the technology design and development, but also project assessment and management. Thus, the evaluation framework presented here strives to offer researchers a step-by-step guide that will walk them through the different elements involved in a structured project evaluation, from the planning through the execution phase.

### *6.2 A Practical Approach to Evaluation*

The experiences of TechBridgeWorld[7] researchers in the field conducting pilot ICTD projects motivated and informed the development of this framework. For past projects researchers relied on existing evaluation techniques and methods, many of which proved to be infeasible given the unpredictable conditions on the ground. Instructions needed to be more practical and adaptable to match the circumstances of a field research project assessment. The framework presented in this chapter addresses this need and also offers guidance for handling potential setbacks.

## 7. The PREval (Pilot Research Evaluation) Framework

The framework presented in this chapter is entitled: "The PREval (Pilot Research Evaluation) Framework", otherwise known as PREval. It is a resource for field researchers who are responsible for conducting project evaluations, but may not have the necessary knowledge or expertise to do so.

Although many existing evaluation guidelines focus on summative evaluations, which are the most common type of evaluation, PREval incorporates both formative and summative elements. In ICTD pilot field research, processes carried out in preparation for a project and while on the ground can have a significant impact on project outcomes. Therefore, conducting a process

[7] TechBridgeWorld (http://www.techbridgeworld.org/) is a research group at Carnegie Mellon University conducting work in the field of ICTD.

evaluation, which is a type of formative assessment, is important to ensure that critical tasks are completed well and on time, so as to increase the chances of the project achieving its end goals.

Since technology itself is a vital component of ICTD interventions, PREval offers guidelines on how to assess the technology output, whether it is hardware, software or a combination of both. This is a component of ICTD project evaluation that is often omitted. Ensuring that the technology functions as it is meant to, is appropriate for the given audience and environment, and can be maintained locally in the long run, is vital to increasing the likelihood that it will be effective within a given community.

In addition, PREval covers the more traditional form of project assessment, summative evaluation, which is conducted at the end of a project or project phase. The framework outlines key steps in planning and executing an outcome evaluation, highlights some of the techniques that are commonly employed, and also directs users to relevant external resources.

PREval is comprised of two major components. The first contains instructions on how to plan and execute three types of evaluation: process evaluation, technology assessment, and outcome evaluation. Section two provides a template for communicating project evaluation findings to decision makers and other stakeholders.

## *7.1 Key Components of the PREval Framework*

A complete version of the PREval framework document is given in Appendix C.

### *7.1.1 Process Evaluation*

Process evaluation is necessary to ensure that critical activities are completed on time and produce desired results. This type of formative assessment enables researchers to monitor progress throughout the entire duration of the project.

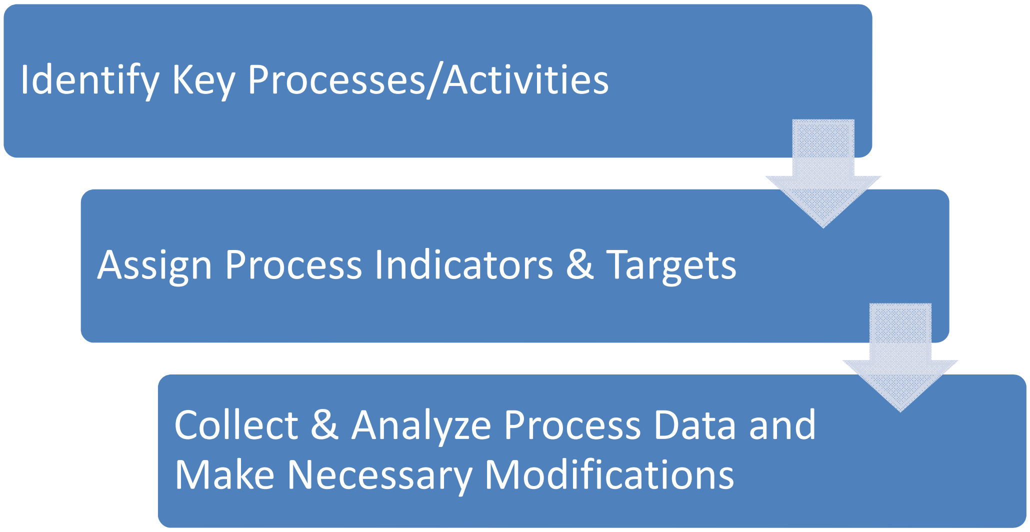


**Figure 7:** Process evaluation stages in PREval

Figure 7 represents typical stages of a process evaluation. The first step is to identify the activities or processes that will be critical to complete in order to conduct an ICTD pilot field study. Next, process indicators need to be assigned such that progress made with each process can be monitored. Additionally, targets should be set for when an activity needs be completed by and the expected results of executing that process. These goals will serve as the benchmark against which actual results can be compared. The next step is to collect and analyze indicator data on key processes. Finally, based on findings from the previous step, process modifications should be made in order to account for any identified problems or changes required to better suit the project location and/or stakeholders.

This section of the PREval framework also provides users with a list of processes to include in a pilot ICTD research endeavor:

a) *Preparatory work*, which entails activities to complete prior to commencing field research. This includes defining project goals, identifying stakeholders, establishing a local partner, conducting background research, managing logistics and legalities, and identifying potential sources of data.

b) *On-site research*, which covers processes that ought to be completed while in the field. This includes obtaining participant consent, conducting a needs assessment and documenting observations. Among these activities, needs assessment is arguably the most important because it not only elicits vital information about the given community, but is also a means by which to involve key members of the community from the onset of the field research. Encouraging community participation from an early stage of an endeavor has proven to produce favorable results in different public or community programs [77].

c) *Technology development*, which entails activities included in the production of the technology output for the project. This involves designing the technology, and iteratively improving the technology by obtaining and incorporating local community input.

d) *Field research wrap-up work*, which covers processes that should be put in place to help ensure that the work begun by researchers can be sustained beyond the pilot project phase, if so desired. This includes monitoring post-pilot progress, integrating technology use into community activities, and maintaining the technology.

Monitoring these activities can alert researchers to potential problems early enough for corrective action to be taken. Moreover, a process evaluation can provide insight into why different aspects of a project were successful or unsuccessful, since outcomes can be linked back to activities that influenced them.

### *7.1.2 Technology Assessment*

This component of the PREval framework suggests seven criteria by which the strengths and weaknesses of the technology output can be evaluated:

i. Functionality – Does the technology work well?

   This includes determining whether both hardware and software properly execute intended tasks, as well as how they carry out target operations.

ii. Reliability – Does the technology work every time you use it?

   This helps determine the consistency in function and typically entails calculating error or failure rates of the technology.

iii. Usability – Is the technology user friendly, particularly for novice users?

   This provides insight as to whether users find the technology accessible and comprehensible. If not, the technology will most likely be left idle.

iv. Suitability – Is the technology a good fit for the given context and locality? This measure will gauge how well the technology output suits the intended user group and accommodates their circumstances.

v. Robustness – Can the technology operate within the required environment, under prevalent conditions?

   This is a measure of how well the technology can function within the given setting or environment where conditions maybe volatile and harsh.

vi. Maintainability – Can the technology be easily maintained locally?

   This is an important criterion for sustaining the technology solution. If the technology is very complicated or difficult to maintain using local or remotely available expertise, the project is not likely to sustain itself post-pilot project.

vii. Cost – How much does it cost to build, use and maintain the technology?

Cost is a significant barrier to deploying technology in developing communities. Thus, keeping track of costs associated with the technology solution will be valuable when assessing whether it can be made affordable to the community of end users.

The PREval framework also offers guidelines on how to select metrics to determine the extent to which the technology is meeting expectations.

### *7.1.3 Outcome Evaluation*

This component of the PREval framework outlines elements necessary in an outcome evaluation. In addition, it provides guidelines on selecting metrics, data collection techniques and methods of data analysis. A unique contribution of this section of the PREval framework is a data analysis algorithm, which directs researchers to methods that can be applied depending on the type of available data: linear data, time-to-event data, count data, categorical data or text data. This section also includes guidelines on how to interpret findings.

### *7.1.4 Summary Report Template*

The final section of the PREval framework provides a template for communicating evaluation findings to facilitate the decision making process for project managers and sponsors. This template includes the following elements:

i. *Background* – Provide a summary of the project details

ii. *Project Goals* – List overall objectives of the project

iii. *Process Evaluation Findings* – Outline results of the process evaluation

iv. *Technology Assessment Findings* – Provide details about the technology as well as results of the technology assessment

   a. Technology Name

b. Technology Type

c. Technology Purpose

d. Technology Design

e. Technology Assessment

v. *Outcome Evaluation Findings* – Outline how the outcome evaluation was conducted and the results obtained from this assessment

a. Evaluation Design

b. Quantitative Findings

c. Qualitative Findings

*vi.* *Conclusions* – Summarize results of the overall project evaluation as follows:

a. Key Findings

- Will the target users actually use the technology?
- Is there the necessary technical infrastructure to house and maintain the technology?
- Does the technology effectively improve conditions in the given community?
- Can user data and feedback be collected remotely from the field?
- Were there any unique factors that contributed to the success and/or failure of any or all components of this pilot project?

b. Recommendations

- Technology Modifications
- Project Continuation
    - Scale up,
    - Gather more data/evidence prior to scaling up or down, or

- Abandon the project

# 8. Testing the Proof of Concept behind the PREval Framework

A preliminary assessment of the PREval framework was conducted to determine its potential value to ICTD field researchers. For this initial testing qualitative information was gathered on the feasibility, potential effectiveness and usability of the PREval framework. This was done in two stages. First, the PREval framework was applied retrospectively to past pilot ICTD projects to ascertain its feasibility and potential contributions. Second, feedback was obtained from possible end-users of PREval within the community of ICTD practitioners, in order to understand the usability and applicability of the framework in pilot ICTD field research.

## *8.1 Retrospective Application to Past ICTD Pilot Projects*

In order to apply PREval to past projects, papers published on those projects were utilized to obtain information collected from the field, and those data were used to fill in the summary report template given in the framework. This process helped identify key evaluation findings of the projects. Two projects were selected for this retrospective analysis:

i. The Automated English Reading Tutor Project in Ghana:

   This project was aimed at understanding whether and how technology can play a role in improving child literacy in developing communities. More specifically, this study investigated whether reading proficiency of students in a developing community (some unfamiliar with computers) can be improved through the use of an automated computer-based reading tutor [78]. The study targeted students in Accra, Ghana, and employed a reading tutor that was previously developed by Project LISTEN[8] at Carnegie Mellon

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[8] Project LISTEN: http://www.cs.cmu.edu/~listen/

University. Two different public schools were involved in the project, based on their proximity to the computer lab or center utilized for the respective study.

ii. The Braille Writing Tutor Project in India

The traditional method of learning to write braille (*i.e.* with a slate and stylus) presents many difficulties for visually impaired students. This is the primary mode for braille writing employed in developing communities across the world. Using this method involves challenges such as learning to write the mirror image of letters and receiving delayed feedback (*i.e.* after a teacher turns the page over and makes corrections). This project utilized artificial intelligence to create a tool that could supplement and assist in the process of learning to write braille using the slate and stylus [79]. The developed device was tested during a six-week pilot study at the Mathru School for the Blind in India and has subsequently been incorporated into the curriculum of that school.

These two studies had a principal investigator (PI) in common who was interviewed to determine what questions she sought to answer post-pilot project, as a decision maker. The extent to which the given projects answered those questions was assessed, and a determination was made as to whether the PREval framework would have added value if applied to those projects (Table 6).

To gauge its feasibility, the PREval framework was also retrospectively applied to two other projects (not linked to the PI interviewed). All four retrospective applications revealed that the PREval framework could have been feasibly applied to the four field studies.

**Table 6:** Assessment of extent to which past ICTD pilot projects were able to answer key questions for decision-makers, and the potential value that the PREval framework could have added, if applied to those projects.

| Questions decision makers hope to answer at the end of a pilot ICTD project | English Reading Tutor Project | | Braille Writing Tutor Project | |
|---|---|---|---|---|
| | **Did the published report answer the question?** | **Could PREval have added value?** | **Did the published report answer the question?** | **Could PREval have added value?** |
| What were the strengths and limitations of the technology? | To an extent | Yes; the technology assessment in PREval would have provided more detailed information about the technology. | To an extent | Yes; the technology assessment in PREval would have provided more detailed information about the technology. |
| Did the technology solution fail or succeed in meeting community needs? | To an extent | Yes; the outcome evaluation would have addressed this question. | To an extent | Yes; the outcome evaluation would have addressed this question, and more thoroughly assessed target community outcomes. |
| What aspect of the user environment could affect the technology (e.g. dust, humidity, etc.)? | No | Yes; this would have been discovered through the technology assessment. | No | Yes; this would have been discovered through the technology assessment. |
| Were there any barriers to users accessing the technology (e.g. language, cultural or literacy barriers)? | Yes | Yes; the technology assessment would have explicitly investigated this. | Yes | Yes; the technology assessment would have explicitly investigated this. |
| Did the community accept the technology? | Yes | No; this was well investigated by the study. | Yes | No; this was well investigated by the study. |
| Is the technology affordable to the targeted users? What is their buying power? | To an extent | Yes; the cost of the technology solution would have been explicitly explored if PREval was used. | Yes | No; although the technology assessment would have investigated the cost of the technology. |
| What are the primary needs of the user community? | No | Yes; a needs assessment is recommended by PREval. | Yes | No; this was well investigated by the study. |
| Should we continue to work with the chosen community partner? Why or why not? | Yes | No; this was discovered naturally through the course of the project. | Yes | No; this was discovered naturally through the course of the project. |
| Can we easily and reliably communicate with the community partner, even remotely? | No | Yes; methods of communication post-pilot would have been investigated if PREval was followed. | Yes | Yes; this was discovered naturally through the course of the project, but would have been explicitly addressed through PREval. |
| What logistical aspects of the projects went well and which did not? | Yes | No; the researchers conducted a fair assessment of logistics. | No | Yes; this would have been discovered through the process evaluation. |

| | | | | |
|---|---|---|---|---|
| Is this project worthwhile pursuing further? If so, how? | To an extent | Yes; the final report template would have explicitly answered this question. | To an extent | Yes; the final report template would have explicitly answered this question. |

### *8.2 Feedback on the PREval Framework*

The PREval framework was presented to six ICTD practitioners to obtain their feedback. This group included principal investigators as well as non-PI researchers. Their comments regarding the PREval framework included the following points:

- The PREval framework is comprehensive and provides a useful step-by-step guide highlighting important aspects of evaluating a pilot ICTD project.
- The technology assessment section offers thoughtful and valuable points to consider when evaluating the output of an ICTD project.
- The PREval framework could be particularly useful to student researchers in ICTD.
- Components of the PREval framework can aid program managers in project planning, and can also serve as a guide when writing grant proposals.
- The PREval framework could provide consistency across projects when managing and evaluating multiple studies.
- The summary report template will be helpful in organizing project findings.
- The outcome evaluation section could be further enhanced by adding more references to tools and techniques that can be used during such an assessment.
- It would be useful to add explicit instructions on how to collect evidence on the scalability and sustainability of a project.

This feedback demonstrates the potential for the PREval framework to be utilized by the ICTD community, and to add value to the evaluation efforts carried out in this field. To further assess usability of the PREval framework, it was provided to a student researcher who was planning the evaluation of an upcoming pilot ICTD study. This student was able to successfully apply the PREval framework to his work, and produced a more comprehensive and organized evaluation plan as a result. His feedback highlighted the need for more examples throughout the framework and streamlining the instructions so that they can be more easily followed by a novice ICTD researcher such as himself. These suggestions have since been incorporated into the framework.

## 9. Conclusions

This chapter presented an approach to evaluation unique to ICTD research. The developed framework (*i.e.* the PREval framework) specifically targets pilot field research interventions, which are common in this relatively new field.

The PREval framework was designed to be a living document that would evolve over time with necessary adaptations based on feedback and lessons learned from its application in various ICTD field projects.

A survey of existing evaluation methods revealed a lack of comprehensive approaches to project assessment that would be accessible to a novice evaluator or field researcher. Given that many ICTD pilot endeavors are carried out by such researchers, the PREval framework fills a prevalent need within this field of study. Initial testing of the framework revealed that it can be feasibly applied to a range of ICTD projects, and has the potential to add value to the evaluation of pilot ICTD endeavors.

# Chapter 4: A Sustainability Analysis of Assistive Technology in a Developing Community Setting – *Examining the Use of an Automated Braille Writing Tutor at the Mathru School for the Blind*


## Abstract

This study investigates the sustainability of the Braille Writing Tutor (BWT) technology at the Mathru School for the Blind in Bangalore, India. The BWT is a computer-based tool developed to facilitate the process of learning to write braille using the traditional slate and stylus method. This device was originally customized to meet the needs of the Mathru School, which has since successfully integrated the use of the BWT in its classroom activities. Thus, the Mathru School provided a natural setting in which to study the sustainability of the BWT. Sustainability is explored based on three different dimensions: financial, technological and social. We found that the BWT could be sustained in all three aspects, with appropriate long term provisions put in place at the Mathru School. Findings here also suggest that the BWT or a modified version of it could be a good candidate for large scale deployment in India, and potentially in other settings in the developing world.


## 1. Introduction

Braille is the principal mode of reading and writing for blind and visually impaired people in the world. "Through the use of braille, people who are blind are able to review and study the written word. It provides a vehicle for literacy and gives an individual the ability to become familiar with spelling, punctuation, paragraphing, footnotes, bibliographies and other formatting considerations" [80]. Literacy among visually impaired people in developing communities across the globe is at a very low rate. It is estimated that fewer than 3% of the visually impaired population in developing communities are literate [81]. Furthermore, the World Health Organization approximates that roughly 87% of the world's 314 million visually impaired people live in developing countries [82]. Thus, there is a need to improve literacy among these communities across the globe. To combat braille illiteracy in developing communities, TechBridgeWorld, a research group at Carnegie Mellon University, developed the Braille Writing Tutor (BWT). As its name indicates, this device assists visually impaired individuals to learn how to write braille.

The BWT has been field tested in several different locations around the world at a small scale, through pilot projects [81][83][84]. This device is now at a stage in its development where TechBridgeWorld is considering its potential for commercialization or larger scale use. The successful transfer of this technology from TechBridgeWorld to the developing world will require independent operation and maintenance of the BWT in such locations, as well as an understanding of how long the device can function in these communities, under given circumstances and type of use. Therefore, prior to embarking on a path of larger scale deployment, there is a need to determine whether the BWT can be sustained in a developing community setting. This study explores the sustainability of the BWT within a specific location, the Mathru School for the Blind in Bangalore, India, where this device has been adopted and utilized since the fall of 2006. Findings from this investigation provide preliminary indicators of the potential for the BWT to be feasibly integrated, utilized and maintained over the long term within a developing community.

## 2. Background

### *2.1 The Mathru School for the Blind*

The Mathru School for the Blind in Bangalore, India is a non-profit, privately run institution, which was founded in 2001 by Ms. Gubbi R. Muktha with the support of some donors [85]. Ms. Muktha was inspired by a tragedy in her own life that rendered her immobile for a few years due to a serious foot injury. During her rehabilitation in India she encountered blind individuals who, she noted, relied heavily on others for help with day-to-day activities such as boarding the correct bus. Given her own struggles to become self-sufficient, she recognized a need for assisting the visually impaired to gain independence and a sense of self worth. The Mathru School for the Blind strives to teach its students to reach their full potential and become valuable members of society, as opposed to a burden as they are most often perceived.

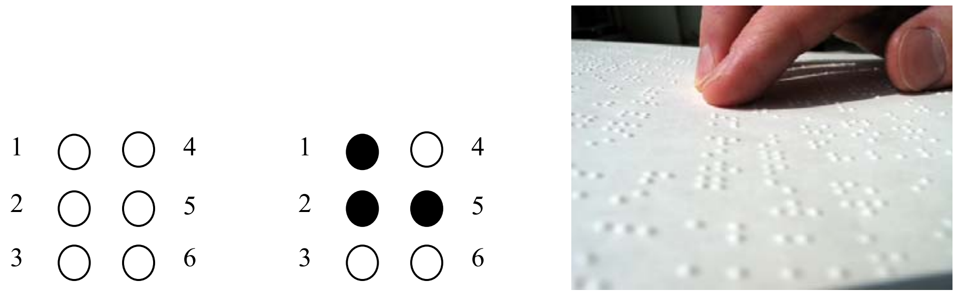
Ms. Muktha's school has surpassed even her expectations with it growing from very humble beginnings to a widely recognized and respected establishment. The school began with just one student and one teacher working in Ms. Muktha's residence. Today there are 82 students, 10 teachers, as well as 5 to 10 administrative and support staff at the school, in its own premises in Bangalore. Most students at Mathru are in-residence, *i.e.* the school provides residential facilities and students live on the premises while receiving their education. This is an added benefit since many students' home towns are far from Bangalore. Moreover, with generous donors and grants continuing to financially support the Mathru Educational Trust, education at Mathru is offered at no cost to students, which enables the school to accept children from low-income socio-economic backgrounds.

The Mathru School covers grades 1 through 10, so that upon graduation students possess the equivalent of a high-school degree in the U.S.A. Students at Mathru qualify at the same level as their sighted peers in the Indian state of Karnataka, by successfully completing state-level examinations in order to graduate. The government exempts visually impaired students from math and science given the visual nature of those subjects. Instead, these students are tested on economics, sociology and political science. Although visually impaired students are required to complete final state-level exams by employing a scribe, the Mathru School focuses on teaching its students braille to enable their independence. Therefore, in addition to the subjects that their sighted peers study, students at Mathru also learn braille in English, Kannada (the local language) and Hindi.

### *2.2 The Braille Language*

The basic braille system consists of cells with six locations, referred to as "dots". Different combinations of these dots represent the different letters of an alphabet. The six dots in a braille cell are aligned in three rows of two, and numbered as depicted in Figure 8. Braille is written by embossing a combination of these six dots onto a paper, and is read using tactile senses by running fingers along the page (left to right for English braille). For example, the letter 'h' in English is represented in a braille cell with dots 1, 2 and 5 embossed (Figure 8). Therefore, when a person reads the letter 'h' in braille they should feel these three dots raised on the page within one cell space. To indicate the capitalization of a letter, the character should be preceded by given symbol. In the case of English braille, dot six would have to be embossed in the cell before the one in which a given letter appears [86]. A similar preceding symbol is required to distinguish between numbers and letters. Different languages have different character maps (*i.e.*

an arrangement matching each character to a unique dot pattern), but typically use the basic six-dot system.




**(a)** **(b)** **(c)**

**Figure 8: (a)** Arrangement and numbering of the six dots in a braille cell. **(b)** The configuration of dots that represent the braille annotation for the letter “h”, where the black circles indicate embossed dots (*i.e.* dots 1, 2 and 5 are embossed). **(c)** Braille characters as they would appear on paper, being read by running fingers across the page [87].

### *2.3 The Slate and Stylus Method for Learning Braille Writing*

In developing communities, the primary means for learning braille writing is the slate and stylus, which is substantially more affordable than advanced implements, such as the six-key braille typewriter (Brailler) [81]. The braille slate consists of two plastic sheets (hinged along one edge), where the top sheet has cut out rectangular sections in a grid-form to represent rows of braille cells, and the bottom sheet has indentations corresponding to the six dots in each of the braille cells on the top sheet (Figure 9). Braille paper is placed between the two plastic sheets of the slate, and different braille characters are embossed onto the paper using a stylus, which is a plastic implement with a metallic tip (Figure 9). The braille cell cutouts on the top plastic sheet of the slate guide the writer. In addition, each of these cell outlines is grooved in three places on either side to help identify the relative positions of the six dots within that cell. The special type of paper (*i.e.* braille paper) used with this tool is relatively thick compared to standard printer paper, and is not pierced by the stylus and is instead embossed.

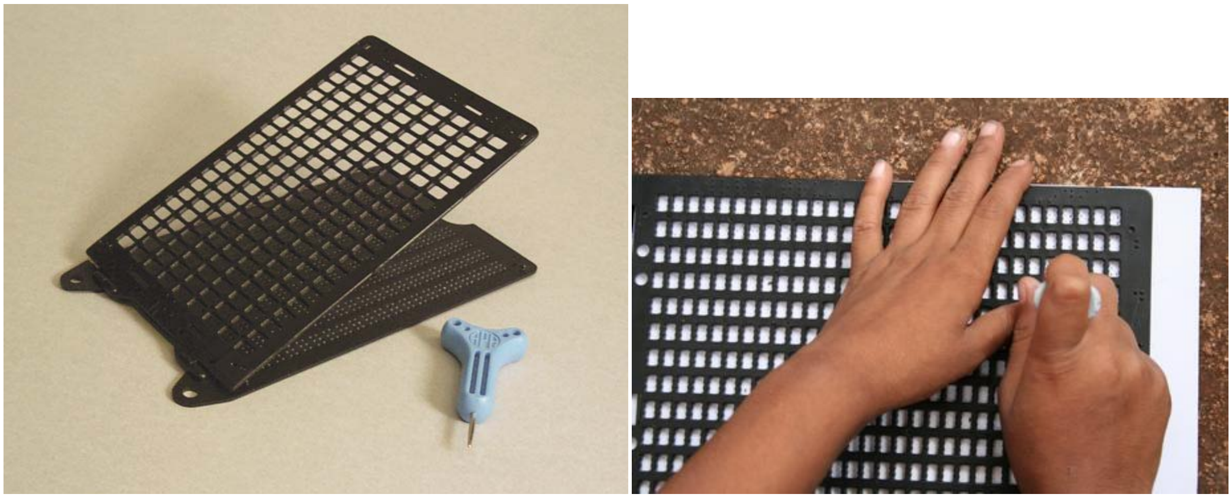


**Figure 9:** Images of a braille slate and stylus (left) [88] and a person writing braille using a standard slate and stylus (right) [89].

With the slate and stylus, braille has to be written in the direction opposite to which it is read. For English braille, this requires writing from right to left, such that when the paper is removed from the slate, it can be flipped over and read from left to right. Thus, to learn braille using the slate and stylus requires learning the alphabet in two different orientations; the orientation in which it is read (left to right, for most languages), as well as its mirror image orientation in which it is written. This complicated process for mastering braille poses a significant barrier to literacy among the visually impaired in developing communities.

### *2.4 The Braille Writing Tutor*

The numerous challenges to achieving braille literacy in a developing community setting were identified through conversations and an extensive needs assessment conducted with the Mathru School for the Blind. To address the difficulties students face when learning to write braille, Kalra *et al.* developed a computer-based device (the BWT) that can be utilized to supplement the slate and stylus method of learning to write braille [81]. The BWT was designed to specifically teach braille writing skills that are necessary when using a slate and stylus, which remains the most affordable and ubiquitous braille writing tool in the world and is likely to remain so for the next decade or more. Thus, the BWT does not seek to replace the slate and stylus, but instead improve its impact by enabling more people to successfully master and use that system of writing braille. The user interface of the BWT is similar to a slate, but computing technology enables this device to provide audio feedback to the user and also detect errors in their braille writing. A standard stylus is utilized to interact with the device. In its current version, the BWT performs the following functions [90]:

- When a user makes an entry (writes) on the device, it provides immediate audio feedback by repeating the dot, letter or word entered.
- It offers corrective audio feedback when mistakes are made.
- The device selects braille practice exercises that suit the user's skill level, based on the type and number of mistakes made during the current user session.
- It offers educational games to make the user's learning experience more enjoyable.

The BWT can facilitate the very difficult process of learning to write braille using a slate and stylus, by providing immediate audio feedback to the user and thus enabling him/her to recognize and rectify mistakes. With a slate and stylus, a student will only be able to identify errors upon completion of an assignment, at which point the paper can be removed from the slate, flipped over and graded by a teacher [81].

### *2.4.1 Hardware*

The hardware for the current version of the BWT is constructed from printed circuit board (PCB), acrylic plastic sheets and additional smaller elements such as buttons, screws and spacers (see Figure 10).

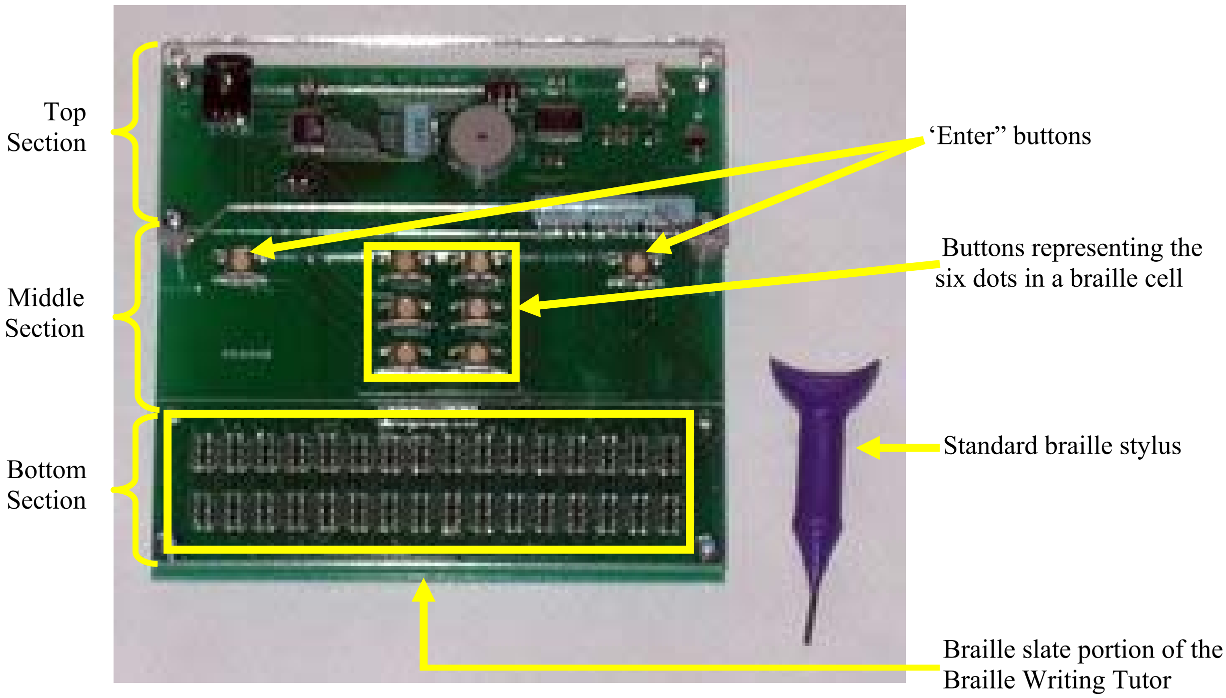



**Figure 10:** Main components of the current version of the Braille Writing Tutor [90].

Positioned in the top section of the BWT are, the microchip with firmware programmed onto it and a USB port to connect the device to a computer. The middle and bottom sections of the tutor comprise the primary user interface. In the middle section there are two "Enter" buttons on each side of the tutor, which enable the user to switch between modes in the software. The function of these two buttons is the same. Additionally, this section of the device contains six buttons positioned such that they represent the six dots in a braille cell. These buttons can be used by younger students to learn the concept of braille while their fine motor skills are still developing.

The bottom portion of the BWT is built to match the design of a braille slate, with two rows of 16 braille cells that can be used to input braille characters with a stylus, just as would be done with a typical slate and stylus, except without the use of paper. When the stylus is inserted into these cells, it completes an electrical circuit, which sends a message to the computer to provide the appropriate audio feedback. The hardware for the BWT was originally designed based on feedback from teachers and testing at the Mathru School, and was refined through field tests in other developing communities around the world.

#### *2.4.2 Software*

The software for the BWT is primarily written in C++. This software enables the device to communicate with a computer and perform the array of functions described previously. Additionally, the software allows instructions and character maps to be easily changed to match different languages and local accents, by facilitating the adjustment of default settings. The BWT has several modes for offering braille instruction including, dot learning modes where the user is tutored on the concept and numbering of the six dots in a braille cell, and letter learning modes that explain the different dot patterns associated with letters of the alphabet. Moreover, the software can adjust the instruction offered based on how the user responds to the testing modes of the tutor. For example, if the BWT asks the user to write the letter 'h', but the incorrect dot combination is entered, then corrective instructions are provided until the correct response is obtained. Furthermore, in the next round of testing, the user will be asked to write the letter 'h' again, since s/he incorrectly entered that letter the previous time. This form of customized instruction is very useful, especially for younger users. After each user session, however, the user's information is not stored, so user tracking is not possible with this version of the BWT.

### *2.4.3 Application*

The BWT has been tested in several locations across the world (including India, Zambia and Tanzania) with positive feedback from users and indications of favorable effects on student learning (Figure 11) [83][90].

**Figure 11:** A student at the Mathru School in India interacting with the Braille Writing Tutor (left) [90], and a student and teacher in Tanzania interacting with the Braille Writing Tutor (right) [83].

The Mathru School for the Blind adopted the BWT in the fall of 2006 and has been utilizing the device since that time. The original version of the BWT was designed to meet the needs of this particular school. Also, most of the curriculum included in the BWT was influenced by teachers and students at the Mathru School. Since conducting the first trials with the BWT at Mathru, the school has integrated the use of this tool into their classroom and other curricular activities. This study explores different aspects of the BWT's sustainability within the context of the Mathru School for the Blind, including factors that led to its successful adoption by this community.

## 3. Related Work

This work is primarily focused on investigating the prospects for sustained application of the BWT to contribute towards improving literacy among visually impaired communities, particularly within underserved populations of the world. In general, however, technology innovations such as the BWT are part of the broader field of assistive technology. This area explores how technology can address the various challenges faced by persons with special needs or disabilities, such that they are better able to actively participate in society. This section presents some examples of research conducted in the space of assistive technology, and reviews studies related to investigating the sustainability of technology interventions in developing communities across the globe.

### *3.1 Assistive Technology*

Technology is ubiquitous in today's world with a range of social and commercial applications, and this has increased awareness around the accessibility of such devices for people with different abilities [91]. Within developing communities, perhaps the most vulnerable population are those with special needs, such as the visually impaired, deaf and hard of hearing, and individuals with other physical and/or mental challenges. Available data indicate that the majority of people with disabilities who live in Latin America and the Caribbean are unemployed, live in poverty and do not obtain a higher education [91]. Through the research field of assistive technology, there are now tools developed to assist such individuals, including refreshable braille displays [92] and eye controlled computer systems [93]. However, much of the existing assistive technology is developed and designed for people in more affluent nations in North America and Western Europe, and as such remain cost prohibitive to most in the developing world [94].

Today, there are research endeavors focused on creating low-cost assistive technology or designing tools that would be specifically applicable to persons with disabilities in developing communities. Israsena and Pan-ngum developed a low-cost assistive listening system that can be utilized in a small classroom setting to aid students who are hearing impaired [95]. This technology is yet at a prototype stage, but initial testing demonstrated the potential for this device to serve people who are hard of hearing and cannot afford the more expensive FM systems.

In order to assist blind and visually impaired web users, Bigham *et al.* designed a low-cost and more convenient alternative to typical screen readers [96]. This technology, known as WebAnywhere, is a web-based application that can be run on most computers, and can enable blind or visually impaired users to browse the web without needing to install more complicated and expensive screen reader software such as JAWS [97].

Xu *et al.* created a software application 'DeSIGN' that can assist young students who are deaf and hard of hearing to improve their English vocabulary and American Sign Language skills [98]. DeSIGN provides tutorials with lessons and tests that adapt to a specific student's level of knowledge. Additionally, this software program offers games to improve motivation for learning. Initial field testing of DeSIGN at the Western Pennsylvania School for the Deaf yielded promising findings and established possible applications of this technology to assist deaf and hard of hearing populations in underserved communities.

These are only a sample of relevant assistive technologies developed for audiences in underserved communities. However, even though valuable work is being done in this area, there still remains a need for more technological innovation and commercialization to better meet the needs of those with special needs in developing communities across the world [99].

### *3.2 Sustainability of Technology Interventions in Developing Communities*

There is an emergent body of research investigating the potential for technology to address challenges in developing communities, specifically in the field of information and communication technology for development (ICTD). Although much of this work has shown potential for benefiting users in underserved parts of the world, there is a growing concern about the future viability of these technology interventions [100]. There is a need to understand factors necessary for implementing sustainable technology solutions to achieve development goals. Sustainability is an especially vital consideration during the stage where successful prototype work is scaled up to serve a wider audience [100].

Danis *et al.* identified threats to sustainability including, economic models that are not self-sustaining, insufficient skills within the local community, and system designs that are not a good fit for the cultural context of targeted users [100]. They emphasized that acquiring a solid understanding of social practices can help overcome these problems. By leveraging the existing community networks, they hope to design sustainable mobile applications for developing communities, using social computing techniques. Kuriyan *et al.* also emphasized the importance of social factors in attaining sustainability of ICTD interventions [101]. They found that the successful implementation of technologies in developing communities does not merely involve technology transfer, but also encompasses a political process that can significantly affect sustainability. There can be trade-offs between achieving financial self-sustenance and social development goals. Often, financial sustainability is accomplished at the expense of serving those who are most in need.

Heeks posited that three factors are necessary for ICTD projects to endure: capacity (available resources are sufficient to meet project needs), utility (the project continues to be useful to stakeholders), and embedding (the project is integrated into the user community environment) [102]. Fu and Polzin drew similar conclusions from an examination of a series of case studies on technology-intensive social innovations [103]. They stressed the need for absorptive capacity, so that the community is capable of adopting the technology, and complementary assets, such that the given technology can work in conjunction with and capitalize on existing resources.

Surana *et al.* studied the deployment of a rural, wireless telemedicine system in India [104]. They identified three key ingredients for achieving project sustainability in ICTD work: optimizing an existing system, financial self-sufficiency, and operational sustainability. Depicting a project as optimizing an existing method can facilitate obtaining local community buy-in, while achieving financial and operational self-sufficiency are necessary for the work to endure in the long term.

Hussain and Tongia investigated the potential for community radio (CR) to be a sustainable tool for development in South Asia [105]. This study primarily focused on financial aspects, but also explored socio-political and technical factors that affect the sustainability of CR. They conducted a technological and economic analysis of three representative CR stations in Nepal, and provided recommendations for these stations to achieve social, financial and technical sustainability, as well as policies that can create an atmosphere for CR stations to endure and continue to serve the community. Best *et al.* took into consideration similar factors when investigating the potential for user-based subsidies to help sustain telecenters [106]. They examined sustainability in terms of financial aspects, *i.e.* to be solvent over time, and social aspects, *i.e.* equitably distributing benefits among targeted users. Additionally, they echoed the need for policies and regulations that will enable telecenters to flourish.

Dunmade explored factors that affect the sustainability of foreign technologies transferred to developing communities [107]. He provided several indices to help identify which foreign technologies are most suitable and sustainable within a developing country setting. Adaptability was highlighted as the primary indicator of sustainability, given how important it is for the technology to meet the specific needs of the given local community. In order to assess adaptability of a technology, Dunmade offered a secondary set of indicators including, technical, economic, environmental and socio-political sustainability. These metrics are useful to consider when deciding on large scale acquisition of foreign technologies to function within the context of a developing community.

The common themes in this literature are financial, technological and socio-political sustainability considerations. In keeping with this body of research, we explore the sustainability of the BWT based on three main dimensions: financial, technological and social. Given that this investigation is primarily focused on the application of the BWT at the Mathru School (*i.e.* at a micro level), political aspects of sustainability are not explicitly examined.

## 4. Study Design

The main purpose of this study is to explore the sustainability of the BWT developed by the TechBridgeWorld research group at Carnegie Mellon University, at the Mathru School for the Blind in Bangalore, India. Underlying research questions for this work include:

- Is the cost to acquire, use and maintain the BWT financially feasible for the Mathru School for the Blind?
- What are the prospects for the durability and maintainability of the BWT technology within this local context?
- Which factors are vital in increasing the likelihood of the continued use and integration of the BWT within this community of users?

An exploration of this particular case should also provide insight into the potential for the BWT to be sustained in comparable developing communities.

### *4.1 Defining Sustainability*

For the purpose of this research study, sustainability is loosely defined as the potential for the BWT to be employed by its targeted users after the initial technology transfer. To answer the above research questions, sustainability of the BWT is explored from a financial, technological and social perspective.

#### *4.1.1 Financial Sustainability*

Unlike much of the literature previously reviewed, the BWT is not designed to be a remunerative venture, so a pure examination of the BWT's profitability is not appropriate here. Instead, we explore the feasibility for the Mathru School to continually afford the cost involved in acquiring, utilizing and maintaining the BWT. Affordability will be gauged based on the school's ability to obtain other necessary equipment and secure sources of funding.

#### *4.1.2 Technological Sustainability*

Technical maintenance of the BWT is vital for its prolonged use. Requirements necessary to keep the BWT in working condition as well as improve its durability are explored here. This is facilitated by an examination of potential factors that may contribute to its malfunction.

#### *4.1.3 Social Sustainability*

Here, an investigation is conducted to determine contributing factors that have led to the successful integration of the BWT into the Mathru School's curricular activities. Additionally, we explore the social atmosphere and conditions necessary for sustained use of the BWT by the target audience.

### *4.2 Methods*

A mix of quantitative and qualitative methods is employed in this study, with a predominance of qualitative techniques.

#### *4.2.1 Data Collection*

A field visit was conducted to obtain information on the Mathru School for the Blind and related data on the BWT's application there.[9] Cost data were collected from available records at the school as well as through discussions with the head of the school. In addition, estimates for expenses related to the production of a BWT were obtained from the main TechBridgeWorld engineer involved with the acquisition and assembly of these tutors.

Qualitative information was collected through one-on-one interviews with Mathru teachers, staff and students to gauge effects the BWT has had on the school and to understand how the tutor has been utilized there. All seven teachers involved with teaching braille or working with the BWT were interviewed. Interviews were also conducted with a sample of 8 students from different grades to gain some insight into their perceptions of the BWT. Additionally, extensive discussions and interviews were carried out with the head of the school and key administrative personnel to obtain information related to the function and organization of the school as well as its utilization of the BWT since the device was first introduced. Finally, researcher observations and experiences during the site visit were recorded, primarily to study interactions between students and teachers at the school, and the BWT.

[9] This field research was approved by the Institutional Review Board (IRB) at Carnegie Mellon University; IRB Protocol Number: HS10-657.

### *4.2.2 Analysis*

Cost data were recorded and analyzed to produce a range of cost estimates for the different components of this study. Interview and discussion transcripts as well as reports on observations were analyzed for relevance to key research questions of this study. Student feedback was not weighed heavily in the analysis, given their tendency to provide mainly positive responses to field researchers, most likely due to cultural reasons (*i.e.* students did not want to be impolite). Finally, stories collected from the field visit were examined for insight into the potential for sustaining the utility of the BWT at this school.

## 5. Current Use and Potential Benefits of the BWT at the Mathru School

There were two BWTs in use at the school since the end of 2006. The current pattern of use for the BWT at the Mathru School is as follows:

- Students in grades 1 through 3 use the BWT.
    - The BWT is specifically designed to assist those who are just beginning to learn the concept of braille writing. Therefore, the current focus at Mathru is on providing the BWT to these younger students.
    - The BWT is designed to supplement the slate and stylus method for learning to write braille (*i.e.* it is not a replacement for this tool). Once a student becomes more adept at writing with the slate and stylus, which is usually when they reach grade 4, they no longer require as much assistance from the BWT. Thus, students in grades 4 and up do not work with the BWT on a regular basis.
- Grades 1 to 3 have their respective scheduled braille class period, during which two students from each grade are able to use the two BWTs; one student uses BWT #1 and the other uses BWT #2.

- BWT use during the braille class period is rotated – so, for grades 1 to 3 students A and B use the BWTs on Monday, student C and D use the BWTs on Tuesday, etc.
- Thus, there are a total of three users (one from each of the grades 1 through 3) per BWT on a given weekday.
- Each user session runs for approximately 45 minutes on a weekday.
- Additionally, the BWT is used for one hour on Saturdays with just weaker students from each of those grades. Teachers determine the weaknesses of students based on their performance in class.
- Older students have access to the BWT, but use it infrequently.
- Teachers also practice using the BWT after school hours to become more familiar with the device when they are first introduced to it.

Under this usage model, it is approximated that the BWT is in use for 12 to 15 hours per week[10]. Table 7 summarizes duration of use and key users.

**Table 7:** Summary of current usage of the Braille Writing Tutor (BWT) at the Mathru School for the Blind.

| Usage Scenario | Duration of BWT Use | Key Users of the BWT |
|---|---|---|
| Three user sessions per weekday + one session on Saturdays | 12 to 15 hours per week | - Students in grades 1 through 3 use the BWT during the week.<br>- In addition, weaker students work with the BWT on Saturdays.<br>- Teachers and older students use the BWT on occasion. |

[10] Three 45 minute sessions per week day, plus 1 hour of use on Saturdays results in 12.25 hours of use per week. To allow for older student and teacher usage time, and some variation in the length of daily student usage sessions, we approximate this model to result in 12–15 hours of use per week.

Under their current usage, based on observations, and interviews and conversations with teachers, staff and students at the Mathru School, the following potential beneficial effects of the BWT were identified:

- Academic effect

  The most commonly noted academic effect of the BWT was that it enabled students to grasp the concept of braille (*i.e.* the six dots, their orientation and patterns that map to letters) much faster than they would using the traditional slate and stylus. Weaker students in particular were reported to have benefited from the audio feedback and instructions offered through the BWT. Additionally, the BWT provided the students with a unique and fun method to practice braille writing and refine their skills.

- Motivational effect

  Another important effect observed and reported was that students were much more motivated to work with the BWT compared with other teaching aids, including the slate and stylus. In particular, younger students who lack the necessary physical strength to work with the slate and stylus were much more excited to learn braille using the BWT. This is primarily because the BWT requires less strength to use and provides audio feedback, which makes the experience less physically taxing and more engaging for these students.

- Effect as a teaching aid

  An additional benefit of the BWT identified by teachers at Mathru is its use as a teaching aid. Students are able to work with the BWT on their own (after some initial guidance), freeing the teacher to focus on other students during the braille class period. Additionally, the BWT can help teachers diagnose student writing problems more quickly and accurately. Also, since students grasp the concept of braille faster with assistance of the BWT, a teacher's task is made somewhat easier by virtue of the teaching aid properties of this device.

# 6. Sustainability of the Braille Writing Tutor at the Mathru School for the Blind

Based on information collected in the field and from experts at TechBridgeWorld this section explores the potential sustainability of the BWT at the Mathru School, according to three dimensions: financial, technological and social.

## *6.1 Financial Sustainability*

Financial sustainability is assessed based on the cost to acquire, use and maintain a BWT at the Mathru School, relative to the financial capacity of the school.

### *6.1.1 Cost to Obtain, Use and Maintain a BWT at the Mathru School*

Prior to investigating the financial sustainability of the BWT at Mathru, it is important to understand the cost associated with acquiring, using and maintaining the BWT at this location. Currently, Mathru does not pay to acquire the BWTs they employ in the school. These tutors are used by the school under a research license established with TechBridgeWorld. Additionally, all the computers at the school, including the two that are used to run the two BWTs in the classroom, are donations that Mathru has received from various companies and donors. The cost of the actual device plus the cost of a computer to run the software comprise the capital expenditure for the BWT. Thus, under their current circumstances the Mathru School does not incur any capital expenditure related to the BWT, but if they did have to pay for both these assets their capital investment per BWT would be between about $350 and $1100 (Table 8). The bulk of this expense would be to obtain a computer. Estimated range of cost for a computer comprises the approximate price of a used computer and a new computer, comparable to the machines currently used at the school. These figures are loosely based on information received from the Mathru School.[11] Based on data from TechBridgeWorld engineers, on its own, a BWT would cost between roughly $140 and $160 when purchased in small quantities (10 units or less).

**Table 8:** Estimated range for the potential capital expenditure required to acquire a single Braille Writing Tutor and a desktop computer to run the software for the device.

| Type of Expense | Lower Estimate (USD) | Upper Estimate (USD) |
|---|---|---|
| Cost to produce/acquire a BWT | $ 140 | $ 160 |
| Cost of a computer to run BWT software | $ 220 | $ 890 |
| **Total Capital Expenses, if computer is purchased** | **$ 360** | **$ 1,050** |

The Mathru School spends between $90 to $130 to operate and maintain the BWT and its associated computer for one year (Table 9). This cost (*i.e.* operation and maintenance, or O&M cost) includes the following elements:

- Electricity to power the computer (CPU and monitor) when the BWT is in use.
- Electricity to power fans and light fixtures in the classroom when the BWT is in use. Note that during most of the school year, the school does not operate fans and lights given the favorable temperature in Bangalore and natural lighting in the classroom.
- Maintenance cost for the computer. Mathru hires a consultant to maintain all their computer systems and pays an annual fee for this service. In Table 9 this cost is

[11] Appendix B outlines all assumptions associated with cost estimates included in this chapter.

approximated for a single desktop computer. This annual fee is treated as a fixed cost (*i.e.* does not vary based on computer use).[12]

- Remote troubleshooting costs for the BWT. This comprises the cost of emails sent to TechBridgeWorld. Mathru pays a fixed monthly rate to access the Internet and the data quota included in this service should not be exceeded with emails alone, so it is assumed that this cost does not vary regardless of the number of emails Mathru sends to TechBridgeWorld.[13]

**Table 9:** Estimated range of the Mathru School's current annual operation and maintenance (O&M) cost for a single Braille Writing Tutor and supporting desktop computer.

| Type of Expense | Lower Estimate (USD) | Upper Estimate (USD) |
|---|---|---|
| Electricity to power computer | $ 10 | $ 30 |
| Electricity to power fan and light bulbs | $ - | $ 10 |
| Maintenance cost for computer | $ 10 | $ 20 |
| Cost to troubleshoot for BWT with TechBridgeWorld | $ 70 | $ 70 |
| **Total Annual O&M Expenses** | **$ 90** | **$ 130** |

As depicted in Table 9, the total annual O&M cost is primarily driven by remote troubleshooting expenses. However, if technical support is locally available, the cost to maintain a BWT annually should be comparable to computer maintenance fees, and therefore much lower than the

[12] Since the Mathru School has designated computers used exclusively with the BWTs, the entire maintenance fee per computer is added to O&M costs associated with a BWT in Table 9. However, such exclusive use is unnecessary, so if the school were to use these computers for other purposes as well, the computer maintenance cost attributable to a BWT would be reduced.

[13] The cost to TechBridgeWorld for these consultations is not included in this analysis because to date, TechBridgeWorld staff members have not spent any time troubleshooting for the BWT with Mathru. Additionally, emails exchanged with Mathru are considered part of a research project and Mathru is not charged for the time of TechBridgeWorld staff. Furthermore, if the BWT is commercialized, technical support should be locally available, in which case the cost for annual maintenance of the BWT should be akin to what Mathru spends on maintaining their computers. That cost should be even lower than the cost to access the Internet, which is included as troubleshooting expenses for the BWT. Therefore, it is reasonable to assume that the estimated cost for troubleshooting for the BWT (in Table 9) captures any potential technical maintenance costs for the BWT, in the event that it is commercialized.

approximated $70 per year. Apart from troubleshooting expenses, the cost to use and maintain one BWT and an associated computer is modest (about $20 – $60 per year).

It is worth noting that since the introduction of the BWT at Mathru in 2006, TechBridgeWorld has received an average of 1 or 2 emails per year from the school related to problems with the device. Moreover, the issues discussed were attributable to the wear and tear of the BWT that could only be resolved by replacing the device. Thus, if/when the BWT is commercialized, it should not require much technical maintenance, but will most likely need to be replaced roughly every 2 to 3 years. To capture the lifetime of a BWT and associated computer, the value of these assets can be annualized to reflect how much Mathru would need to spend each year for both capital and O&M expenses. In line with methods utilized by Surana *et al.* [104], assuming zero salvage value for assets and not accounting for interest rates, total annual expenses associated with a BWT's application at Mathru are roughly between $250 and $450 (Table 10).[14]

**Table 10:** Total annual expenses associated with one BWT at the Mathru School, including annualized capital expenses and annual operation and maintenance (O&M) costs.

| Type of Expense | Lower Estimate (USD) | Upper Estimate (USD) |
|---|---|---|
| Annualized cost to produce/acquire a BWT | $ 70 | $ 80 |
| Annualized cost of a computer to run BWT software | $ 110 | $ 220 |
| Annual O&M expenses | $ 90 | $ 130 |
| **Total Annual Expenses, if computer is purchased** | **$ 270** | **$ 430** |

Cost estimates given in Table 10 assume a 2 year lifetime for a BWT, a 2 year lifetime for a used computer and a 4 year lifetime for a new computer. If the BWT requires replacement only once every 3 years, the annual cost per BWT device drops to about $50 (Appendix B). Accounting for

[14] Annualizing capital costs entails spreading the capital cost over the lifetime of the given asset. For example, if a machine costs $500 and lasts for 5 years, its annualized cost will be $100, assuming zero salvage value and not accounting for interest.

an estimated 8% annual interest rate that could be earned using the money invested in these assets increases the total annual expenses associated with a BWT to between roughly $300 and $550 (Appendix B). Thus, it is estimated that a BWT can be obtained, utilized and maintained by the Mathru School for about $400 per year.

### *6.1.2 Financial Capacity at the Mathru School for the Blind*

To understand the purchasing power of the Mathru School, their spending on other braille educational tools is first examined. Table 11 presents the Mathru School's total annual expenses on other braille teaching aids. Upfront capital costs are annualized as was done for assets in Table 10 (see Appendix B for a complete explanation of cost calculations). A single slate and stylus would cost under $3. These tools are used throughout the school year and are also sent home with students on occasion. To maintain the necessary number of slates and styluses year after year, the school is required to replace lost or missing slates and styluses in a given year. This replacement cost is considered the maintenance cost for these tools.

Another braille teaching device used at Mathru is the marble board (Figure 12). The marble board is a wooden block with six circular indentations carved out to represent a braille cell. Marbles can be placed in these grooves to represent different letters. This tool is used with young students when they are beginning to learn braille. The trailor frame is a tool used to assist in teaching students basic math functions (Figure 12). Maintenance cost for these two tools comprise of estimated costs to replace lost or misplaced components.

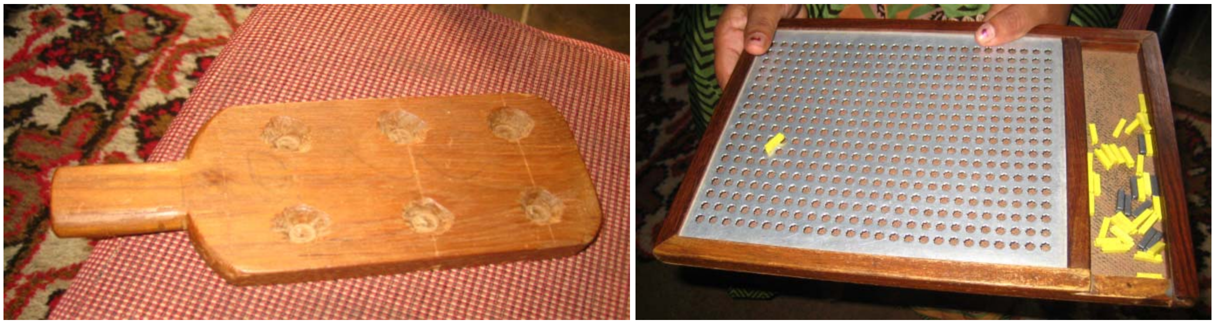


**Figure 12:** Images of a marble board (left) and a trailor frame (right) used at the Mathru School for the Blind.

As Table 11 indicates, purchasing braille paper constitutes a significant annual cost to the school (roughly $2,000 - $3,000). Although braille paper is typically used with a slate and stylus, the Mathru School resourcefully utilizes old magazine paper or newspaper (which are freely available), cut to the appropriate size, in their classrooms.[15] Instead, the braille paper purchased is primarily used to print braille books, including text books. Outside of braille paper, braille educational tools other than the BWT cost the Mathru School about $20 to $50 per year. This is comparable to the amount spent on electricity to use the BWT for a year ($10 - $40).

**Table 11:** The Mathru School's estimated annual expenditure on braille teaching supplies other than the Braille Writing Tutor.

| Braille Educational Tool | Annualized Capital Cost (USD) | | Annual Maintenance Cost (USD) | | Total Annual Cost (USD) | |
|---|---|---|---|---|---|---|
| | Lower Est. | Upper Est. | Lower Est. | Upper Est. | Lower Est. | Upper Est. |
| Braille slate | $ 9 | $ 12 | $ 10 | $ 30 | $ 19 | $ 42 |
| Braille stylus | $ 1 | $ 1 | $ 2 | $ 4 | $ 3 | $ 5 |
| Marble board | $ - | $ 1 | $ - | $ 1 | $ - | $ 2 |
| Trailor frame | $ - | $ 1 | $ - | $ 1 | $ - | $ 2 |
| Braille paper | $ 2,110 | $ 2,960 | $ - | $ - | $ 2,110 | $ 2,960 |
| **TOTAL** | ***$ 2,120*** | ***$ 2,975*** | ***$ 12*** | ***$ 36*** | **$ 2,132** | **$ 3,011** |

[15] This saves the school from spending roughly $10 per student on braille paper per school year (assuming one student uses about 250 sheets in a year).

The Mathru School has also made more significant capital investments in educational tools such as one standard Perkins Brailler and one Next Generation Perkins Brailler (*i.e.* a smaller and lighter model), which cost roughly $300 and $500 respectively (Figure 13). The Braillers are essentially typewriters for the visually impaired and can serve the school for several years (at least 15 – 25 years), given their robust design.[16] Thus, over their lifetime these devices would cost about $20 per year on average.


**Figure 13:** Images of a standard Perkins Brailler (left) [108] and a Next Generation Perkins Brailler (right) [109].

If the production of the BWT was undertaken by a commercial vendor, the cost to produce it should still fall within the range estimated in Table 8. Thus, if Mathru is not required to purchase a computer to run the BWT, the total annual cost the school would have to manage, per BWT, is roughly $150 to $250. Based on the school's annual expenditure on other educational tools explored above, it appears that Mathru has the financial capacity to sustain the use of a BWT.

In total, each year the Mathru School spends approximately $67,000 - $78,000. This amount covers administrative and educational expenses as well as costs associated with providing room

[16] Note that braille paper would be required to work with these Braillers.

and board for students. Considering this total annual budget, the annual cost associated with a BWT is relatively very small (under 1%). Therefore, obtaining, maintaining and utilizing a BWT is well within the financial means of the Mathru School.

For the past 10 years, since its foundation in 2001, the Mathru School has successfully secured the necessary financial support to operate and expand the school. Although the Mathru School does not have a guaranteed source of funding, it has been able to obtain long term funding from different foundations, donors and grants. Ms. Muktha is instrumental in securing financial resources for the school. However, Mathru is now taking steps to train more staff in fund raising duties that Ms. Muktha has been responsible for in the past. Thus, it is foreseeable that the Mathru School can continue to obtain the necessary financial resources to maintain the school at its current level. As with any non-profit, the Mathru School is also vulnerable to financial shortages in future years. However, at its current financial capacity (or even at a marginally reduced capacity), the BWT is an affordable educational tool to the school.

## *6.2 Technological Sustainability*

### *6.2.1 Positive Indicators of the BWT's Technological Sustainability*

The Mathru School is located in Bangalore, India where the climate is fairly pleasant throughout the year with the temperature ranging from about 60 to 80 degrees Fahrenheit during most of the year [110]. In recent years, the area near the Mathru School has become more populated and therefore seen an increased amount of dust and pollution. However, within the school itself, cleaning staff maintain the school well and leave very little dust accumulation. Therefore, the physical environment at the Mathru School is conducive to sustaining the function of devices such as BWTs and computers, in terms of ambient temperature and air particulate matter levels.

In its 5 years of use at the Mathru School, the BWT has experienced hardware malfunction, but to date the software for the BWT has not been corrupted during its use at the Mathru School. This is a testament to how well the computers at the school are being maintained, and protected from viruses and other forms of software file corruption, which bodes well for the sustained use of the BWTs at the school.

Additionally, during the BWT's tenure at Mathru thus far, the school has not required frequent technical support from TechBridgeWorld. Queries regarding technical issues with the BWT were limited to one or two emails per year at most. The school was able to resolve most technological glitches concerning the BWT on their own, by simply disconnecting and reconnecting the device to the computer. This indicates that the BWT does not require constant checkups and troubleshooting and is fairly self-maintaining.

### *6.2.2 Potential Barriers to the BWT's Technological Sustainability*

Based on reports from the school, the two BWTs originally installed there in 2006 began to malfunction after about 2 years of use. Similarly, the replacement BWTs provided to the school in 2008 were functioning at a very limited capacity by 2010. The buttons on the BWT were the first components to fail, followed by certain braille cells that no longer produced audio feedback with the contact of a stylus. This information implies that the current version of the BWT has a lifespan of about 2 years at the Mathru School, given their pattern of use.

Possible reasons for the malfunction of these devices were investigated during the field visit conducted for this study.

- The collection of moisture between the plates of the BWT appeared to be the primary reason for device failure. This moisture is most likely the result of sweat and vapor condensation accumulating on the BWT during its use. The moisture interferes with the electric circuit and various components of the BWT begin to fail.

- Also, given the frequency with which the buttons are used, particularly by younger students, it is not surprising that these components were the first to fail.
- Finally, many of the students are not gentle users of the device, and this contributes to an accelerated decline of its function.

Thus, moisture accumulation and general wear-and-tear from its use contributed to the BWT hardware malfunctioning within a two year period at the Mathru School.

Apart from the above findings from the field, the TechBridgeWorld engineer has identified other potential weaknesses of the BWT that could affect its sustainability. These include:

- The bottom section of the BWT is too exposed to environmental factors, which most likely led to the collection of moisture observed at the Mathru School.
- The USB connector of the BWT is very susceptible to damage from regular plugging and unplugging of the device.
- The printed circuit boards of the BWT are held together by just 8 solder points, which leaves gaps in some areas between the boards. If someone were to frequently press the boards together in these areas, function of the BWT could be compromised.

Thus, certain components of the hardware of the BWT are vulnerable to damage, particularly the circuit boards.

### *6.2.3 Improving the Technological Sustainability of the BWT*

To better preserve the BWTs at Mathru, the school has begun the practice of wiping down the BWT after each user session and placing it in a box when not in use so as to further protect the device from moisture damage. This should extend the lifespan of the BWT at Mathru. Additionally, to protect the USB connector from damage, as recommended by the TechBridgeWorld engineer, the school could unplug the BWT from the computer rather than detaching the USB cable from its connection to the device itself.

In terms of hardware upgrades, a relatively simple design change to the BWT may prolong its functional life. By introducing a casing for the device, the circuit board could be better protected from moisture accumulation. Additionally, this will render the BWT more robust to rough handling. A moderately low-cost casing could be built for the device, so this is a very practical solution to prolong the lifetime of a BWT at the Mathru School.[17] The TechBridgeWorld engineer pointed out two additional hardware modifications that could be made to the BWT:

i. Install structural solders to provide more physical support for USB connector.
ii. Upgrade the hardware to a single circuit board design, or to one in which there is no spacing between boards.

These modifications will make the BWT more mechanically secure and improve its technological sustainability.

For improving the long term technological sustainability of the BWT it would be useful to obtain the support of and train local technical experts on the mechanics of the BWT. This will allow for in-person technical consultations for the BWT when necessary, and would enable the device to be maintained locally, independent of TechBridgeWorld support. Additionally, providing users with access to backup copies of necessary software and training them on how to install the

[17] Note that in its latest design, TechBridgeWorld is including a case for the BWT. Additionally, the second version of the BWT (which is currently used at the school) included more of a protective cover than the first version. Thus, the encasing of the BWT is being improved with each stage of its development.

software and do basic troubleshooting for the BWT would be important in sustaining the use of the device at minimal cost.

### *6.3 Social Sustainability*

In 2006 Kalra *et al.* began to work with the Mathru School for the Blind to design a device that could facilitate the process of students learning to write braille using a slate and stylus [81]. Through this collaboration the first version of the BWT was created and tested with teachers and students at Mathru. After the initial BWT project was completed by Kalra *et al.* two of these original devices were left with Mathru and TechBridgeWorld maintained a research partnership with the school. Since the introduction of this device in 2006, the Mathru School utilized the BWT with its students on a regular basis. In 2008 another group of TechBridgeWorld researchers traveled to Bangalore to introduce and field test an improved version of the BWT. Two of these newer devices were then left with Mathru, and the school continued to incorporate the use of the BWT into their curriculum. The BWT is now a standard feature of the school's braille class period for students in grades 1 through 3.

Several factors contributed to the successful integration of the BWT into the Mathru School's curricular activities.

- The enthusiasm of the founder and director of the school, who also participated in designing the device, was a primary factor in promoting the BWT's use at the Mathru School. Given the hierarchical structure at the school, her acceptance of the BWT permeated through the rest of the school as well.
- Another important reason for the BWT's continued use at the school is that it was originally created and customized with the participation of staff and teachers at the

Mathru School to suit the specific needs of students at the school. This provided a sense of ownership in the BWT's development on the part of the Mathru School.

- The benefit of the BWT as perceived by teachers, staff and students at Mathru has been vital to its continued use at the school. In spite of hardware failures, the school continued to use the BWT with students, even at its limited capacity, and perceived a benefit from its application. This indicates that the school values the BWT as an educational tool.
- Additionally, the novelty and modern aspect of the BWT was an attractive feature that promoted the use of the device.
- Finally, Mathru was able to expand its reputation in part by playing a pioneering role in the development and use of the BWT. For example, the school was invited to attend a conference to provide reports on their experiences with the BWT. This type of exposure also attracted more media attention and volunteers to the school. Therefore, the Mathru School places a lot of pride in having access to this tool, and this contributed to the BWT's successful integration into the school.

In the long term, continuing to generate champions of the BWT at the school will improve its chances for sustained use at Mathru. If the founder of the school is no longer available to promote the use of the BWT, it will be critical to have other staff and teachers at the school who are equally enthusiastic about the use of this device at the school. In fact, such BWT champions already exist at Mathru. For example, although teachers do not receive any financial compensation for learning how to use the BWT, they are keen to learn about and use the device because they view it as beneficial to students and also helpful in their work.[18] Therefore, the

[18] Note that TechBridgeWorld researchers trained some Mathru teachers on how to use the BWT and these teachers in turn, train others at the school.

BWT has achieved a significant level of institutional sustainability at Mathru, since the school is invested in and has assumed ownership of this technology.

## 7. The Stand-Alone Braille Tutor (SABT)

The fact that a computer is required to operate the BWT has been an obstacle to implementing this device in communities that cannot support such infrastructure. Apart from difficulty obtaining computers, the primary issue is the lack of access to stable and reliable electricity. In developing communities power outages can be frequent, long, and unpredictable. Therefore, since 2010 a stand-alone version of the BWT has been in development. This device is similar to the BWT, except that it does not require a computer to operate. The Stand-Alone Braille Tutor (SABT) as it is called, runs on four AA batteries and all the software is onboard the device itself. Currently a prototype version of this technology has been developed and is being tested with different users. There are three designs of the SABT, primary, intermediate and advanced. The primary SABT user interface only has six buttons (configured as a braille cell, similar to the buttons on the BWT), and is designed for beginners. In the intermediate version, there are three sets of buttons (to represent three braille cells) as well as two rows of regular braille cells (similar to the bottom portion of the BWT). This design is the closest to that of the BWT. In the advanced SABT there are six rows of regular braille cells and no buttons. The current prototype developed has a primary user interface. Table 12 compares the potential costs associated with a BWT versus the prototype primary interface SABT based on current usage levels at the Mathru School. It is assumed that troubleshooting costs and electricity costs to power lights and fans is the same for both devices.

**Table 12:** Cost comparison between Braille Writing Tutor and Stand-Alone Braille Tutor, based on current usage at the Mathru School

| Type of Expense | BWT | | SABT | |
|---|---|---|---|---|
| | Lower Est. (USD) | Upper Est. (USD) | Lower Est. (USD) | Upper Est. (USD) |
| Capital Costs: | | | | |
| Cost to produce/acquire | $ 140 | $ 160 | $ 250 | $ 330 |
| Cost of desktop computer to run BWT software | $ 220 | $ 890 | N/A | N/A |
| Annual O&M Costs: | | | | |
| Electricity to power computer for BWT | $ 10 | $ 30 | N/A | N/A |
| Cost to purchase replacement batteries (AA) for SABT | N/A | N/A | $ 70 | $ 110 |
| Electricity to power fan and light bulbs | $ - | $ 10 | $ - | $ 10 |
| Maintenance cost for computer used with BWT | $ 10 | $ 20 | N/A | N/A |
| Cost to troubleshoot with TechBridgeWorld | $ 70 | $ 70 | $ 70 | $ 70 |
| ***Total Annual O&M Expenses*** | ***$ 90*** | ***$ 130*** | ***$ 140*** | ***$ 190*** |
| | | | | |
| **TOTAL EXPENSES (if computer is donated)** | **$ 230** | **$ 290** | **$ 390** | **$ 520** |
| **TOTAL EXPENSES (if computer is purchased)** | **$ 450** | **$ 1,180** | **$ 390** | **$ 520** |

Compared to the BWT, the SABT requires roughly $150 of additional initial investment (*i.e.* in the case that a computer is donated for use with the BWT) and about $50 more to operate over the course of a year. However, if rechargeable AA batteries are utilized, the O&M costs associated with the SABT would be significantly lower while slightly increasing upfront capital costs (*i.e.* to purchase an AA battery recharging device). Provided electricity is easily accessible, this can also improve the SABT's sustainability.

Although the SABT is more expensive, it offers the much more convenient feature of running independently of a computer. This renders the SABT more portable and because it is not tied to a computer, it is not affected by viruses and other issues that often disrupt the function of computers in many developing communities. The design of the SABT is more complex since all the computing takes place onboard the device itself. Additionally, this device has more interface points (SD card slot, sound/headphones jack, power switch, etc.), which are exposed to outside elements including handling by users. Thus, in its current prototype state the SABT is more fragile than a BWT. However, with appropriate casing the SABT might be as durable as the BWT. The three designs of the SABT can better accommodate the needs of students at different levels in terms of their braille writing skills. Therefore, the SABT could potentially offer more benefits to students and teachers at Mathru, is more convenient to use, and can be made equally durable compared to the BWT. Finally, the Mathru School has on several occasions requested a BWT that did not require a computer, so it is likely to be accepted and used by the school. Therefore, the SABT promises to be a more sustainable option for the Mathru School, in spite of its marginally higher cost.

## 8. Scalability of the BWT

When thinking about sustainability, it is also important to consider if and/or how the use of this technology might be scaled up over the long term. This decision will primarily depend on how scaling is defined in terms of this particular device and its community of users. This chapter is limited to exploring two options for scaling up the use of the BWT.

i. Increase the number of BWTs at the Mathru School, such that during a class braille period each student will have their own BWT to work with.

ii. Deploy the BWT to schools for the blind across Karnataka State (in which the Mathru School is located) or all of India.

### *8.1 Scale-Up within the Mathru School*

The Mathru School currently houses 8 – 10 computers in their computer lab and two additional computers, which are kept in a classroom and used with the two BWTs currently at the school. On average, there are 7 to 8 students in each grade at Mathru. Therefore, if the school had 10 BWTs (*e.g.* connect one BWT to each computer in the lab) then during the braille class period each student would be able to have access to a device, as opposed to rotating the use of the BWT. Since the school already has the necessary computers to run up to 10 BWTs at a time, the additional capital investment for this scenario would be to purchase the devices themselves. Producing ten BWTs would cost between $1400 and $1600. Bulk discounts on components of the BWT will not be available for a small quantity such as 10 units. There will also be an increase in operating costs, given that 7-8 students will each be operating a BWT. The school already pays an annual fee to maintain all its computers, so they should not have to incur an added cost for this purpose. Also, costs associated with remote troubleshooting for the BWT should not increase with more BWTs implemented at the school given that this cost does not vary regardless of the number of emails sent to TechBridgeWorld. Therefore, the added O&M cost to the school (compared to what they currently pay) will be attributed to the extra cost of electricity to power the computers during their use with the BWTs.[19] It is estimated that the cost to power 10 compared to 2 computers for a year of BWT use at Mathru will be on average $175 higher (see Appendix B). If the added O&M cost and required capital investment are financially feasible, this scaled-up use of the BWT at the Mathru School might be justified given the added convenience and potential additional benefit to students and teachers.

[19] Note it is also assumed that the cost to power fans and lights will not be affected by using more BWTs.

### *8.2 State- or Nation- wide Deployment*

If the BWT is manufactured in bulk and produced locally, cost savings per device could be significant, depending mostly on the quantity generated. Manufacturing the BWT in Bangalore or India could save up to 10% due to lower cost of labor; however, quality control might be difficult unless there are trained, local technical experts to work with the manufacturer. Producing 1,000 to 10,000 units at a time could yield 10% to 50% in bulk discounts.[20] This could as much as halve the cost per BWT to about $70 per unit. It is estimated that there are about 50 schools for the blind in the state of Karnataka and roughly 800 - 1000 such schools across India.[21] Therefore, in order to realize the most bulk discounts (*i.e.* on the order of 50%), roughly 10 BWTs would have to be deployed in each school, nationwide. However, scaling up the deployment in stages might be a more cautious and practical approach. For example, initially two BWTs could be deployed to each school in Karnataka, and based on the success of that scale-up process a nationwide deployment strategy could be developed.

Although there might be significant reductions in the unit cost for a BWT owing to bulk production, it is important to also consider the cost to provide computers to run each of the deployed BWTs. If the state or national government wished to deploy the BWT at a large scale, they would first need to ensure that the schools obtaining the tutors had the necessary infrastructure and capacity to operate these devices. Given that the SABT does not require a computer and could yield just as much in terms of bulk discounts with larger quantities of production, the SABT would be more suitable than the BWT for a large scale deployment on the order of 10,000. Even with the SABT, however, it would be necessary to first work with the

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[20] Cost savings estimates for manufacture in India (vs. the U.S.A.) and bulk production of components for devices such as the BWT were obtained from an expert on large scale purchasing of electronic/hardware components.
[21] Based on information from the Mathru School for the Blind.

schools receiving these devices to ensure that they have the needed training and knowledge to use the technology, and support to maintain and finance the operation of the SABT. This would also involve training local technical experts on the mechanics of the SABT so that troubleshooting support for the device will be locally available and more easily accessible.

To achieve social sustainability of the BWT or SABT at a school other than Mathru, it will be necessary to ensure that the community assumes some ownership in the application and development of the device. Providing a means for users to communicate their feedback about the technology and incorporating this input when making product upgrades should facilitate community involvement and encourage community ownership of the device. Additionally, demonstrating the benefit of the technology to students and teachers would be necessary to create champions of the device within any given group. To this end, testimonies from the Mathru School can be used to generate enthusiasm about the potential educational benefits of the device. However, prior to any large scale deployment, it will be important to conduct a more formal study to ascertain the effects of the BWT or SABT on students' braille writing skills. Results from such an investigation will help identify the best uses of this device as well as its limitations, and will better inform the decision on if and how to commercialize the BWT or SABT.

## *8.3 Investigating the Effectiveness of the BWT or SABT*

This section outlines key elements that would need to be considered when designing a study to investigate the technology's effectiveness.

### *8.3.1 Defining Effectiveness*

The ultimate goal of the BWT or SABT is to improve braille writing skills among visually impaired students. However, defining effectiveness of these tools is not straightforward because there are several contributing factors that can ultimately improve student braille writing skills, outside of simply increasing student test scores. Based on findings from the field visit to the Mathru School, effectiveness of the BWT or SABT can be defined based on three dimensions: academic effect, motivational effect and effect as a teaching aid. Academically, this educational tool can increase the pace at which students grasp the concept of braille and could also affect their performance on braille tests. The BWT or SABT can also serve as a motivational tool that encourages students to practice their braille writing, which can in turn improve their skills. Finally, teachers' tasks might be facilitated through the use of a BWT or SABT as a teaching aid in the classroom. This technology can help diagnose student problems, occupy students so that teachers are free to attend to other tasks, and also assist teachers in conveying to their students instructions on how to write braille.

### *8.3.2 Selecting Metrics*

A mix of quantitative and qualitative metrics should be selected to provide an overall perspective on the effectiveness of the BWT or SABT.

- Academic effect:

  Two potential metrics can be utilized to measure the effect of the BWT or SABT on students' academic performance. To determine whether students grasp the concept of braille faster using these devices, braille aptitude tests can be administered at different time periods (*e.g.* two weeks, one month, two months and six months). These tests can be as simple as asking students to locate specific dots within a braille cell, or as complex as an oral test to map particular letters to respective dot patterns. Teacher input will be valuable in designing these tests such that they will measure improvements in students' understanding of the braille concept. Apart from these tests, student braille writing tests scores can be utilized to detect any improvements in student performance in class. Typically, such braille writing tests are administered on a regular basis (*e.g.* semi annually or annually) in schools for the blind. If so, these test scores can be used to gauge any changes in student performance. In the event that such tests are not administered, students can for example, be tested on the speed and accuracy with which they write the alphabet. These tests would be administered after students have had time to learn the concept of braille and how to apply it. Again, teachers should be consulted when constructing these tests. Qualitatively, anecdotes or opinions can be collected from teachers to determine whether they perceived any changes in student academic achievement after the use of these educational tools.

- Motivational effect:

  Changes in student motivation can be captured by monitoring student attendance and participation in the classroom. If students are more enthusiastic about learning to write braille, they will demonstrate an increased eagerness to attend braille class and also participate more by volunteering to provide answers to teachers' questions, for example. Thus, attendance rates, and the number of times students raise their hands in class or ask a question in class can be used as metrics to gauge changes in student motivation. Additionally, qualitative data on changes in student motivation, if any, can be collected through interviews with teachers and students, as well as from observations in the field.

- Effect as a teaching aid:

  Qualitative measures will be best suited to ascertain any effects of the BWT or SABT on the tasks of teachers. If these tools serve as useful teaching aids they should alleviate teachers' workload or at least facilitate their work. Teachers can be asked to rate the difficulty level of their work on a Likert scale, based on the different types of tasks they need to complete on a typical work day. For example, tasks can cover preparatory work, in class teaching, and homework creation and grading. Comparing ratings from before the use of the BWT or SABT to ratings after utilizing these devices in the classroom can offer insight into their potential effects as teaching aids. Additionally, any other reports from teachers about changes in their workload that they attribute to the use of the BWT or SABT can be collected through interviews and observations.

### *8.3.3 Study Participants*

Participants for this investigation should be selected from a pool of visually impaired students and their teachers who have previously not had experience working with a BWT or SABT. This will enable researchers to obtain baseline data that can be compared against post technology intervention data. Students selected for this study should be beginners in terms of learning to write braille, since the technology is designed to assist these types of students. In most schools this would include students in grades 1 through 3. Class sizes for visually impaired students are typically small consisting of roughly 7-8 students. Therefore, acquiring a sample size large enough to obtain statistically significant results will be a challenge, regardless of the school chosen for this study. However, if students in grades 1, 2 and 3 of a school for the blind are recruited for this study, a sample size of close to 30 can be achieved. This size should enable researchers to compare mean scores and obtain statistically significant results, provided that there is no attrition among participants. If it is possible to involve more than one school in the study, the power of the analysis can be improved. However, it will be important to ensure that the schools are comparable, or that any base-level differences between the schools are controlled for in the analysis. Finally, randomly assigning participants into treatment and control groups will further strengthen results of the study.

### 8.3.4 Data Collection and Analysis

Baseline quantitative and qualitative data on metrics need to be collected prior to introducing the technology to participants. This will be especially important in the event that a control or comparison group cannot be established. Data should be collected at several stages in the project, depending on what is being measured. For example, to ascertain student gains in learning the concept of braille, data should be collected at shorter intervals in order to capture very fast learning speeds with or without the use of these educational tools. Demographic information on all participants should also be collected in order to determine whether baseline differences influenced results of the investigation. A range of data collection techniques should be utilized for this study, including focus groups, interviews, observations and tests. Various forms of data analysis should be conducted ranging from univariate analysis to multivariate analysis, as well as qualitative analysis. Descriptive statistics can offer insight into conditions at a specific moment in time. Comparing mean test scores using t-tests can help detect any changes between treatment and control group data, as well as between pre-test and post test data. Conducting multivariate regression analyses will allow researchers to control for base-level differences between participants so as to better isolate any effects of the BWT or SABT. Finally, analyzing qualitative data to detect common themes and significant stories of change can provide additional insight into the impact of these technology educational tools.

## 8.4 Policy Implications

In 2006 the United Nations introduced the Convention on the Rights of Persons with Disabilities (CRPD), by which endorsing states agree to enact national laws and policies that would protect the rights of this vulnerable population [99]. India is one of the signatory nations ratifying CRPD, however, there are currently no mandates in India to ensure that children with disabilities receive an education, as stated in the articles of CRPD [111]. Utilizing assistive technology to bring about social inclusion of individuals with disabilities is explicitly mentioned in the convention [99]. Therefore, the BWT and the SABT are ideal tools that the Indian government can employ to help fulfill its commitment to the CRPD. Outside of providing necessary resources to acquire such technologies, the state or national government could encourage local manufacturers to produce these devices locally by offering incentives such as tax breaks or subsidies. In addition, academic and industry research groups can be involved through similar incentive programs to further enhance these technologies so as to accommodate the needs of local users (*e.g.* adding necessary sound files and making software upgrades to support other braille languages used in India). Finally, organizations or institutions such as the Mathru School for the Blind should be consulted to assist in the large scale deployment of these tools, so as to help ensure that the investment made in such technology is not wasted (for example, by intended users not having the means with which to use the devices). Mathru can offer invaluable insight into factors necessary for the successful integration and utilization of this technology so as to provide the most benefit to the visually impaired population of India.

### *8.5 Potential Environmental Impact*

One important factor to consider with large scale deployment of any technology is the potential environmental impact. Much like cell phones that are typically used for an average of 2 years and then disposed of, the BWT or SABT could also contribute to the growing electronic waste production around the world. Extending the durability and improving the maintenance of these devices can prolong their lifetime and thereby reduce their turnover rate; this will help reduce their ecological footprint. In the particular case of the SABT, utilizing rechargeable batteries will significantly reduce its environmental impact. Additionally, producing the technology locally would reduce the environmental costs associated with transporting these devices from the U.S.A. to users in India or any other community across the globe. Finally, building these devices with components that can be reused or refurbished for a different purpose could reduce the amount of waste produced at the end of the life of a BWT or SABT.

### *8.6 Broader Issues to Consider for Large Scale Deployment of the Technology*

This chapter is limited to investigating the sustainability of the BWT at the micro level. However, when deciding on whether to deploy the BWT or SABT on a larger scale, there are several other issues that need to be considered. For example, this chapter does not explore uncertainties involved with leadership and resources at the institutional, state or national level for this large scale deployment scenario. These factors could significantly affect the scalability of the BWT or SABT in Karnataka or all of India. Some of these elements are qualitatively explored in this section, at a broad level.

There needs to be sufficient financial backing in order to support scale up efforts related to this technology. Although the Mathru School could afford to purchase their own BWT or SABT, it is unlikely that this will be true of all schools for the blind in India. Many schools will probably require assistance to afford these technology tools, particular those that depend on public funding. Since this large scale deployment will be at a state or national level, it will be necessary to obtain the endorsement of the local and national government. If governmental divisions support this endeavor, they may also be encouraged to finance aspects of the deployment of this technology. Additionally, government advocacy might be necessary to create demand for these educational tools among schools for the blind in India. Outside of public funding, private individuals or organizations could be solicited to donate BWTs or SABTs to these schools. Such a donation can be marketed as a philanthropic gesture that these groups can be credited for in the media and within the local community. Such publicity might be appealing to certain corporations or organizations.

Next the decision on where to manufacture the technology will be important in determining the viability of this scale up effort, particularly from a financial and technological perspective. If the technology is manufactured in the U.S. production costs will be higher due to relatively higher labor costs. Production in China or India would provide about 10% in cost savings. If a local manufacturer is chosen, there will be fewer tax implications in terms of marketing the devices in India. However, if the technology needs to be imported, taxes can be a significant factor to consider. The government of India could render these educational technologies tax exempt so as to reduce the cost to the manufacturer and consumer. Outside of tax considerations, there ought to be some incentives to produce and distribute these devices. Typical corporations will not undertake manufacturing these technologies without the prospect of profitability. Additionally, it would have to be clear that there is a demand for these products so as to justify their mass production. Incentives to manufacture these products will be important to help secure a reasonable price for these devices so that they will be affordable to schools for the blind in India. Competition among potential manufacturers can keep profit margins and associated product prices low. To obtain the initial batch of devices for the first stage of the scale up quotes can be obtained from different manufacturers. If financial backing can be obtained for the larger scale deployment, a price may be negotiated with the chosen manufacturer, who might subsequently be encouraged to continue to produce these educational tools at an affordable price to the consumer. However, as Kuriyan *et al.* found, meeting societal needs while achieving financial sustainability can be extremely challenging for entrepreneurs [101]. There are many political and economic factors that can complicate the attempt to balance providing a service to society and remaining financially solvent. Such considerations are beyond the scope of this study, but can significantly influence the sustainability and scalability of the BWT or the SABT.

Where the technology is manufactured also affects the technological sustainability of the large scale deployment of these educational tools. First there needs to be a transfer of knowledge from TechBridgeWorld to the manufacturing company. While the BWT technology specifications are available via open source, there will still likely be a need for some information exchange between TechBridgeWorld and the manufacturer. In essence, producers of the technology would have to become experts on the technology (hardware and software), particularly regarding troubleshooting and maintenance. Another option is to train local technical experts to serve as consultants in maintenance and troubleshooting for the devices. Consumers of the technology will require assistance in maintaining these devices and addressing problems that occur during their use. Additionally, the schools for the blind that utilize the BWT or SABT will have to be trained on how to operate the device, install the software and conduct basic troubleshooting (such as rebooting the device if the software stalls). TechBridgeWorld currently manages all these tasks related to the technology manufacture, maintenance, troubleshooting and user training. Thus, these responsibilities will have to be transferred to a group or different groups that will be able to support the long term application of the BWT or SABT in India. This in turn introduces additional costs to the large scale deployment of the technology since such groups will require remuneration for their services. Such expenses should be accounted for when considering funding options for the scale up effort.

It is also important to recognize that Mathru is a very unique school and is mostly likely not representative of other schools for the blind in India. Thus, factors that led to the successful acceptance and integration of the BWT at Mathru may not be replicable in other locations.

Creating local champions for the technology will be critical in promoting its long term use in India. Some schools might be intimidated by or resistant to accepting technological educational tools. If the government mandates the use of the technology, acceptance will be forced and therefore may not be sustainable. Rather, creating enthusiasm about the BWT or SABT will be critical in encouraging schools in India to accept and adopt this technology. Promoting the BWT or SABT as tools that can be used to optimize the existing method for learning to write braille (*i.e.* the slate and stylus) can facilitate the process of achieving community buy-in, as observed by Surana *et al* [104]. Additionally, if a popular politician or celebrity agrees to personally endorse the technology, it will more readily be accepted by the general population. However, there are risks associated with this approach since the chosen politician or celebrity may fall out of favor within the community and this disapproval could be tied to the technology that they promoted. Perhaps the most sustainable solution is to create champions for the device among community leaders who can in turn promote its use through grassroots efforts. This socio-political process can be riddled with challenges since each school or community will have specific needs and different apprehensions about incorporating the use of the BWT or SABT.

A comparative analysis between the BWT and the SABT revealed that the SABT has great promise to be sustainably utilized at the Mathru School. Given its greater portability and convenience, and because it does not require stable electricity or a computer to operate, the SABT might be better suited, compared to the BWT, for deployment at a state or national level. However, prior to large scale deployment, it will be important to extend the work presented in this chapter by collecting additional data on the sustainability and effectiveness of the BWT and SABT at different locations, so as to offer greater insight into the scalability of this technology.

Additionally providing more definitive proof of the technology's impact on student learning may assist in assuaging any reservations about the BWT or SABT.

As this section describes, in order for the large scale deployment of the BWT or SABT to be successful many factors will have to be considered, apart from its micro-level financial, technological and social sustainability. In particular, scalability of this technology will be heavily influenced by political processes at the local and national level. Therefore, prior to large scale commercialization of this device, there may need to be an interim study that explores the various elements that will affect the transition from applying the technology at a small scale to deploying its use among a broader audience. Finally, it will be necessary to consider challenges involved in appropriately documenting all of the steps related to scaling up and sustaining the use of a technology intervention such as the BWT or SABT. Capturing and disseminating these experiences will greatly benefit future studies in this area and reduce the chances of those endeavors encountering the same issues.

## 9. Recommendations

Based on the sustainability analysis presented in this chapter, related work and anecdotal evidence, we propose the following set of preliminary recommendations for sustaining a large scale deployment of the BWT or SABT technology.

### *9.1 Financial Sustainability*

- This study found that the Mathru School for the Blind has the necessary financial capacity to sustain its use of the BWT. If the BWT or SABT is commercialized, it will be important to ensure that this technology is still affordable to schools like Mathru. Production costs should decrease with large scale manufacture, due to bulk discounts available on components of the

BWT or SABT. Thus, the key step is to ensure that the price of the device is not significantly increased to offer greater profit margins to manufacturers and distributors.

- Most schools for the blind in India or other developing communities may not be able to afford to purchase and use a BWT or SABT. Therefore, in order to finance the initial phases of the large scale deployment of this technology, a combination of private and public sources should be targeted. Having a diverse range of funding support for this endeavor will improve its financial viability and sustainability.

- Creating a demand for the BWT or SABT will be important in incentivizing manufacturers to produce these devices at an affordable price. If financial backing is obtained for at least the initial phases of deployment, manufacturers can be assured that they will be able to sell a certain number of units, at minimum, and thus potentially make a financial gain. Soliciting quotes from several different manufacturing groups will create competition among them and could therefore lead to a more favorable price for the commercialized technology product.

### *9.2 Technological Sustainability*

- The BWT experienced technical failures roughly every 2 years of its use at the Mathru School. Moisture accumulation on the hardware led to malfunction of the circuitry onboard the device. Additionally, it was identified that the most vulnerable components of the BWT's hardware are its buttons. Given their frequent use, these buttons were the first to fail. Technical experts are now working on solutions for these issues, so as to extend the lifetime and improve the robustness of the BWT.

    - Encasing the hardware of the BWT and providing more structural support for the USB connector will extend its lifespan and durability, and thus improve the technological sustainability of the device. This will also reduce costs associated with repairing and replacing the BWT.

    - Upgrading the buttons on the BWT to be more robust to frequent and rough handling by younger students could improve its sustainability at Mathru.

- When deploying these devices (BWT or SABT) at a larger scale, it will be necessary to transfer technical knowledge from TechBridgeWorld to the manufacturer.

- Responsibility for technical maintenance and troubleshooting as well as user training will also need to be transferred from TechBridgeWorld to local technical experts so as to render the BWT or SABT more technologically sustainable when deployed at a large scale.

### *9.3 Social Sustainability*

- Use of the BWT has been sustained at the Mathru School for the Blind for about 5 years. Involvement of the Mathru School at early stages of design and development of the BWT, contributed to the successful integration of this technology at the school. Additionally, the enthusiastic acceptance of the BWT by the head of the school, customization of the BWT features to suit the needs of the school, and the perceived educational benefits of the BWT have enabled this device to achieve social sustainability at Mathru. To maintain this level of social sustainability at Mathru, it will be important to continue to involve the school in research on the BWT, and consult them when considering plans to commercialize the device and deploy it at a larger scale.

- To encourage use of the BWT or SABT among a wider audience it will be important to promote this technology as a means for optimizing the existing method of learning to write braille in these communities. This type of messaging has been shown to be effective in terms of achieving user buy-in.

- Involving local leaders, and possibly politicians and celebrities to serve as champions for the BWT or SABT can help create enthusiasm about this technology, and thus improve its social sustainability at a large scale.

- Finally, collecting further evidence of the effectiveness and sustainability of the BWT or SABT will be important in order to encourage the acceptance, adoption and integration of this technology among a larger group of schools for the blind in India or across the globe.

## 10. Conclusions

This study has demonstrated the potential for the BWT to be sustained at the Mathru School for the Blind in India, financially, technologically as well as socially. Given the current circumstances at the Mathru School, the cost involved in obtaining, utilizing and maintaining a BWT at this school is financially feasible. A key finding resulting from this sustainability analysis was the identification of major causes of failure of the BWT at the Mathru School. In its current form the BWT's lifespan is roughly 2 years, at which point various components begin to fail. Thus, technologically, the BWT can be improved to extend its lifetime so as to reduce financial and environmental costs entailed in replacing these devices. Finally, the BWT has been successfully integrated into the Mathru School curriculum and achieved social sustainability at this institution due in part to Mathru's involvement in its development, its perceived educational benefits, as well as acceptance by the school's founder. Based on findings to date, it is anticipated that making this education technology available to more institutions across India has the potential to improve access to education for visually impaired citizens, and thus help India fulfill its commitment to comply with articles outlined in the United Nations' Convention on the Rights of Persons with Disabilities.

## Conclusions

This dissertation aimed to investigate the effects of policies that affect interventions in science and technology (S&T), and to determine the impact of S&T interventions themselves.

Chapter 1 explored the effects of the USA PATRIOT and Bioterrorism Preparedness Acts on microbiology research in the U.S. Although many speculated the these laws would stifle scientific progress, the results of this study indicated that on a macro level, research involving viable virulent *B. anthracis* and Ebola virus was not inhibited by the biosecurity laws. Increases in funding for select agent research may have influenced more researchers to enter this field and contributed to the observed increase in research publications. However, increased funding does not completely explain these phenomena. The most striking effect observed was not associated with individual authors or institutions; it was a loss of efficiency, with an approximate 2- to 5-fold increase in the cost of doing select agent research as measured by the number of research papers published per millions of US research dollars awarded. This chapter demonstrated how a specific policy change affected scientific research.

In Chapter 2 a pilot research intervention in the field of information and communication technology for development (ICTD) was examined. ICTD is a relatively new area of research that investigates how ICTs can be harnessed to address needs in developing communities. The specific pilot project explored in this chapter investigated how mobile phone technology can be used to assist para-social workers in Tanzania. Apart from other duties, para-social workers are responsible for collecting information on orphans and vulnerable children in their communities and relaying this information to the national database. Researchers developed a SMS-based application to make this data transfer more efficient and affordable to para-social workers. Initial assessments in the field indicated that this technology has the potential to be successfully implemented in Dar es Salaam, Tanzania. Researchers' experience in the field also identified the challenges and rewards of conducting field research in ICTD. This chapter highlighted the potential for interventions in ICTD to impact developing communities.

Chapter 3 explored methods for addressing some of the challenges field researchers face in evaluating pilot ICTD interventions. To this end, an evaluation framework was developed to meet the specific needs of ICTD researchers in the field. This framework, entitled the PREval (Pilot Research Evaluation) framework, draws from established evaluation techniques and other available resources on project assessment. However, PREval is unique in that it offers instructions customized for ICTD pilot research interventions. Initial testing of the concept behind PREval indicated that this framework can be feasibly applied to a range of ICTD projects, and has the potential to add value to the evaluation of pilot ICTD endeavors. This chapter presented an approach to capturing effects of ICTD interventions on developing communities.

In the final chapter (Chapter 4), the sustainability of an ICTD intervention was explored. This study examined whether the use of a particular assistive technology (the Braille Writing Tutor) could be sustained within a developing community setting. Sustainability was explored based on three dimensions: financial, technological and social. The Braille Writing Tutor (BWT) has been utilized by the Mathru School for the Blind in India since 2006. Thus, the focus of this study was to understand the BWT's sustainability within the specific context of the Mathru School. Findings suggest that this assistive technology is financially sustainable given the current financial conditions of the Mathru School. Additionally, the BWT technology can be modified to render it more technologically sustainable at this location. Findings of this analysis revealed two key weaknesses of the hardware: the collection of moisture on the device which caused circuit failure, and the fragility of the BWT buttons that are the first to fail due to rough handling. Finally, this study found that the BWT achieved social sustainability at the Mathru School by obtaining acceptance from the school and encouraging this user community to assume ownership of the BWT. This chapter demonstrated the potential for an assistive technology to impact a developing community in the long term.

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# Appendix A: Supporting Information for Chapter 1

## 1. Collaboration network for live pathogenic Ebola virus research

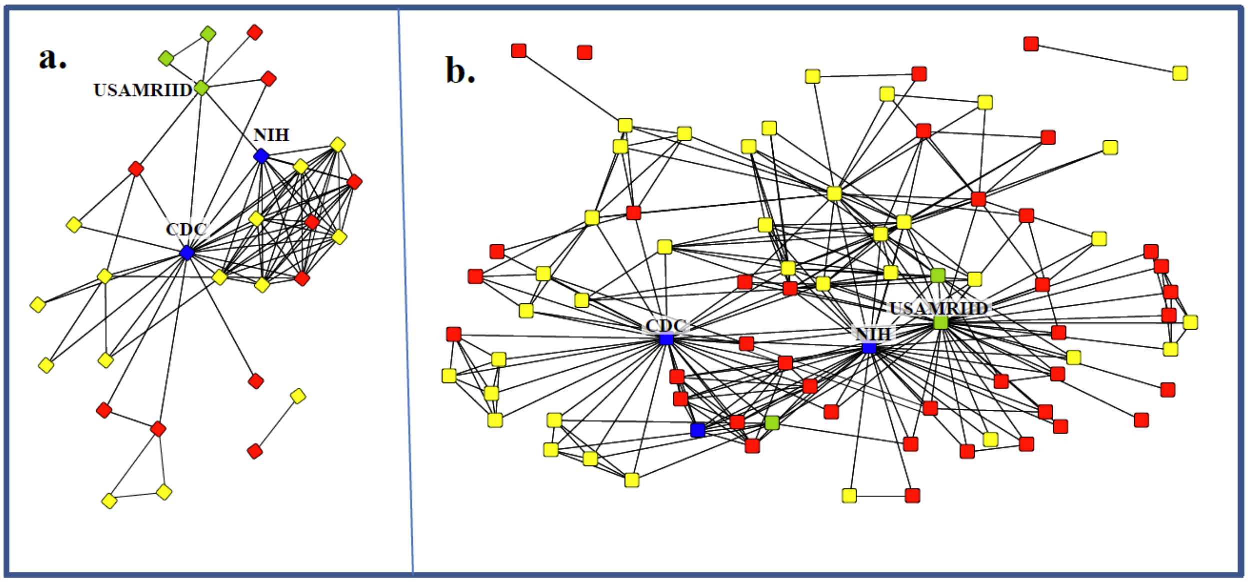


**Figure A1:** Schematic of the collaboration networks of research organizations working with live pathogenic Ebola virus. A link between two nodes indicates a co-authorship involving members of the institutions. (a) Publication network 1997-2001, (b) Publication network 2003-2007. Red nodes indicate U.S. educational or research institutions; blue, U.S. government; green, U.S. military; and yellow, foreign institutions collaborating with U.S. institutions. CDC: Centers for Disease Control and Prevention, NIH: National Institutes of Health, USAMRIID: United States Army Medical Research Institute for Infectious Diseases.

## 2. Share of degree centrality for U.S. co-authorship networks

**Table A1:** Share of degree centrality (SDC) by institutional class for U.S. co-authorship networks† in the five years preceding and following the passage of U.S. biosecurity legislation

| U.S. Sector | Live-pathogen | | | Non-pathogenic | | |
|---|---|---|---|---|---|---|
| | **1997 - 2001** | **2003 - 2007** | **Change** | **1997 - 2001** | **2003 - 2007** | **Change** |
| ***B. anthracis* Network** | | | | | | |
| **Acad./Comm. ‡** | 41% | 44% | 7% | 40% | 44% | 10% |
| **Government** | 29% | 11% | -62% | 29% | 11% | -62% |
| **Military** | 12% | 19% | 58% | 6% | 19% | 217% |
| **Non-U.S.** | 18% | 26% | 44% | 26% | 26% | 0% |
| **Ebola Virus Network** | | | | | | |
| **Acad./Comm.** | 30% | 30% | 0% | 43% | 39% | -9% |
| **Government** | 32% | 22% | -31% | 21% | 14% | -33% |
| **Military** | 6% | 20% | 233% | 11% | 9% | -18% |
| **Non-U.S.** | 32% | 28% | -13% | 24% | 39% | 63% |
| ***K. pneumoniae* Network** | | | | | | |
| **Acad./Comm.** | 45% | 24% | -48% | NC | 41% | NC |
| **Government** | 35% | 18% | -47% | NC | 9% | NC |
| **Military** | 43% | 37% | -15% | NC | 0 | NC |
| **Non-U.S.** | 37% | 39% | 6% | NC | 50 | NC |

NC: Insufficient number of institutions to calculate share of degree centrality
† co-authorship networks of papers having at least one U.S. author
‡ Academic/Commercial category includes universities, hospitals, non-profit institutions and commercial laboratories

## 3. Institution rankings

**Table A2:** Institutions ranked by number of research papers published

| (a) "Live pathogen" *B. anthracis* publications | | | | | | |
|---|---|---|---|---|---|---|
| **Institution Name** | **Number of Papers** | | **Share of Papers (%)** | | **Rank** | |
| | **1997-2001** | **2003-2007** | **1997-2001** | **2003-2007** | **1997-2001** | **2003-2007** |
| USAMRIID | 10 | 43 | 32 | 34 | 1 | 1 |
| Northern Arizona University | 10 | 10 | 32 | 8 | 1 | 2 |
| University of Texas | 2 | 10 | 6 | 8 | 6 | 2 |
| Centers for Disease Control & Prevention (CDC) | 0 | 10 | 0 | 8 | | 2 |
| U.S. Navy | 1 | 9 | 3 | 7 | 12 | 5 |
| Battelle Memorial Inst. | 0 | 9 | 0 | 7 | | 5 |
| NIH | 1 | 6 | 3 | 5 | 12 | 7 |
| Inst. Genomic Research | 0 | 6 | 0 | 5 | | 7 |
| University of New Mexico | 0 | 6 | 0 | 5 | | 7 |
| Johns Hopkins University | 0 | 5 | 0 | 4 | | 10 |
| Translational Genomics Research Institute | 0 | 5 | 0 | 4 | | 10 |
| Los Alamos National Lab. | 8 | 3 | 26 | 2 | 3 | 15 |
| University of Michigan | 2 | 3 | 6 | 2 | 6 | 15 |
| Louisiana State University | 8 | 2 | 26 | 2 | 3 | 25 |
| University of Scranton | 3 | 2 | 10 | 2 | 5 | 25 |

| "Live pathogen" Ebola virus publications | | | | | | |
|---|---|---|---|---|---|---|
| **Institution Name** | **Number of Papers** | | **Share of Papers (%)** | | **Rank** | |
| | **1997-2001** | **2003-2007** | **1997-2001** | **2003-2007** | **1997-2001** | **2003-2007** |

| | | | | | | |
|---|---|---|---|---|---|---|
| USAMRIID | 22 | 44 | 51 | 51 | 2 | 1 |
| NIH | 4 | 29 | 9 | 33 | 4 | 2 |
| CDC | 23 | 27 | 53 | 31 | 1 | 3 |
| University of Manitoba – CA | 0 | 12 | 0 | 14 | | 4 |
| Public Health Agency – CA | 0 | 10 | 0 | 11 | | 5 |
| University of Wisconsin | 2 | 9 | 5 | 10 | 6 | 6 |
| University of Tokyo – JP | 1 | 9 | 2 | 10 | 14 | 6 |
| Uniform Services University of Health Sciences | 2 | 8 | 5 | 9 | 6 | 8 |
| University of Marburg – DE | 1 | 8 | 2 | 9 | 14 | 8 |
| University of Pennsylvania | 0 | 6 | 0 | 7 | | 10 |
| Emory University | 6 | 5 | 14 | 6 | 3 | 11 |
| Scripps Research Institute | 2 | 2 | 5 | 2 | 6 | 18 |
| U.S. Army | 2 | 2 | 5 | 2 | 6 | 18 |
| University of Michigan | 2 | 1 | 5 | 1 | 6 | 33 |
| National Institute of Virology – ZA | 4 | 0 | 9 | 0 | 4 | 82 |

**(b) "Non-pathogenic" *B. anthracis* publications**

| Institution Name | Number of Papers | | Share of Papers (%) | | Rank | |
|---|---|---|---|---|---|---|
| | 1997-2001 | 2003-2007 | 1997-2001 | 2003-2007 | 1997-2001 | 2003-2007 |
| NIH | 18 | 73 | 26 | 14 | 2 | 1 |
| Harvard University | 22 | 40 | 32 | 8 | 1 | 2 |
| University Michigan | 4 | 24 | 6 | 5 | 4 | 3 |
| USAMRIID | 3 | 24 | 4 | 5 | 7 | 3 |
| U.S. FDA | 2 | 24 | 3 | 5 | 9 | 3 |
| University of Chicago | 1 | 23 | 1 | 5 | 16 | 6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| University of Texas | 7 | 22 | 10 | 4 | 3 | 7 |
| Scripps Research Institute | 0 | 21 | 0 | 4 | | 8 |
| University of Maryland | 1 | 20 | 1 | 4 | 16 | 9 |
| CDC | 0 | 18 | 0 | 4 | | 10 |
| University of Alabama | 1 | 16 | 1 | 3 | 16 | 11 |
| Burnham Inst. Medical Research | 1 | 11 | 1 | 2 | 16 | 12 |
| University of California, San Diego | 1 | 11 | 1 | 2 | 16 | 12 |
| University of California, Los Angeles | 0 | 11 | 0 | 2 | 55 | 12 |
| Yeshiva University | 2 | 10 | 3 | 2 | 9 | 15 |

**"Non-pathogenic" Ebola virus publications**

| Institution Name | No. of Papers | | Share of Papers (%) | | Rank | |
|---|---|---|---|---|---|---|
| | 1997-2001 | 2003-2007 | 1997-2001 | 2003-2007 | 1997-2001 | 2003-2007 |
| University of Wisconsin | 5 | 12 | 25 | 21 | 2 | 1 |
| University of Tokyo – JP | 4 | 12 | 20 | 21 | 3 | 1 |
| University of Pennsylvania | 3 | 12 | 15 | 21 | 6 | 1 |
| NIH | 0 | 10 | 0 | 18 | | 4 |
| USAMRIID | 4 | 7 | 20 | 12 | 3 | 5 |
| Japan Science & Technology Agency | 0 | 6 | 0 | 11 | 23 | 6 |
| CDC | 8 | 5 | 40 | 9 | 1 | 7 |
| Hokkaido University – JP | 4 | 5 | 20 | 9 | 3 | 7 |
| Science Centre Human & Animal Health – CA | 0 | 4 | 0 | 7 | | 9 |
| Public Health Agency – CA | 0 | 4 | 0 | 7 | | 9 |
| University of Manitoba – CA | 0 | 4 | 0 | 7 | | 9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| University of California, San Francisco | 2 | 1 | 10 | 2 | 8 | 18 |
| Harvard University | 3 | 0 | 15 | 0 | 6 | 60 |
| Microbiological Associates Inc. | 2 | 0 | 10 | 0 | 8 | 60 |
| National Inst. Med. Research – UK | 2 | 0 | 10 | 0 | 8 | 60 |

## 4. Institutional share of degree centrality

**Table A3:** Institutional share of degree centrality (SDC) for (a) "live-pathogen" and (b) "non-pathogenic" *select agent* networks

| Institution | 1997-2001 | | 2003-2007 | |
|---|---|---|---|---|
| | SDC (%) | Rank | SDC (%) | Rank |
| ***B. anthracis* Network** | | | | |
| USAMRIID | 2 | 6 | 7 | 1 |
| Northern Arizona University | 18 | 1 | 3 | 2 |
| Johns Hopkins University | | | 3 | 3 |
| University of Texas | 5 | 3 | 2 | 4 |
| Institute of Genomic Research | | | 2 | 5 |
| U.S. Navy | 0† | | 2 | 6 |
| Robert Koch Institute -DE | | | 2 | 7 |
| Battelle Memorial Institute | | | 2 | 7 |
| Centers for Disease Control & Prevention | | | 2 | 8 |
| Translational Genomics Research Institute | | | 2 | 9 |
| University of Oslo -NO | 2 | 6 | 2 | 10 |
| Porton Downs - GB | | | 2 | 10 |
| University of Michigan | 3 | 5 | 1 | 11 |
| U.S. Army (excluding USAMRIID) | 0 | | 1 | 12 |

| | | | | |
|---|---|---|---|---|
| Louisiana State University | 16 | 2 | 1 | 13 |
| NIH | 2 | 6 | 1 | 13 |
| Los Alamos National Laboratory | 16 | 2 | 1 | 14 |
| Duke University | 5 | 3 | | |
| **Ebola Virus Network** | | | | |
| USAMRIID | 6 | 3 | 11 | 1 |
| NIH | 6 | 2 | 10 | 2 |
| University of Manitoba - CA | | | 6 | 3 |
| Centers of Disease Control & Prevention | 19 | 1 | 6 | 4 |
| Public Health Agency Canada - CA | | | 6 | 5 |
| University of Wisconsin | 2 | 7 | 5 | 6 |
| University of Tokyo - JP | 0.01 | 9 | 5 | 6 |
| Uniformed Services University of Health Sciences | 0.01 | 8 | 3 | 7 |
| University of Marburg - DE | 0.005 | 10 | 3 | 8 |
| Hokkaido University - JP | 0.01 | 9 | 2 | 9 |
| Emory University | 4 | 6 | 2 | 10 |
| University of Pennsylvania | | | 2 | 10 |
| U.S. Army (excluding USAMRIID) | 1 | 8 | 1 | 14 |
| Scripps Research Institute | 1 | 8 | 1 | 17 |
| Centre Internationale de Recherches Medicales de Franceville – GA | 1 | 9 | 1 | 17 |
| CUNY | 0.5 | 10 | 0.5 | 18 |
| University of Michigan | 1 | 9 | 0.1 | 21 |
| WHO-ZAIRE | 6 | 2 | | |

† Single-institution papers have a DC of 0. A blank indicates no papers by that institution

## 5. Data acquisition and sorting

The bibliography was assembled from ISI Web of Science, using the following search strings: "anthrax OR anthracis OR anthraxin" for *B. anthracis*, "Ebola" for Ebola virus, and "Klebsiella AND pneumoniae" for *K. pneumoniae*. The same search criteria were used with the two funding database search engines. Microbial strains were classified as "Live-pathogen" or "Non-pathogenic" according to the key in Table A4. Only research papers that would have been subject to the biosecurity laws and grants supporting such research were retained. The tally of papers in the final dataset is presented in Table A5, and the funding data are summarized in Table A6.

**Table A4:** Classification of pathogenic and non-pathogenic strains of (a) *Bacillus anthracis*, (b) Ebola virus, and (c) *Klebsiella pneumoniae*

| ***(a) Bacillus anthracis*** | |
|---|---|
| ***Avirulent Strains*** | ***Virulent Strains*** |
| *4230* | *9602* |
| *6602* | *17JB* |
| *7700* | *A0843* |
| *9131* | *Ames* |
| *14185* | *ATCC 6605* |
| *34F2* | *ATCC 8705* |
| *A16R* | *EY 3169 = Vollum* |
| *A34* | *Ferrara* |
| *ANR-1* | *Mayo 1* |
| *ATCC 11966* | *NCTC 10340 = Vollum* |
| *ATCC 14185* | *RA3* |
| *ATCC 4229* | *Vollum (ATCC 14578)* |
| *BH441* | *Zimbabwe* |
| *BH445* | |
| *Carbosap* | |
| *NNRI* | |
| *Pasteur I* | |
| *RA3R* | |
| *RBAF140* | |
| *RBAF143* | |
| *RBAF144* | |
| *RP42* | |
| *RPGI* | |
| *RPL686* | |
| *SM11* | |
| *SM11* | |

| | |
|---|---|
| *SM95* | |
| *SM95* | |
| *Sterne (7702)* | |
| *STI* | |
| *STI-1* | |
| *UM23C1-1* | |
| *UM44 = Weymouth* | |
| *UT500* | |
| *V770-NP1-R* | |
| *VNR-1* | |
| *Weybridge = Sterne* | |
| ***(b) Ebola Virus*** | |
| ***Avirulent Strains*** | ***Virulent Strains*** |
| *Reston* | *Zaire* |
| *Reston-Siena/Philippine-92* | *Sudan* |
| | *Côte D'Ivoire* |
| ***(c) Klebsiella pneumoniae*** | |
| ***Avirulent Strains*** | ***Virulent Strains*** |
| *215* | *AF144323-1* |
| *277* | *ATCC 15380* |
| *5058* | *ATCC 25306* |
| *52K10* | *ATCC 43861* |
| *ATCC 15050* | *CG43* |
| *CG253* | *DSM 2026* |
| *CK 263* | *EB 4335* |
| *DSM7342* | *EB 5221* |
| *F201* | *K2* |
| *I-145* | *KAY2026* |
| *M5a1* | *KC 4727* |
| *NCIB 12204* | *KC 4989* |
| *RU 41740 (Biostim)* | *KP 62-1* |
| *SAP* | *KP A1* |
| *SDF15* | *LEN 1* |
| *SDF20* | *M426* |
| *UN 5058* | *MGH78578* |
| *UN 727* | *NCBI 418* |
| *UN 729* | *NCTC 418* |
| *UN4357* | |
| *UNF 932* | |

**Table A5:** Numbers of peer-reviewed papers meeting relevance criteria, by organism and type of research

| Year | *B. anthracis* | | Ebola virus | | *K. pneumonia* | |
|---|---|---|---|---|---|---|
| | Live pathogen | Non-pathogenic | Live pathogen | Non-pathogenic | Live pathogen | Non-pathogenic |
| 1992 | 2 | 5 | 4 | 2 | 46 | 6 |
| 1993 | 2 | 7 | 3 | 0 | 35 | 9 |
| 1994 | 2 | 13 | 1 | 0 | 36 | 9 |
| 1995 | 3 | 10 | 3 | 1 | 47 | 6 |
| 1996 | 3 | 6 | 3 | 4 | 43 | 4 |
| 1997 | 3 | 5 | 2 | 1 | 39 | 6 |
| 1998 | 4 | 10 | 5 | 4 | 55 | 8 |
| 1999 | 11 | 24 | 17 | 5 | 39 | 6 |
| 2000 | 6 | 9 | 8 | 5 | 52 | 7 |
| 2001 | 7 | 20 | 11 | 5 | 57 | 7 |
| 2002 | 22 | 26 | 15 | 6 | 52 | 1 |
| 2003 | 11 | 72 | 21 | 5 | 59 | 4 |
| 2004 | 29 | 83 | 11 | 6 | 70 | 5 |
| 2005 | 28 | 106 | 10 | 13 | 74 | 1 |
| 2006 | 33 | 119 | 14 | 14 | 62 | 4 |
| 2007 | 26 | 129 | 31 | 18 | 72 | 5 |
| Total | 192 | 644 | 159 | 89 | 838 | 88 |
| 1997-2001 | 31 | 68 | 43 | 20 | 242 | 34 |
| 2003-2007 | 127 | 509 | 87 | 56 | 337 | 19 |

**Table A6:** Average annual federal funding for research† on the three organisms

| Year | Annual Federal Research Funding (in Millions of $US) ‡ | | |
|---|---|---|---|
| | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| 1993 | 0.45 | - | 1.49 |
| 1994 | 0.45 | - | 1.53 |
| 1995 | 0.63 | - | 1.87 |
| 1996 | 0.63 | 0.70 | 1.81 |
| 1997 | 1.13 | 0.75 | 2.15 |
| 1998 | 1.82 | 1.13 | 2.47 |
| 1999 | 2.60 | 1.18 | 3.07 |
| 2000 | 3.48 | 0.70 | 2.77 |
| 2001 | 4.40 | 0.72 | 3.16 |
| 2002 | 12.45 | 1.37 | 3.71 |
| 2003 | 65.48 | 10.35 | 3.97 |
| 2004 | 79.99 | 13.70 | 4.57 |
| 2005 | 121.62 | 14.64 | 4.61 |
| 2006 | 118.34 | 13.48 | 4.14 |

† Non-research grants were purged.

‡ From the RAND Corporation's RaDiUS database

## 6. Sensitivity Analyses

Table A7 presents sensitivity analyses on the effects of the choice of boundary year, inclusion of boundary year papers, and the lag between funding award and publication date, on the regression model results. Sections ***a*** through ***c*** of the table report the odds ratios derived from the regression coefficient of the "law" variable. This is the key variable in this study. In the sensitivity analysis, we look to see if the significance of these odds ratios is changed by variations in the assumptions. The significance of the odds ratios were the same whether 2002 or 2003 was used as the boundary year, and were very similar whether 2002 papers were removed or left in the data set. Also, the regression results were remarkably similar for alternative models with different representations of the funding lag. This indicates that our main conclusions are robust to the particular definition of the appropriate funding lag.

**Table A7:** Sensitivity Analyses

| **(a) Choice of boundary year** | | | |
|---|---|---|---|
| **Odds Ratio of "Live-Pathogen" Research After Boundary Year** | | | |
| **Boundary Year** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| 2002 | 0.54 * | 2.25 | 1.57 |
| 2003 | 1.70 | 1.48 | 1.29 |
| **Odds Ratio of All Author "Entry" After Boundary Year** | | | |
| **Boundary Year** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| 2002 | 9.63 *** | 4.41 *** | 1.11 |
| 2003 | 9.25 *** | 0.06 *** | 1.34 *** |
| **Odds Ratio of All Author "Exit" After Boundary Year** | | | |
| **Boundary Year** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| 2002 | 1.87 *** | 1.69 ** | 0.97 |
| 2003 | 0.52 *** | 9.87 *** | 2.05 *** |
| **Odds Ratio of "Career Scientist" "Entry" After Boundary Year** | | | |
| **Boundary Year** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| 2002 | 3.91 *** | 2.42 *** | 0.71 |
| 2003 | 20.94 *** | 0.18 | 0.43 *** |
| **Odds Ratio of "Career Scientist" "Exit" After Boundary Year** | | | |
| **Boundary Year** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |

| | | | |
|---|---|---|---|
| 2002 | 0.82 | 4.81 *** | 1.12 |
| 2003 | 0.43 | 0.12 | 3.16 *** |
| **(b) Including or excluding papers published in 2002** | | | |
| **Odds Ratio of “Live-Pathogen” Research After 2002** | | | |
| **Year 2002 Papers** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| Papers Omitted | 0.54 * | 2.25 | 1.57 |
| Papers Included | 0.44 *** | 2.16 | 0.93 |
| **Odds Ratio of All Author "Entry" After 2002** | | | |
| **Year 2002 Papers** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| Papers Omitted | 9.63 *** | 4.41 *** | 1.11 |
| Papers Included | 5.34 *** | 4.07 *** | 1.35 *** |
| **Odds Ratio of All Author "Exit" After 2002** | | | |
| **Year 2002 Papers** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| Papers Omitted | 1.87 *** | 1.69 ** | 0.97 |
| Papers Included | 2.49 *** | 1.84 *** | 0.98 |
| **Odds Ratio of “Career Scientist” "Entry" After 2002** | | | |
| **Year 2002 Papers** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| Papers Omitted | 3.91 *** | 2.42 *** | 0.71 |
| Papers Included | 3.20 *** | 2.52 *** | 0.67 ** |
| **Odds Ratio of “Career Scientist” "Exit" After 2002** | | | |
| **Year 2002 Papers** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| Papers Omitted | 0.82 | 4.81 *** | 1.12 |
| Papers Included | 0.88 | 3.72 *** | 1.46 * |
| **(c) Funding Lag Influence on Odds Ratio of Effect of Laws** | | | |
| **Odds Ratio of “Live-Pathogen” Research After 2002** | | | |
| **Funding Lag** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |

| | | | |
|---|---|---|---|
| No Lag | 0.49 | NC | 1.57 |
| 1 Year Lag | 0.54 * | 2.25 | 1.57 |
| 2 Year Lag | 0.62 * | 1.28 | 2.43 |
| 3 Year Lag | 0.58 ** | 0.88 | 2.27 |
| 1 and 2 Year Lags | 0.40 *** | 2.50 | 2.03 |
| 1, 2, and 3 Year Lags | 0.31 *** | 2.21 | 1.68 |
| **Odds Ratio of All Author "Entry" After 2002** | | | |
| **Funding Lag** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| No Lag | 4.37 *** | 15.02 *** | 0.99 |
| 1 Year Lag | 9.63 *** | 4.41 *** | 1.11 |
| 2 Year Lag | 10.73 *** | 2.93 *** | 0.92 |
| 3 Year Lag | 11.07 *** | 2.41 *** | 0.92 |
| 1 and 2 Year Lags | 7.55 *** | 4.73 *** | 1.23 ** |
| 1, 2, and 3 Year Lags | 5.33 *** | 4.03 *** | 1.33 ** |
| **Odds Ratio of Author "Exit" After 2002** | | | |
| **Funding Lag** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| No Lag | 2.38 *** | 1.54 | 1.19 |
| 1 Year Lag | 1.87 *** | 1.69 ** | 0.97 |
| 2 Year Lag | 1.82 *** | 2.00 *** | 0.78 ** |
| 3 Year Lag | 2.00 *** | 1.74 *** | 0.54 *** |
| 1 and 2 Year Lags | 2.40 *** | 1.60 ** | 0.84 |
| 1, 2, and 3 Year Lags | 3.04 *** | 1.43 | 0.65 *** |
| **Odds Ratio of “Career Scientist” "Entry" After 2002** | | | |
| **Funding Lag** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| No Lag | 1.26 | 4.72 | 0.67 * |
| 1 Year Lag | 3.91 *** | 2.42 *** | 0.71 |

| | | | |
|---|---|---|---|
| 2 Year Lag | 3.68 *** | 1.72 ** | 0.89 |
| 3 Year Lag | 5.61 *** | 1.37 | 1.07 |
| 1 and 2 Year Lags | 3.78 *** | 2.29 *** | 0.77 |
| 1, 2, and 3 Year Lags | 1.38 | 2.11 ** | 0.93 |
| **Odds Ratio of "Career Scientist" "Exit" After 2002** | | | |
| **Funding Lag** | ***B. anthracis*** | **Ebola virus** | ***K. pneumoniae*** |
| No Lag | 0.74 | NC | 1.40 |
| 1 Year Lag | 0.82 | 4.81 *** | 1.12 |
| 2 Year Lag | 0.93 | 3.29 *** | 0.75 |
| 3 Year Lag | 1.72 | 2.63 *** | 0.60 ** |
| 1 and 2 Year Lags | 1.49 | 6.51 *** | 1.19 |
| 1, 2, and 3 Year Lags | 2.13 | 5.87 *** | 0.87 |

**(d) Logistic Regression Model Coefficients, $\alpha_i$, varying the specification of funding lag (one model per column)**

| | No Lag | 1 Yr. Lag | 2 Yr. Lag | 3 Yr. Lag | 1&2 Yr. Lags | 1-3 Yr. Lags |
|---|---|---|---|---|---|---|
| **Likelihood of "Live-Pathogen" *B. anthracis* Research After 2002** | | | | | | |
| Constant | -0.938 *** | -0.914 *** | -0.818 *** | -0.776 *** | -0.828 *** | -0.791 *** |
| Law | -0.712 | -0.608 * | -0.482 * | -0.544 ** | -0.928 *** | -1.162 *** |
| Funding $_t$ | 0.003 | | | | | |
| Funding $_{t-1}$ | | 0.002 | | | 0.011 ** | 0.015 ** |
| Funding $_{t-2}$ | | | -0.001 | | -0.010 ** | -0.006 |
| Funding $_{t-3}$ | | | | -0.002 | | -0.008 |
| **Likelihood of "Live-Pathogen" Ebola Virus Research After 2002** | | | | | | |
| Constant | 1.065 *** | 0.773 *** | 0.713 *** | 0.658 *** | 0.758 *** | 0.730 *** |
| Law | 4.272 ** | 0.812 | 0.250 | -0.129 | 0.917 | 0.791 |
| Funding $_t$ | -0.379 *** | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Funding $_{t-1}$ | | -0.100 ** | | | -0.138 * | -0.083 |
| Funding $_{t-2}$ | | | -0.053 * | | 0.035 | -0.082 |
| Funding $_{t-3}$ | | | | -0.012 | | 0.094 |
| **Likelihood of "Live-Pathogen" *K. pneumoniae* Research After 2002** | | | | | | |
| Constant | 1.191 ** | 1.417 ** | 2.058 *** | 1.971 *** | 1.808 *** | 1.560 * |
| Law | 0.452 | 0.450 | 0.889 | 0.821 | 0.706 | 0.520 |
| Funding $_{t}$ | 0.300 | | | | | |
| Funding $_{t-1}$ | | 0.241 | | | 0.304 | 0.410 |
| Funding $_{t-2}$ | | | -0.018 | | -0.227 | -0.462 |
| Funding $_{t-3}$ | | | | 0.023 | | 0.255 |
| **Logistic Regression Model Coefficients, $\beta_i$, varying the specification of funding lag** | | | | | | |
| **Likelihood of Author "Entries" to *B. anthracis* Research After 2002** | | | | | | |
| Constant | -4.291 *** | -4.215 *** | -4.122 *** | -4.073 *** | -4.129 *** | -4.086 *** |
| Law | 1.474 *** | 2.265 *** | 2.373 *** | 2.404 *** | 2.022 *** | 1.673 *** |
| Funding $_{t}$ | 0.012 *** | | | | | |
| Funding $_{t-1}$ | | 0.003 *** | | | 0.010 *** | 0.015 *** |
| Funding $_{t-2}$ | | | 0.0004 | | -0.007 *** | 0.0005 |
| Funding $_{t-3}$ | | | | -0.002 | | -0.017 *** |
| **Likelihood of Author "Entries" to Ebola Virus Research After 2002** | | | | | | |
| Constant | -3.333 *** | -3.319 *** | -3.222 *** | -3.145 *** | -3.194 *** | -3.106 *** |
| Law | 2.710 *** | 1.484 *** | 1.075 *** | 0.878 *** | 1.553 *** | 1.393 *** |
| Funding $_{t}$ | -0.115 *** | | | | | |
| Funding $_{t-1}$ | | -0.016 | | | -0.111 *** | -0.071 *** |
| Funding $_{t-2}$ | | | 0.018 * | | 0.096 *** | -0.012 |
| Funding $_{t-3}$ | | | | 0.045 *** | | 0.095 *** |
| **Likelihood of Author "Entries" to *K. pneumoniae* Research After 2002** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Constant | -2.970 *** | -2.861 *** | -2.954 *** | -2.961 *** | -2.566 *** | -2.472 *** |
| Law | -0.009 | 0.104 | -0.088 | -0.089 | 0.210 ** | 0.282 ** |
| Funding $_t$ | 0.092 ** | | | | | |
| Funding $_{t-1}$ | | 0.055 | | | -0.423 *** | -0.477 *** |
| Funding $_{t-2}$ | | | 0.128 *** | | 0.399 *** | 0.522 *** |
| Funding $_{t-3}$ | | | | 0.143 *** | | -0.119 |
| **Likelihood of Author "Exits" from *B. anthracis* Research After 2002** | | | | | | |
| Constant | -1.474 *** | -1.454 *** | -1.466 *** | -1.471 *** | -1.459 *** | -1.460 *** |
| Law | 0.868 *** | 0.627 *** | 0.599 *** | 0.692 *** | 0.877 *** | 1.113 *** |
| Funding $_t$ | -0.0002 | | | | | |
| Funding $_{t-1}$ | | 0.004 *** | | | -0.008 *** | -0.012 *** |
| Funding $_{t-2}$ | | | 0.006 *** | | 0.012 *** | 0.007 ** |
| Funding $_{t-3}$ | | | | 0.008 *** | | 0.012 *** |
| **Likelihood of Author "Exits" from Ebola Virus Research After 2002** | | | | | | |
| Constant | -1.358 *** | -1.513 *** | -1.559 *** | -1.506 *** | -1.574 *** | -1.517 *** |
| Law | 0.430 | 0.525 ** | 0.694 *** | 0.554 *** | 0.469 ** | 0.359 |
| Funding $_t$ | -0.011 | | | | | |
| Funding $_{t-1}$ | | 0.001 | | | 0.044 | 0.064 ** |
| Funding $_{t-2}$ | | | -0.013 | | -0.041 * | -0.104 *** |
| Funding $_{t-3}$ | | | | -0.004 | | 0.061 ** |
| **Likelihood of Author "Exits" from *K. pneumoniae* Research After 2002** | | | | | | |
| Constant | -0.581 *** | -0.987 *** | -1.279 *** | -1.577 *** | -1.190 *** | -1.230 *** |
| Law | 0.178 | -0.033 | -0.244 ** | -0.610 *** | -0.175 | -0.433 *** |
| Funding $_t$ | -0.086 | | | | | |
| Funding $_{t-1}$ | | 0.084 | | | -0.091 | 0.040 |
| Funding $_{t-2}$ | | | 0.213 *** | | 0.268 *** | -1.088 *** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Funding $_{t-3}$ | | | | 0.413 *** | | 1.418 *** |
| **Likelihood of "Career" Author "Entries" to *B. anthracis* Research After 2002** | | | | | | |
| Constant | -3.489 *** | -3.408 *** | -3.292 *** | -3.281 *** | -3.291 *** | -3.302 *** |
| Law | 0.233 | 1.362 *** | 1.302 *** | 1.725 *** | 1.329 *** | 0.323 |
| Funding $_{t}$ | 0.015 *** | | | | | |
| Funding $_{t-1}$ | | 0.004 * | | | -0.001 | 0.023 *** |
| Funding $_{t-2}$ | | | 0.006 ** | | 0.007 | 0.012 ** |
| Funding $_{t-3}$ | | | | -0.009 ** | | -0.047 *** |
| **Likelihood of "Career" Author "Entries" to Ebola Virus Research After 2002** | | | | | | |
| Constant | -2.749 *** | -2.672 *** | -2.584 *** | -2.512 *** | -2.571 *** | -2.485 *** |
| Law | 1.552 | 0.884 *** | 0.541 ** | 0.313 | 0.830 *** | 0.747 ** |
| Funding $_{t}$ | -0.083 | | | | | |
| Funding $_{t-1}$ | | -0.051 ** | | | -0.068 | -0.063 |
| Funding $_{t-2}$ | | | -0.038 | | 0.017 | -0.010 |
| Funding $_{t-3}$ | | | | -0.023 | | 0.037 |
| **Likelihood of "Career" Author "Entries" to *K. pneumoniae* Research After 2002** | | | | | | |
| Constant | -2.675 *** | -2.607 *** | -2.306 *** | -2.014 *** | -2.469 *** | -2.219 *** |
| Law | -0.406 * | -0.340 | -0.116 | 0.067 | -0.262 | -0.075 |
| Funding $_{t}$ | 0.044 | | | | | |
| Funding $_{t-1}$ | | 0.013 | | | 0.292 | 0.498 * |
| Funding $_{t-2}$ | | | -0.122 | | -0.361 * | 0.219 |
| Funding $_{t-3}$ | | | | -0.280 * | | -1.045 ** |
| **Likelihood of "Career" Author "Exits" from *B. anthracis* Research After 2002** | | | | | | |
| Constant | -3.202 *** | -3.166 *** | -3.116 *** | -3.138 *** | -3.105 *** | -3.129 *** |
| Law | -0.301 | -0.198 | -0.074 | 0.541 | 0.400 | 0.758 |
| Funding $_{t}$ | 0.013 * | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Funding $_{t-1}$ | | 0.019 *** | | | -0.011 | -0.015 * |
| Funding $_{t-2}$ | | | 0.021 *** | | 0.028 *** | 0.024 *** |
| Funding $_{t-3}$ | | | | 0.022 *** | | 0.010 |
| **Likelihood of "Career" Author "Exits" from Ebola Virus Research After 2002** | | | | | | |
| Constant | -2.890 *** | -3.043 *** | -3.196 *** | -3.155 *** | -3.156 *** | -3.096 *** |
| Law | 4.681 *** | 1.571 *** | 1.189 *** | 0.967 *** | 1.873 *** | 1.770 *** |
| Funding $_t$ | -0.315 *** | | | | | |
| Funding $_{t-1}$ | | -0.055 ** | | | -0.183 *** | -0.154 ** |
| Funding $_{t-2}$ | | | -0.003 | | 0.135 ** | 0.064 |
| Funding $_{t-3}$ | | | | 0.027 | | 0.058 |
| **Likelihood of "Career" Author "Exits" from *K. pneumoniae* Research After 2002** | | | | | | |
| Constant | -3.447 *** | -3.860 *** | -4.391 *** | -4.423 *** | -3.751 *** | -3.764 *** |
| Law | 0.339 | 0.110 | -0.288 | -0.516 ** | 0.171 | -0.136 |
| Funding $_t$ | 0.353 ** | | | | | |
| Funding $_{t-1}$ | | 0.573 *** | | | -0.529 ** | -0.289 |
| Funding $_{t-2}$ | | | 0.838 *** | | 1.120 *** | -0.312 |
| Funding $_{t-3}$ | | | | 0.993 *** | | 1.387 *** |

* $p \le 0.10$, ** $p \le 0.05$, *** $p \le 0.01$, NC: not calculable

An examination of the statistical significance of coefficients of the lagged funding time series (Table A7 Section ***d***) shows that several different definitions of the relationship between funding and the dependent variables have merit. There are regressions where the coefficient for a one-year lag has a greater statistical significance, some (fewer) where a two-year lag is a better predictor, and others where using both one and two year lags together works the best. One- or two-year lagged funding were always better predictors of outcomes than no lag or a three-year lag. Since the choice of funding lag does not significantly alter the main conclusions, we decided to use a one year lag in the main paper.

## 7. Phone Interview Questions

These questions were e-mailed to select agent researchers. Anonymity was promised. The survey was approved by Carnegie Mellon University's Institutional Review Board.

1. Have you changed the way you conduct research as the result of the USA PATRIOT Act or the Bioterrorism Preparedness Act? Please specify.
2. Did the laws stymie your research work in any way? Please describe.
3. Was your ability to collaborate with other scientists, particularly foreign partners, altered by the legislation?
4. Were there any other outcomes, negative or positive, to your own work and to the field in general that you attribute to the legislation? Please specify.
5. Other than the laws, what were the two most important events or developments that changed select agent research in the last 10 years? What were the changes? When did they occur?

# Appendix B: Supporting information for Chapter 4

## 1. Assumptions and Considerations Made in Cost Calculations

An exchange rate of 1 USD (U. S. Dollar) = 45 INR (Indian Rupees) is applied for all calculations. Also, all figures are rounded, since these values are approximates and cannot be known to exact the dollar.

Assumptions and considerations incorporated into Table 8:

- TechBridgeWorld purchases components for the BWT, and a research engineer assembles the parts to create one device.
- Components cost between $135 and $150, based on TechBridgeWorld figures.
- Assembly costs include 15 minutes of the engineer's time (paid at $17 - $25 per hour), as well as 1-2 minutes of electricity used to solder parts (assume 40-60 Wattage for soldering iron, and a cost of 12-17 cents per kWh).
- If a computer was to be purchased:
    - The cost of a comparable used desktop in India is about 10,000 INR.[22]
    - The cost of a comparable new desktop in India is about 40,000 INR.[23]
    - Therefore, the cost range used was 10,000 – 40,000 INR.

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[22] "Alibaba.com." Hong Kong Limited and licensors. n. d. 8 June 2011. <http://www.alibaba.com/countrysearch/IN/used-desktop-computers-manufacturers.html>.
[23] Based on information from Mathru. Also, verified based on: PriceIndia.in: Computer Hardware Price List in India. n. d. 8 June 2011. <http://www.priceindia.in/computer/hp-pavilion-desktop-pc/>.

Assumptions and considerations incorporated into Table 9:

- For O&M costs, we assume 12 – 15 hours of BWT use per week at Mathru, for 36 – 40 weeks during a calendar year (students receive about 3 months of vacation time during a given calendar year).
- Cost per kWh of electricity in Bangalore, India is approximated to be between 5 – 8 INR (based on electricity bills received by the Mathru School).
- Watts required to power a comparable desktop computer (monitor + CPU) is assumed to be between 230 and 300.
- Ceiling fan used in the classroom is estimated to draw 10-50 Watts of power.
- Light fixtures in the classroom draw approximately 20-70 Watts of power.
- Annual maintenance cost per computer at the Mathru School is estimated to be 400 – 700 INR (based on information received from Mathru).
- Cost to troubleshoot for the BWT remotely with TechBridgeWorld is captured as expenses related to emails sent. Mathru pays a flat rate of 250 INR per month for internet access, and the data quota allotted is not expected to be exceeded by the number of emails sent for troubleshooting. So the cost of sending one vs. 100 emails should still be 250INR per month. This information is based on a bill received by Mathru from the school's Internet service provider.

- It would also be possible to troubleshoot over Skype[24]. This would not add to the cost of troubleshooting since this too will not cause Mathru to exceed their data quota of their Internet access package.

Assumptions and considerations incorporated into Table 10:

- To annualize capital costs, the cost of the asset is simply divided by the number of years in its lifetime.
- Interest is not considered in this calculation.
- Zero salvage value is assumed for all assets.
- The lifetime of a BWT is assumed to be 2 years.
- The lifetime of a used computer is assumed to be 2 years.
- The lifetime of a new computer is assumed to be 4 years.
- Total annual O&M costs are obtained from Table 9.

Table B1 presents the annualized capital cost per BWT, assuming that a BWT has a lifetime of 3 years, as opposed to 2 years (as is assumed in Table 10) and no interest.

[24] "Skype." Skype Limited. n. d. 9 June 2011. <http://www.skype.com/intl/en-us/welcomeback/>.

**Table B1:** Annualized capital costs associated with a BWT at the Mathru School, assuming no interest and a 3 year lifetime for the BWT

| Type of Expense | Lower Estimate (USD) | Upper Estimate (USD) |
|---|---|---|
| Cost to produce/acquire a BWT | $ 50 | $ 50 |
| Cost of a computer to run BWT software | $ 110 | $ 220 |
| ***Total Annual Capital Expenses, if computer is purchased*** | ***$ 160*** | ***$ 270*** |

Table B2 (below) presents the annualized capital cost per BWT, assuming that a BWT has a lifetime of 2 years and accounting for an annual interest rate of 8% (as opposed to the no interest assumption used in Table 10). An 8% annual interest rate was used, based on the methods of Surana *et al.* [104].[25]

**Table B2:** Annualized capital costs associated with a BWT at the Mathru School, assuming an 8% annual interest rate and a 2 year lifetime for the BWT

| Type of Expense | Lower Estimate (USD) | Upper Estimate (USD) |
|---|---|---|
| Cost to produce/acquire a BWT | $ 80 | $ 90 |
| Cost of a computer to run BWT software | $ 130 | $ 300 |
| ***Total Annual Capital Expenses, if computer is purchased*** | ***$ 210*** | ***$ 390*** |

Table B3 (below) presents the total annual cost (capital expenses plus O&M costs) per BWT, assuming that a BWT has a lifetime of 2 years and accounting for an annual interest rate of 8% (as opposed to the no interest assumption used in Table 10).

[25] This rate is roughly equivalent to interest that can be earned on a 9 – 12 month deposit in India: "Axis Bank." Axis Bank Foundation. n. d. 8 June 2011. <http://www.axisbank.com/personal/interestrates/domesticdepositrates/Domestic-Deposit-Rates.asp>.

**Table B3:** Total annual expenses associated with a BWT at the Mathru School, assuming an 8% annual interest rate and a 2 year lifetime for the BWT

| Type of Expense | Lower Estimate (USD) | Upper Estimate (USD) |
|---|---|---|
| Annualized cost to produce/acquire a BWT | $ 80 | $ 90 |
| Annualized cost of a computer to run BWT software | $ 130 | $ 300 |
| Annual O&M expenses | $ 90 | $ 130 |
| **Total Annual Expenses** | **$ 300** | **$ 520** |

Assumptions and considerations incorporated into Table 11:

- Capital costs are annualized using the same method as in Table 10. Interest is not accounted for.
- Table B4 presents assumptions that are made to arrive at figures given in Table 11.
- Unit cost figures were obtained from the Mathru School.
- The number of units of each tool at the school is also estimated based on information from the school.
- Total upfront cost is calculated by multiplying unit cost by the number of units required.
- Lifetime assumptions for the braille slate and stylus, marble board, and trailor frame were guesstimates based on the fact that these tools are very robust and should therefore last several years.
- Braille paper is assumed to have a 1 year lifetime since the school reportedly utilizes 50 – 70 thousand sheets every year.
- Annual maintenance cost for the tools is assumed to be the cost to replace lost or misplaced components.

- The school reported that they purchase an extra 5 – 15 braille slates to cover lost or missing units.
- It is assumed that braille styluses will be lost or misplaced more frequently than slates, so their maintenance is assumed to require the purchase of 10 – 20 styluses per year.
- For the marble board and trailor frame, we guesstimate that the maintenance cost per year will be roughly equal to half the unit cost of these tools.
- No maintenance cost is included for braille paper, which is exhausted in a given year.

**Table B4:** Assumptions and calculations feeding figures in Table 11 of Chapter 4.

| Braille Educational Tool | Unit Cost (USD) | Number of Units School Requires | | Total Upfront Cost (USD) | | Estimated Lifetime (Years) |
|---|---|---|---|---|---|---|
| | | Lower Est. | Upper Est. | Lower Est. | Upper Est. | |
| Braille slate | $ 2.00 | 70 | 90 | $ 140 | $ 180 | 15 |
| Braille stylus | $ 0.22 | 70 | 90 | $ 16 | $ 20 | 15 |
| Marble board | $ 2.22 | 1 | 5 | $ 2 | $ 11 | 15 |
| Trailor frame | $ 2.00 | 1 | 5 | $ 2 | $ 10 | 15 |
| Braille paper | $ 0.04 | 50,000 | 70,000 | $ 2,110 | $ 2,960 | 1 |

## 2. Cost Comparison between Operating 2 BWTs versus 10 BWTs at the Mathru School

Assumptions in Tables 11 and 12 include:

- Capital costs are derived by simply multiplying figures in Table 8 by the number of BWTs (*i.e.* by 2 and 10). The same is done to calculate cost of electricity to power the computers used with the BWTs, as well as computer maintenance costs.
  - Note that for computer maintenance, the school currently pays to maintain all its computers, so there would be no additional cost to the school. The calculations

shown in Table B5 and Table B6 represent what the school would have to pay if they were paying for maintenance on a per computer basis.

- Cost of electricity to power the fan and light bulbs and remote troubleshooting costs are not varied based on the number of BWTs in uses.
    - There is no reason to turn on more fans and lights to support additional BWTs.
    - The cost of emails does not change regardless of the number of emails sent.

**Table B5:** Costs associated with 2 Braille Writing Tutors at the Mathru School, based on current usage patterns.

| **Type of Expense** | **Lower Estimate (USD)** | **Upper Estimate (USD)** |
|---|---|---|
| Capital Costs: | | |
| Cost of main components of the BWT | $ 270 | $ 300 |
| BWT assembly costs | $ 10 | $ 10 |
| ***Total Capital Expenses*** | ***$ 280*** | ***$ 310*** |
| Annual Operating Costs: | | |
| Electricity to power computer | $ 20 | $ 60 |
| Electricity to power fan and light bulbs | $ - | $ 10 |
| Maintenance cost for computer | $ 20 | $ 30 |
| Cost to troubleshoot for BWT with TechBridgeWorld | $ 70 | $ 70 |
| ***Total Operating Expenses*** | ***$ 110*** | ***$ 170*** |
| | | |
| **TOTAL EXPENSES** | **$ 390** | **$ 480** |

**Table B6:** Costs associated with 10 Braille Writing Tutors at the Mathru School, based on current usage patterns.

| Type of Expense | Lower Estimate (USD) | Upper Estimate (USD) |
|---|---|---|
| Capital Costs: | | |
| Cost of main components of the BWT | $ 1,350 | $ 1,500 |
| BWT assembly costs | $ 40 | $ 60 |
| ***Total Capital Expenses, if computer is donated*** | ***$ 1,390*** | ***$ 1,560*** |
| Annual Operating Costs: | | |
| Electricity to power computer | $ 110 | $ 320 |
| Electricity to power fan and light bulbs | $ - | $ 10 |
| Maintenance cost for computer | $ 90 | $ 160 |
| Cost to troubleshoot for BWT with TechBridgeWorld | $ 70 | $ 70 |
| ***Total Operating Expenses*** | ***$ 270*** | ***$ 560*** |
| | | |
| **TOTAL EXPENSES** | **$ 1,660** | **$ 2,120** |

## 3. Considering Different Usage Models for the BWT at the Mathru School

Under the current usage model at Mathru, we approximate that the BWT is in use for 12 to 15 hours per week. This is can be considered fairly heavy use of the BWT, given that students are relatively rough handlers of the BWTs. Here, two other scenarios are considered where the BWT is used for less time per week.

The second model assumes only one-user-session-per-weekday (as opposed to three) for grades 1 and 2 (i.e. excluding grade 3), plus the Saturday hour-long session for weaker students in those grades. This prioritizes the benefit of the BWT to weaker students as well as very young students which seems to be its key role at the Mathru School. At the same time this model allows for potentially longer usage of each BWT (*i.e.* an extended lifetime due to less wear and tear) at the school and thus affecting the cost-benefit ratio. Note that on weekdays students will take turns using the tutor based on a roster, similar to what is currently done at Mathru. Additionally, this model will allow for limited teacher and older student usage time, as well as some variation in daily usage, to result in 4 to 6 hours of use per week.

The final model considered here is a weak-students-only scenario, where the daily use is eliminated and the Saturday session is lengthened to cater to just weaker students. Here again, weaker students are prioritized. This may also re-purposes the BWT as a tool for weak students only. Under this third model it is assumed that Saturday sessions will be extended by 30 to 60 minutes (for a total of 1.5 to 2 hours), only weaker students from grades 1 through 3 will participate in Saturday sessions, and teachers may still use the BWT on occasion, although older students will not have access to the BWT. Thus, the BWT will be in use for an estimated 1.5 to 2.5 hours per week in this final scenario.

Table B7 summarizes duration of use and key users associated with each of these three models; where model 1 represents the current usage behavior, model 2 is the one-user-session-per-weekday scenario, and model 3 is the weak-students-only scenario.

**Table B7:** Summary of three different usage scenarios for the Braille Writing Tutor (BWT) at the Mathru School for the Blind. U1 represents current usage pattern; U2 is restricted to one user session per day; and U3 is limited to weaker student use of the BWT.

| Usage Scenario | Duration of BWT Use | Key Users of the BWT |
|---|---|---|
| ***Usage Model 1 (U1):*** Three user sessions per weekday + one session on Saturdays | 12 to 15 hours per week | Students in grades 1 through 3 use the BWT during the week. In addition, weaker students work with the BWT on Saturdays. Teachers and older students use the BWT on occasion. |
| ***Usage Model 2 (U2):*** One user session per weekday + one session on Saturdays | 4 to 6 hours per week | Students in grades 1 and 2 use the BWT during the week. In addition, weaker students work with the BWT on Saturdays. Teachers and older students use the BWT on occasion. |
| ***Usage Model 3 (U3):*** One weaker-students-only session per week | 1.5 to 2.5 hours per week | Weaker students from grades 1 through 3 use the BWT weekly. Teachers use the BWT on occasion, but older students have no access to the device. |

Considering these different usage scenarios can help schools like Mathru make more informed decisions on how best to use the BWT according to resource availability and student needs.

Under U2, students in grade 3 will not benefit from using the BWT. Weaker students in that grade, in particular, will not be able to take advantage of the additional guidance offered on Saturdays. Given that user sessions are limited to one per weekday, an individual student will have to wait longer to get another turn at using the BWT. This delay between BWT uses for that student might limit the benefit s/he might accrue from it. Additionally, students may be discouraged by their limited access to the BWT. This scenario also implies that teachers will have additional students to attend to during the braille class period, since students who would be typically using the BWT in that time will not have access to it. Furthermore, teachers may need to work extra with students to help them grasp the concept of braille, given the reduced amount of time students will have to practice with the BWT. Thus, the assistance that the BWT offers to teachers may be somewhat diminished.

Under the U3 model, only weaker students will be able to utilize the BWT. Therefore, other students in grades 1 through 3 will not be able to practice and hone their braille writing skills using the BWT. Given the enthusiasm shown by students towards the BWT, this scenario might encourage some students to pretend to be weak so as to receive a chance to work with the BWT. Therefore, this scenario may also cause students to feel less motivated to improve their braille writing skills. Additionally, weaker students will have only a limited time with the BWT on Saturdays, so even they may not attain as much benefit from using the BWT as they do under the current model (U1). Also, similar to U2, the assistance that the BWT offers to teachers may be diminished in this scenario as well.

There is, however, a chance that the aforementioned effects will not materialize in the two alternative usage scenarios. Also, although students and teachers may gain less from using the BWT than they do currently, they should still accrue some benefit from using the BWT in the limited capacities described in usage models 2 and 3.

Table B8 presents annual operating costs for Mathru for the three usage scenarios considered (U1, U2 and U3).

**Table B8:** Estimated range of annual operating expenses for the Mathru School, to use and maintain one Braille Writing Tutor and a supporting computer, based on three different usage models.

| Type of Expense | Usage Model 1 | | Usage Model 2 | | Usage Model 3 | |
|---|---|---|---|---|---|---|
| | Lower Est. (USD) | Upper Est. (USD) | Lower Est. (USD) | Upper Est. (USD) | Lower Est. (USD) | Upper Est. (USD) |
| Electricity to power computer | $ 10 | $ 30 | $ - | $ 10 | $ - | $ 10 |
| Electricity to power fan and light bulbs | $ - | $ 10 | $ - | $ 10 | $ - | $ - |
| Maintenance cost for computer | $ 10 | $ 20 | $ 10 | $ 20 | $ 10 | $ 20 |
| Cost to troubleshoot for BWT with TechBridgeWorld | $ 70 | $ 70 | $ 70 | $ 70 | $ 70 | $ 70 |
| **Total Operating Expenses** | **$ 90** | **$ 130** | **$ 80** | **$ 110** | **$ 80** | **$ 100** |

Thus, the potential average annual cost savings from changing the pattern of use to one of the alternative models, would amount to about $10 to $30. So, the annual O&M cost savings from changing usage behavior are not very significant, especially given that these savings would only materialize after one whole year. However, changing usage patterns to U2 or U3 could extend the lifetime of the BWT and thus reduce the cost to replace the device. For example, if the BWT's lifetime was extended to four years, its capital cost can be annualized to be between just $35 and $40 (*i.e.* $140/4 - $160/4). This would be a significant cost reduction.

Given that the frequency of use can affect the durability of the BWT, under the alternative usage models (U2 and U3) the device is likely to function fully for more than two years. Particularly, in the case of U3 where usage goes down to 1.5 to 2.5 hours per week (compared to 12 – 15 hours), the BWT is less likely to accumulate as much moisture from users and will also not be worn down as fast. It is, however, unclear as to how much longer the BWT will function under this scenario; it could be months or years. The potential loss in benefits to the students may not warrant the limited use model to extend the life of the BWT by 3 or 4 months, but could be deemed appropriate if the BWT's durability is extended to 4 years instead of 2.

Since the sustained use of the BWT at the Mathru School thus far was influenced by the perceived benefit of the device, altering the pattern of use and therefore the potential benefits, may affect the social sustainability of the BWT at the school. If students' access to the tutor is limited as in usage models 2 and 3 (U2 and U3) they could demonstrate fewer improvements in their braille writing skills. It is, however, important to note that no formal results show any correlation between improved braille writing skills and use of a BWT. Scenario U3 is particularly restrictive and could cause some students to feel deprived of using what they perceive to be a fun tool. However, this will just be a transitional issue since if students never use the BWT they won't be as affected by not being able to use it in future classes. Therefore, it is unclear as to whether altering usage patterns will affect social sustainability. Provided that students who need it most are able to use the BWT and benefit from it, the school may opt to switch usage patterns in order to prolong the life of a BWT.

## 4. Average Braille Test/Exam Scores at the Mathru School

| Average Annual Exam Braille Scores | | | |
|---|---|---|---|
| Grade | 2007 - 2008 | 2008 - 2009 | 2009 - 2010 |
| 1 | 42% | 55% | 44% |
| 2 | 58% | 49% | 58% |
| 3 | 72% | 46% | 57% |
| 4 | 59% | 39% | 55% |
| 5 | 68% | 53% | 50% |
| 6 | 71% | 39% | 55% |
| 7 | 39% | 47% | 46% |
| **Average Quarterly Exam Braille Score** | | | |
| Grade | 2008 - 2009 | 2009 - 2010 | 2010 - 2011 |
| 1 | 57% | 40% | 47% |
| 2 | 50% | 55% | 52% |
| 3 | 61% | 70% | 51% |
| 4 | 56% | 64% | 61% |
| 5 | 52% | 66% | 69% |
| 6 | 49% | 72% | 67% |
| 7 | 64% | 52% | 69% |
| **Average Monthly Test Braille Score** | | | |
| Grade | 2007 - 2008 | 2008 - 2009 | 2009 - 2010 |
| 1 | 39% | 61% | 49% |
| 2 | 52% | 46% | 57% |
| 3 | 73% | 70% | 54% |
| 4 | 64% | 72% | 55% |
| 5 | 62% | 58% | 63% |
| 6 | 64% | 58% | 54% |
| 7 | 68% | 65% | 49% |

# Appendix C: The PREval (Pilot Research Evaluation) Framework – Evaluating Pilot Projects in Information Communication Technology for Development (ICTD)

## Overview

Information and communication technology for development (ICTD or ICT4D) is a burgeoning field that has attracted increasing interest from researchers, sponsors and policymakers in the last decade. Much of the work being carried out in this area is at the pilot stage, where researchers explore potential technology solutions to challenges in developing communities across the globe. Although ICTD projects are now widespread, there is still little in the way of theory or standards for this body of work. In terms of project outcomes, Heeks posits that "Most of the ICT4D research being produced is…descriptive not analytical."[26] While there is a need for standards in many aspects of this field, there is a particularly evident lack of structure concerning how such projects are appraised. Therefore, this document was created to offer a systemic approach to evaluating pilot-stage field projects in ICTD.

Most currently employed evaluation methods in ICTD are borrowed from economic development and information systems projects and programs. However, since ICTD combines development endeavors with efforts in technology innovation and adaptation, there is a need for an approach to project evaluation that specifically caters to the unique aspects of this field. Thus, we developed an ICTD-centric, practical method for conducting more comprehensive pilot project evaluations.

Our belief is that laying the foundation for evaluation of pilot-stage ICTD projects can benefit this emergent field of research in many ways. First, it would offer an opportunity to improve pilot studies, learn more from them and also make better decisions on how to scale them. Second, it can generate a standardized and more comprehensive approach to reporting results of ICTD endeavors. Finally, it could improve the overall quality of work produced in the field of ICTD and thereby better serve the relevant developing communities.

[26] Heeks, R., "Theorizing ICT4D Research", Information Technologies and International Development, Vol. 3, No. 3, pp. 1-4, 2007.

# *Acknowledgements*

The PREval framework was created in collaboration with the core members of the TechBridgeWorld research group, and incorporates valuable contributions from Dr. Brett Browning, Dr. David Dausey, Dr. M. Bernardine Dias, Dr. Elizabeth Casman, Dr. Mitchell Small and Dr. Faheem Hussain. The work described in this publication was made possible by the support of NPRP grant #30-6-7-91 from the Qatar National Research Fund. The statements made herein are solely the responsibility of the authors.

# About The PREval Framework

This evaluation framework is intended to serve as a step-by-step guide for field researchers to complete a comprehensive evaluation of an ICTD pilot project. To this end the content of this document is designed to assist researchers in planning and executing evaluations, as well as organizing findings so as to aid decision making.

## Purpose

The purpose of the PREval framework is to assist in the planning and execution of ICTD pilot project evaluations. Additionally, it is designed to improve reporting of project evaluation results by organizing findings in a way that would better enable decision makers to determine the best course(s) of action to take post-pilot study.

## Intended Users

This framework is intended to be used primarily by ICTD field researchers who are directly responsible for project execution and who typically will not be trained on how to conduct evaluations. From an administrative perspective, the PREval framework is designed to be utilized by program or project managers to obtain the information they require to make sound decisions on whether or how to continue the work.

## Contents

There are two major sections of this framework:

1. *Planning and Executing Evaluation*, which is what the bulk of this document is dedicated to. This section is divided into to three parts, according to major elements of an ICTD project:
    a. Process Evaluation
    b. Technology (Output) Assessment
    c. Outcome Evaluation

    Within each subsection steps necessary in planning and executing the respective evaluation will be outlined. Additionally, worksheets are offered to facilitate data entry and analysis.
2. *Reporting Project Results to Decision Makers*. This section offers a template for organizing findings so as to answer critical questions involved in the decision making process.

## Scope and Application

Since ICTD is still a relatively new field, much of the work in this area is at a trial stage. Therefore, we limit the scope of the PREval framework to pilot level projects, which are typically limited in time and resources, and are designed to test a proof of concept rather than a specific hypothesis.

The PREval framework is intended to be used from the planning stages of a project onward, so that each phase of a project is evaluated, and such that lessons learned from earlier stages can better inform the latter phases of the project. To apply the PREval framework, users should first familiarize themselves with its contents, decide on how to incorporate it into their specific undertaking, and accordingly budget for required time and resources. Users can follow the guidelines detailed in the framework to determine what data are needed for project evaluation as well as how that information can be collected. Once this aspect of the evaluation is mapped out, users can utilize the worksheets included in the PREval framework to collect and organize data. Additionally, the framework offers guidelines on how to conduct data analysis. Finally, after data is collected and analyzed, the template included in the final section of the PREval framework can be used to systematically summarize key findings from the pilot project.

## Planning and Executing Evaluation

In order to provide a comprehensive assessment of a project, an evaluation should examine, on an ongoing basis, whether and how well critical project activities and procedures are executed (*formative evaluation*), and assess output and outcome of a project relative to expected results (*summative evaluation*). To cover both formative and summative evaluations for a given project, the PREval framework offers guidance on how to plan and execute:

- *I. Process evaluation* (formative),
- *II. Technology (output) assessment* (summative), and
- *III. Outcome evaluation* (summative).

Processes are carried out throughout the course of a project, and at a certain point in an ICTD endeavor a technology output is introduced. Once the technology is applied in the field, outcomes of this intervention can be discerned. Thus, the three types of evaluation covered by the PREval framework should offer a thorough judgment of a project (see Figure C1).

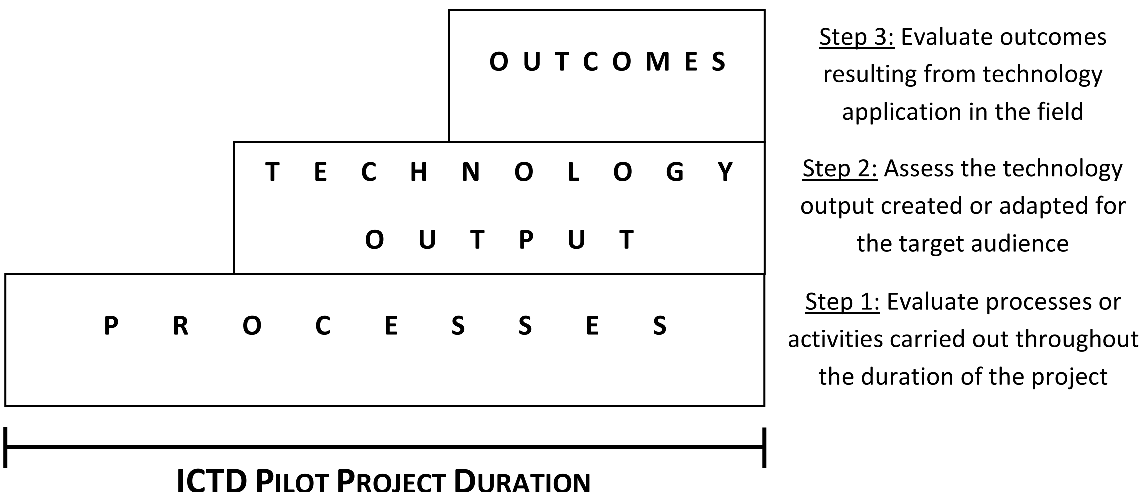


**Figure C1:** Simple diagrammatic representation of components included in the PREval Framework, based on the timeline of a typical ICTD pilot project in the field.

There are four basic steps involved in any evaluation: (1) Define goals/objectives, (2) Assign metrics/indicators to gauge progress towards achieving goals, (3) Collect data on metrics, and (4) Analyze collected data. Note that steps may need to be revisited out of sequence if process, output and outcome modifications are necessary during the course of a project. In the following sections, the PREval Framework offers guidance on how to carry out these steps for each of the three types of evaluation discussed above.

## Process Evaluation

Well thought out and executed processes lead to more fruitful outcomes in a project. Additionally, in evaluating a project, solely focusing on outcomes does not provide a holistic view of the project. In particular, through an examination of processes, evaluators can ascertain why project outcomes turned out as they did and determine how the project can be improved. This section of the PREval framework is designed to assist ICTD field researchers in planning and implementing a project process evaluation.

### *1. Identify Key Processes*

The first step in a process evaluation is to identify key activities[27]. For this evaluation, the objective is to execute these processes as intended. Specific processes may vary from project-to-project, but there are four main areas of activities that ICTD researchers can focus on: *preparatory work*, *on site research*, *technology development*, and *field research wrap up work*. Monitoring activities in these categories will help shape outcomes and also improve operations during the course of a project. Refer to the PREval Appendix A for some tips on how to conduct key activities.

#### *a) Preparatory Work*

This entails activities that ought to be carried out prior to commencing field research. Such processes will better prepare researchers for on site work and improve chances of achieving project goals. These tasks will also lay the groundwork for project evaluation.

- *Identify stakeholders*

  It is important to identify the different groups that need to invest time, resources and personnel into the project and understand each of their roles in the endeavor. Additionally, each stakeholder's expectations for the project should be determined to ensure they are in line with what researchers hope to accomplish through the project.

- *Establish a partnership with a local group or organization*

  Having a local partner who is recognized by the project's target community can be very beneficial in establishing trust and communicating with the local community, enabling researchers to successfully adapt to the field setting, and sustaining a project beyond the pilot stage. Therefore, it is important to take steps to identify and secure a local partner or partners who can collaborate with researchers in the field.

- *Conduct background research*

  Apart from conducting a standard literature review as is done for most studies, it is also vital to gain a better understanding of the target location and culture prior to commencing

[27] Note that we use the words 'process' and 'activity' interchangeably.

field research. Being educated about the local community will facilitate researchers' transition into the field and reduce the chances of offending participants of the study. This type of situational awareness is also necessary to provide context for planning the project evaluation.

- ***Logistics and legalities***
  With any field research there are logistics and paperwork that need to be managed. This includes making travel arrangements and complying with regulatory requirements (e.g. obtaining IRB approval for the work). These steps are necessary for field research to take place and require a significant amount of time, so monitoring progress on such endeavors can reduce the risk of encountering bottlenecks.
- ***Identify and form agreements with data sources***
  Data is an important element of any evaluation and in many ICTD projects obtaining sufficient reliable data can be challenging. When possible, researchers should identify and communicate with potential providers of data in advance, so as to increase the likelihood of obtaining credible information when in the field. For example, a school might agree to collect and share data on student performance in math class before, during and after the project.

*b) On Site Research*

While on site researchers need to execute certain key processes to understand the target audience and realities in the field, in order to create a location and user appropriate technology solution. Additionally, these tasks will provide valuable information for the overall project assessment. This includes the following activities:

- ***Obtaining participant consent***
  Participants are a critical component of studies involving output ultimately intended for human consumption. It is therefore good practice to ensure participants comprehend the exact nature of their role in the project and provide written consent. This can be particularly challenging when faced with cultural and language barriers. Moreover, research with human subjects typically needs to be vetted by an authority such as an institutional review board, prior to commencing work. Thus, planning ahead is prudent.
- ***Needs assessment***
  Conducting needs assessment can offer a rich set of data about the target community that will provide context for the technology and overall study. This can facilitate the design of a solution that will be effective and sustainable.
- ***Observations***

It is vital to document what researchers observe in the field throughout the course of the time they are on site. These records can serve three purposes: (1) Help validate information received via the needs assessment, (2) Provide more insight into how things function on the ground, which may lead to follow up questions or clarifications, and (3) Offer clues as to how the technology intervention may have altered user behavior.

*c) Technology Development*

This phase of the project will revolve around the actual design, construction, or modification of the technology output. It is a critical step in an ICTD project since the technology is a major output of ICTD work and subsequently affects project outcomes in a significant way. At this stage, the main activities to monitor will include the following:

- ***Technology design***

  When designing the technology it is important to assess whether community needs can be addressed by the technology and whether the envisioned product is realistic given the available time and resources.
- ***Iterative development of technology***

  Developing the technology in stages allows for continually improving the project output to better suit its intended user. During this process it is useful to evaluate whether the target community's input is solicited on each prototype and user input is incorporated while developing the technology.

*d) Field Research Wrap Up Work*

Just as it is important to complete preparatory work before entering the field, it is also useful to prepare for departing the field. There may be valuable opportunities for post-pilot data collection and long-term assessment of the technology solution that researchers could take advantage of, if considered in advance. During this final stage of the project, a major objective is to set up processes that will help assess the potential for sustaining and scaling the intervention beyond the scope of a pilot study. Tasks at this phase include:

- ***Post-Pilot Monitoring***

  Develop a plan to monitor progress post-pilot study, which includes a communication as well as a data collection plan.
- ***Technology Integration***

  Work with the local community to design a method to integrate use of the technology into users' typical activities. For example, if it is an educational tool, the technology can be used once a week during class time.
- ***Technology Maintenance***

Look into ways to maintain the technology after researchers leave the field.

## 2. *Assign Process Indicators & Targets*

Once key processes have been identified mechanisms need to be put in place to ascertain whether (1) these processes are being or have been carried out, and/or (2) these activities are being or have been executed as planned. Process indicators are measures employed to answer these two main questions regarding project activities. We incorporate the two categories of process indicators introduced by the RAND Corporation:

(a) 'Single-event measures' that record the completion of key project activities (e.g. completing background research on the project location). These will take the form of checking off an item on a checklist, and

(b) "Longitudinal measures that can be evaluated on a periodic basis to track program trends over time"[28] (e.g. number of site visits per week).

Along with these indicators, there need to be corresponding targets to achieve during the course of a project. See Table C1 for some examples.

**Table C1:** Key processes and examples of associated indicators and targets

| Process Category | Activity | Indicators | Target |
|---|---|---|---|
| Preparatory Work | Identify stakeholders | Checklist of tasks to complete including, for example: Create list of stakeholders and Solicit stakeholder expectations for project. | Complete checklist three weeks prior to commencing field work |
| Preparatory Work | Establish a partnership with a local group or organization | Checklist of tasks to complete including, for example: Research potential partners, Communicate project details with chosen partner and Form agreements with local Partner. | Complete checklist two months prior to researchers' departure into the field |
| Preparatory Work | Conduct background research | Checklist of tasks to complete including, for example: Conduct a literature review and Ascertain technology infrastructure on site. | Complete checklist one month prior to commencing field work |

[28] Farley, D., Chinman, M., D'Amico, E., Dausey, D., Engberg, J., Hunter, S., Shugarman, L., Sorbero, M., Evaluation of the Arkansas Tobacco Settlement Program: Progress from Program Inception to 2004, RAND Corporation, 2004.

| | | | |
|---|---|---|---|
| Preparatory Work | Logistics and legalities | Checklist of tasks to complete including, for example: Buy airline tickets and Obtain visas or travel permits. | Complete checklist two weeks prior to researchers' departure into the field |
| Preparatory Work | Identify and form agreements with data sources | Checklist of tasks to complete including, for example: Identify potential sources of data on metrics, Device a plan for data collection and Communicate with data providers. | Complete checklist one month prior to commencing field work |
| On Site Research | Obtaining participant consent | Proportion of people who provide written consent out of those who show interest in participating in project | 100% |
| On Site Research | Needs assessment | Questionnaire completion rate | 80% |
| On Site Research | Observations | Number of site visits conducted per week of field work | One |
| Technology Development | Technology design | Checklist of criteria including: Design addresses at least one identified community need, Technology can be developed during the timeframe of project | At least 90% of criteria met by technology design |
| Technology Development | Iterative development of technology | Percentage of participants (potential users) who provided feedback on prototype technology | 60% |
| Field Research Wrap Up Work | Post-Pilot Monitoring | Checklist of tasks to complete including, for example: Develop a plan for communicating with users post-pilot and Agree on type of data to be collected post-pilot. | Complete checklist by last week of field work |
| Field Research Wrap Up Work | Technology Integration | Checklist of tasks to complete including, for example: Test use of technology during a regular community activity and Identify potential challenges to integrating technology use. | Complete checklist one week before wrapping up field work |
| Field Research Wrap Up Work | Technology Maintenance | Checklist of tasks to complete including, for example: Create list of local technical support experts and Design a user manual to provide guidance on technology set up and use. | Complete checklist by last week of field work |

### *3. Collect & Analyze Process Data and Make Necessary Modifications*

Once activities and indicators are identified, a plan for data collection and analysis should be established. In general, if people responsible for conducting a specific activity are also given the task of documenting their progress and analyzing the data, this would provide immediate feedback to field researchers if the process got off track. Therefore, once researchers have laid out the different activities and associated process indicators and targets, they should also consider at what point(s) and how they will be collecting and analyzing data.

Since process evaluations can help improve a project as it is ongoing, analyzing process data at different stages of a project will be necessary if modifications or improvements are to be made during the course of that project. Checking the status of various processes on at least a weekly basis will be prudent, especially during the beginning stages of a project. An analysis of process evaluation data can be as simple as examining how actual data compares to what was expected. For example, researchers can examine whether targets for process indicators were met and if not investigate reasons as to why. This will facilitate efficient decision making on how to improve a project as it develops. Based on findings from process data analyses, researchers need to decide whether and how processes or the way in which they are carried out can be modified to better meet targets, or whether to set more realistic targets.

## Technology (Output) Assessment

Technology output can be divided into two broad categories: hardware and software. Hardware can be defined as the physical technology output such as equipment, machines and devices (e.g. a computer); whereas, software takes the form of executables or programs that encode a sequence of commands to operate hardware in a desired manner (e.g. Microsoft Windows). Typically, ICTD projects produce technology systems that include both hardware and software components, which work together to produce a desired result. Since technology is a key product of ICTD projects, it is important to understand whether it is performing well enough to accomplish the overall goals of the project. This chapter outlines a set of considerations to be made for technology assessment in ICTD projects, and proposes criteria and metrics that could be used for this endeavor.

### *1. Technology Assessment Criteria*

Below are seven major of assessment criteria for technology innovations.[29] The objective here is to create technology output that performs satisfactorily based on the given criteria. While each criterion is valuable, the ranking of importance should vary based on the type of project, audience and location involved.

viii. Functionality – Does it work well?
This includes determining whether both hardware and software properly execute intended tasks, as well as how they carry out target operations.

ix. Reliability – Does it work every time you use it?
This helps determine the consistency in function and typically entails calculating error or failure rates of the technology.

x. Usability – Is it user friendly, particularly for novice users?
This is an important assessment criterion since it provides insight as to whether users find the technology accessible and comprehensible. If not, the technology will most likely be left idle.

xi. Suitability – Is it a good fit for the given context and locality?
This measure will gauge how well the technology suits the intended audience and their environment. For example, a computer based program that uses visual cues will not be applicable to a community of visually impaired students.

xii. Robustness – Can it operate in the required environment under prevalent conditions?

[29] Fenton, N.E. and Pfleeger, S.L., Software Metrics: A Rigorous & Practical Approach, 2nd edition, PWS, 1998.

This is a measure of how well the technology can function within the given setting or environment where conditions maybe volatile and hostile. For example, hardware might be dropped and software might be subject to viruses.

xiii. Maintainability – Can it be easily maintained?

This is another important criterion for sustaining the technology solution. If the technology is very complicated or difficult to maintain using local or remotely available expertise, the project is not likely to sustain itself post-pilot project.

xiv. Cost – How much does it cost to build, use and maintain?

Cost is a significant barrier to deploying technology in developing communities. Thus, keeping track of costs associated with the technology solution will be valuable when assessing whether it can be made affordable to the community of end users.

## 2. *Metrics for Technology Assessment*

Table C2 lists factors that should be considered when assessing ICTD technology innovations. Note however, that these metrics may need to be modified for different projects, depending on the actual technology itself and conditions in the field. Additionally, some assessment criteria might be beyond the scope of a given pilot study due to any time or resource constraints.

**Table C2:** Potential metrics associated with assessment criteria for technology output

| **I. Functionality** | | |
|---|---|---|
| **Metrics** | **Applicable Technology** | **Details** |
| Set up time | Hardware | This will provide some idea of how difficult a task it is to set up the technology. It will be useful to time researchers as well as end users within the community, as they set up the hardware. |
| Time to power on or start | Hardware and Software | Understand whether the technology works right away or takes a long time to power on and start working. For software, installation time should also be considered. |
| Power source options | Hardware | List of options available to power hardware (e.g. grid, batteries, solar power, etc.). |
| Power usage | Hardware | The amount of power utilized in order for the hardware to function. |
| Performance level | Hardware and Software | Proportion of functions actually performed, relative to expected performance level. |
| Battery quality | Hardware | Battery life and time require to fully charge. |

| | | |
|---|---|---|
| Output quality | Hardware and Software | Quality of sound, picture, etc. |
| Working/Processing speed | Hardware and Software | Determine whether technology is slow or fast in terms of executing tasks. Can compare to similar devices or researcher objectives for speed of operation. Also, can determine whether tasks are completed more efficiently with the technology than without (if applicable). |
| Technical specifications | Hardware | These are physical characteristics (e.g. weight, size, number of megapixels, etc.) that can be used to gauge how that technology compares to other commercially available hardware, in terms of functionality. Also, some specifications might be requested by users or necessary for the given context (e.g. device needs to weigh less than 2lbs). |
| **II. Reliability** | | |
| **Metrics** | **Applicable Technology** | **Details** |
| Failure/Error rate | Hardware and Software | Number failures/errors experienced during a specified period of time or number of sessions. Also gauge severity of problems and difficulty in resolving them. |
| Mean time to failure | Hardware and Software | Average time between failures or errors. |
| Up time | Hardware and Software | Time required to repair or rectify a problem so as to make the technology available for use once again. |
| Error density | Software | Coding errors per line of code. |
| **III. Usability** | | |
| **Metrics** | **Applicable Technology** | **Details** |
| User complaints | Hardware and Software | Range of user complaints, regarding difficulty of use. |
| Learning time | Hardware and Software | Average time required for users to learn how to use technology. |
| Mastery rate | Hardware and Software | Proportion of users who achieved mastery of the technology. |
| Comprehension failure rate | Hardware and Software | Percentage of users who failed to understand how to use the technology. |

| | | |
|---|---|---|
| Resource access | Hardware and Software | Availability and accessibility of a "Help" system or user manual. |
| **IV. Suitability** | | |
| **Metrics** | **Applicable Technology** | **Details** |
| User interface comprehension rate | Software | Percentage of users who understood how to maneuver through the user interface, in terms of language used and any pictorial, audio or video instructions provided. |
| Infrastructure fit | Hardware | Available vs. required technical infrastructure to operate technology. |
| Technology applications | Hardware and Software | List of potential applications of technology within the given user community (e.g. use device to administer homework and exams to students, and also use as a practice tool for students - i.e. three possible applications). |
| Suitability rating | Hardware and Software | User rating of technology in terms of its suitability for the given user population, location and context. |
| Content rating | Hardware and Software | User rating of technology content. For example, ask users whether content is repetitive or redundant, dynamic, suitable, challenging enough etc. Also consider whether content can be easily modified based on user needs - this will improve sustainability of content. |
| **V. Robustness** | | |
| **Metrics** | **Applicable Technology** | **Details** |
| Material strength | Hardware | Fragility of material used to build hardware. This will provide some insight as to whether the device will break from a fall, for example. However, if the device is commercial (e.g. a computer) there should already be some knowledge of its physical weaknesses. |
| Failures in the field | Hardware | Number and type of failures experienced while operating in local environment, due to dust, humidity or other environmental factors. Determine whether these failures can be avoided through design changes. |
| Corruptibility | Software | Potential ways in which software may be corrupted over a given period of time (e.g. from viruses). |
| Vulnerability to damaging user manipulation | Hardware and Software | Ease with which users can alter components, such that the technology is rendered dysfunctional. Can gauge the vulnerability of software or hardware by hypothesizing a list of ways technology can be altered by the user such that operation is halted. For software, can also |

| | | |
|---|---|---|
| | | determine percentage of a sample of users who are able to access administrative elements. |
| Backup availability | Software | Determine whether backup software is available and accessible to users and researchers in the event of file corruption or the like. |
| Hazardousness | Hardware | Presence of long wires, sharp edges and other potentially hazardous or accident prone aspects of hardware. |
| Portability | Hardware and Software | In the case of software - number of other devices that the software can operate on and are available to users (i.e. is the software compatible with multiple platforms?). In case of hardware - ease with which device can be moved, if necessary; can rate this based on weight, fragility and other physical factors. |
| **VI. Maintainability** | | |
| **Metrics** | **Applicable Technology** | **Details** |
| Monthly checks | Hardware and Software | Anticipated number of monthly checks or modifications for hardware and software, in order to maintain operations. Gauge whether this is feasible. |
| Potential problem ratings | Hardware and Software | Difficulty level of resolving common or potential issues that may occur with the technology. Base this on technology expert opinions. For example, if problems can be resolved remotely they ought to be of a low rating. Should track number of technical issues resolved via remote vs. in-person consultation. |
| Local technical support | Hardware and Software | List of available local resources for technical assistance. Should take into account distance of technical experts from user community as well as ease or difficulty of accessing these local experts (i.e. available transportation and communication options). |
| Remote technical support | Hardware and Software | Remote access to technical experts for assistance. Should take into account ease or difficulty of accessing these technical experts (e.g. available and affordable communication options, speed of response, etc.). |
| Local technical expertise | Hardware and Software | Expertise level of local technical assistance relative to what is needed to maintain the hardware and software. Should interview/converse with local experts to gauge skill and experience level. |
| Problem solving resources | Hardware and Software | Existence of available resources in the form of documentation, manuals or contact person that users can consult in case of problems with the technology. |
| Backup and spare part access | Hardware and Software | Proportion of software backup files and hardware spare parts available locally. |

| | | |
|---|---|---|
| Adaptability | Hardware and Software | Availability of options for growing or improving on current design of technology such that it can continue to be applicable to the given community/context. |
| Environmental sustainability | Hardware | Expected impact on environment: e.g. regular disposal of material (particularly hazardous batteries) and any potential for environmental pollution during technology use (example air pollution from diesel generators). |
| **VII. Cost** | | |
| **Metrics** | **Applicable Technology** | **Details** |
| Product/Component cost | Hardware | Cost of hardware material or entire (assembled) product. |
| Maintenance cost | Hardware and Software | Anticipated maintenance costs per month for hardware and software. |
| Development labor cost | Hardware and Software | Labor costs involved in developing software or hardware. |
| Backup cost | Software | Cost to purchase software in the event of file corruption or the like. |
| Power cost | Hardware | Cost of power required to operate hardware. |
| Repair cost | Hardware | Potential cost to fix faulty or defective components of hardware. |

## 3. *Technology Data Collection and Analysis*

The data collection for technology assessment is relatively straightforward. Researchers need to test the technology with users and in prevailing conditions in the field, and investigate estimates for cost and values/status of other metrics. Once metrics are established, actual performance of the given technology can be compared to researchers' expected measures or standards in the field, if available. This analysis can provide insight into features that work well in the field, and aspects of the technology that need to be improved either during the pilot study or as future work.

## Outcome Evaluation

An outcome evaluation is designed to determine whether a project performed according to expectations by achieving targeted results. This type of assessment is widely conducted and has been thoroughly studied. Therefore, there are many different approaches available when executing an outcome assessment. We do not attempt to provide an exhaustive guide on all those existing methods. Rather, this section outlines major components of an outcome evaluation, and offers suggestions on how to apply commonly used techniques in the field. Refer to PREval Appendix F for external resources on different methods used in outcome evaluations.

### *1. Setting Project Goals*

Setting goals or objectives for a project is a critical first step in planning an evaluation since the project will be assessed based on whether or not it accomplishes those goals. To assist in setting project goals researchers can refer to the SMART criteria, which advocates for Specific, Measurable, Achievable, Relevant and Time-based objectives[30,31] (see Figure C2 for examples). Key points to keep in mind are:

- Consider the resources and time available for the project and set realistic goals accordingly.
- Avoid setting objectives that are vague or so broad that they leave room for various interpretations; try to be as explicit as possible in describing what you hope to accomplish through the project.
- Ensure that there is a mechanism, by way of a metric, for verifying whether or not each goal was achieved.
- When setting objectives consider what can be achieved in the short term vs. the long term (or mid term). This will set realistic milestones for the project and facilitate the evaluation.

× *Improve English literacy in the developing world* – Too broad and unrealistic for a pilot study.
× *Empower women in a rural Tanzanian village* – Although this is narrow in scope, it is too vague to be able to measure in any practical way.
✓ *Reduce absenteeism rates by 25% in the next six months for grade 2 students in a given primary school in Sri Lanka* – A well defined goal.

**Figure C2:** Example project objectives

[30] Alexander, M. Management Planning for Nature Conservation: A Theoretical Basis & Practical Guide, 1st edition, Springer-Verlag New York, LLC, December 2007.
[31] Wikipedia: http://en.wikipedia.org/wiki/SMART_criteria

## 2. *Metrics Selection*

Metrics are measures used to help ascertain the extent to which project objectives are achieved. Below are two considerations that can aid the process of deciding on metrics to employ in an outcome evaluation:

a) *Match each project objective (expected outcome) with at least one metric*
   Once a list of objectives has been compiled, researchers need to think about how those outcomes can be assessed. It is vital to ensure that each objective can be captured by at least one metric so that there is a method for measuring progress on all project outcomes.
b) *Think of metrics in terms of numerators and denominators*
   To capture effects of the technology intervention, it is often useful to think of metrics in terms of numerators and denominators. This would show a statistic relative to a base value and allow for facilitated interpretation of an effect's magnitude and/or existence.

## 3. *Data Collection*

Once metrics are identified, the next step is to determine how data on these metrics will be collected. Collecting a mix of both quantitative and qualitative data is generally necessary to evaluate all objectives.

Below are different techniques available for data collection.[32]

i. *Surveys*: A set of predetermined questions that typically require short answers. Can be used to collect quantitative and qualitative data
ii. *Interviews*: Technique used to elicit in-depth information from participants. Primarily results in qualitative data.
iii. *Focus groups*: Allows for obtaining a variety of opinions from a representative group of participants in one setting. Primarily results in qualitative data.
iv. *Observations*: Primarily results in qualitative data.
v. *Tests*: A commonly used approach for collecting quantitative data for statistical analysis. Includes methods such as pre- and post- testing. Alternatively, existing data may be used as a baseline for comparison with test results after a given intervention.
vi. *Document studies*: Involve an examination of project records or any written documents. Primarily results in qualitative data.

[32] Joy Frechtling (Westat), The 2002 User Friendly Handbook for Project Evaluation, The National Science Foundation, January 2002: http://www.nsf.gov/pubs/2002/nsf02057/nsf02057.pdf

vii. *Key informant*: This entails finding a trustworthy source within the target community who can provide context and details about participants and the research location. Primarily results in qualitative data.

viii. *Case studies*: Involves conducting a descriptive study of different locations or settings in which the project or program is ongoing. Primarily results in qualitative data.

Data collected can be broadly classified as quantitative and qualitative. Quantitative data generally refers to numeric information (e.g. test scores, weight, salary, etc.), which is deemed objective. Alternatively, qualitative data is thought to be subjective and in general comprises of text-heavy information resulting from surveys and interviews for example. However, there are types of qualitative data that can be assigned a numerical value – e.g. asking people to rate their opinion based on a Likert scale, coding categories of responses with a corresponding number, etc. Therefore, there can be crossover between these two general categories of data. Figure C3 depicts some commonly encountered types of data including:

- Linear data (quantitative) – *e.g.* test scores or absentee rates
- Time-to-event data (quantitative) – *e.g.* time to graduate or number of months to find a job
- Count data (quantitative or qualitative) – *e.g.* number of students who passed their English test in a given month or number of times interviewees mention a particular key word
- Categorical data (quantitative or qualitative) – e.g. number of data points or observations categorized by gender or socio-economic background
- Text data (qualitative) – *e.g.* interview transcripts or reports on observations

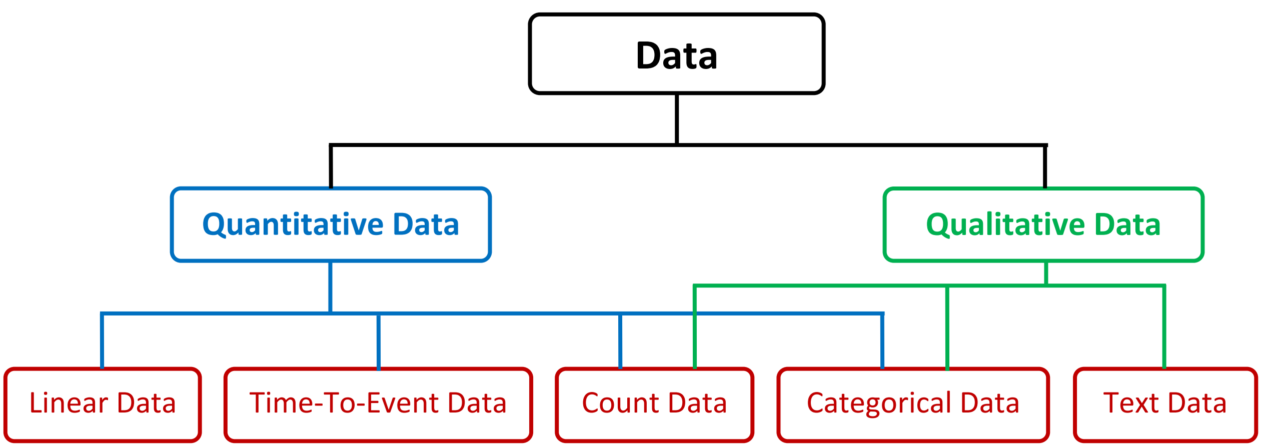


**Figure C3:** Commonly used classifications for quantitative and qualitative data

## *4. Data Analysis*

The type of analyses conducted will depend heavily on the kind of data collected. Just as there are many different types of data, there are also a plethora of methods available to analyze information. Statistical analysis of quantitative data is generally held at a high standard in many areas of study. However, in ICTD field research such methods are not always practical, and not necessarily the best approach. Qualitative data analysis can produce extremely insightful judgments of project outcomes, and can also be useful in interpreting quantitative results, and therefore should not be discounted.

The following algorithm provides some commonly used options for analyzing the different types of data given in Figure C3.

**Step 1: Univariate Analysis**

Univariate implies studying one variable individually. This kind of analysis will allow researchers to determine whether the assumptions necessary to conduct further analyses are satisfied or not. For example, by examining the distribution of outcome data, researchers can establish whether it is normally distributed and thus would qualify for a t-test. Additionally, univariate analyses can provide a better understanding of participant demographics (age, gender, socio-economic status, etc.). So, researchers will be able to determine whether their sample population is representative of the larger population targeted by the study.

- ➔ If linear data, then
  - o Calculate descriptive statistics (mean, median, standard deviation, etc.)
- ➔ If time-to-event data, then
  - o Calculate average, standard deviation, median, maximum and minimum
- ➔ If count data, then
  - o Calculate average, standard deviation, median, maximum and minimum
- ➔ If categorical data, then
  - o Calculate frequencies with which each category occurs

**Step 2: Bivariate Analysis**

The next step is to investigate relationships between two variables – typically between the outcome variable and a hypothesized predictor variable. This will provide researchers with an understanding of how different factors may independently influence an outcome.

- ➔ If linear data, then possible analyses include:
  - o Correlation analysis
  - o T-tests

  - Median and quantile regression – understand how median and other quantiles (10th, 25th, 75th percentile, etc.) of outcome variable are affected by predictor variables. This analysis is robust to outliers.
- ➔ If time-to-event data, then possible analyses include:
  - Kaplan-Meier Survival curve – can be used to determine how long a person is likely to stay in a particular state (e.g. how long students stay in school without dropping out, after 1 year of technology intervention).
  - Log-Rank test
- ➔ If count data, then possible analyses include:
  - Bivariate Poisson regression
- ➔ If categorical data, then possible analyses include:
  - Chi-Squared test to determine whether outcome is independent of categorical variables

**Step 3: Multivariate Analysis**

Although bivariate analyses can provide clues as to how different predictor variables affect the outcome, it is important to understand whether this observed effect is influenced by factors other than the hypothesized predictor variable. To account for any confounding effects, conducting multivariate analyses can be very useful since they enable researchers to better isolate the effect of a particular predictor on the given outcome.

- ➔ If linear data, then conduct:
  - Multiple regression analysis
  - ANOVA (Analysis of Variance)
  - Median and quantile multiple regression
- ➔ If time-to-event data, then use:
  - Cox proportional hazards model
- ➔ If count data, then conduct:
  - Multi-variable Poisson regression
- ➔ If categorical data, then conduct:
  - Logistic regression
  - Probit analysis

**Step 4: Analyzing Text Data**

With text data, it is important to organize results such that documents are searchable for key words and are catalogued according to type of interviewee or data collection method. This organization will facilitate analysis, particularly when contending with a large volume of information or documents. Text-heavy data is often disregarded as subjective or biased.

However, there can be great value in this information because it generally reflects the opinions or sentiments and behavior of a target population. This type of understanding of the human element of a project should not be discounted, especially in ICTD work, since ultimately, the end user will determine whether the technology solution is used and perhaps bears fruit, or is left idle and rendered useless. Therefore, there is a trend in the evaluation field toward utilizing both objective and subjective information when analyzing project findings.

To decipher text-data, a researcher can pose and attempt to answer the following questions:

- ➔ Are there common themes or key words within the data?
- ➔ How many times are certain words and themes encountered?
- ➔ How frequently do certain words and themes occur? (*e.g.* during every interview, on average once every 5 lines of text data, etc.)
- ➔ What are the most common answers to different questions?
- ➔ If, pre- and post- intervention data are available:
    - o Is there a significant change in the frequency with which certain key words or themes are encountered (proportions tests)?
    - o Is there a significant change in the average number of times different words and themes are encountered?
- ➔ What outcomes are associated with intervention according to interview transcripts?
- ➔ What are commonly cited outcomes associated with intervention?
- ➔ What percentage of sample population believe the intervention was effective?

Researchers may also utilize the software atlast.ti,[33] and tools such as q-sorting (to examine opinions and attitudes)[34] and Boolean analysis[35] (to detect relationships between questions on a survey, for example).

**Step 5: Interpretation of Findings**

This is perhaps the most important step in analysis. The following questions are useful to consider during the interpretation step in analysis:

- ➔ Did hypothesized results materialize?
    - o Were they statistically significant?

[33] "Atlas.ti: Qualitative Data Analysis." ATLAS.ti Scientific Software Development GmbH. http://www.atlasti.com/
[34] Thomas, D. and Watson, R. Q-sorting and MIS Research: A Primer. Communications of the Association for Information Systems, Volume 8, pp. 141-156, 2002. http://www.terry.uga.edu/~dominict/Thomas%20and%20Watson%20CAIS%202001.pdf
[35] "Boolean analysis." Wikipedia: The Free Encyclopedia. http://en.wikipedia.org/wiki/Boolean_analysis

- ➔ Did quantitative findings agree with reports from participants and other qualitative/subjective findings?
- ➔ Were there surprise/unintended outcomes as a result of the intervention?
- ➔ What were the outliers in the collected data? How can these outliers be explained?

## 5. Outcome Logic Model

Components of an outcome evaluation can be mapped out by employing an outcome logic model similar to that presented in Figure C4. Such logic models are used to ensure that there is logical reasoning behind steps taken in an evaluation. The elements of the presented outcome logic model are: Identified Needs, Project Output, Outcomes and Metrics. First, community *Needs* are identified through the needs assessment process and those needs are met via *Output or Technology* that is developed for the project. Implementing this technology solution results in *Outcomes*, which are represented in the logic model by project objectives that researchers expect to accomplish through application of the technology. It is useful to break them out into short versus mid-to-long term outcomes. Finally, outcomes can be assessed by collecting data on *Metrics*.

| Identified Needs | Project Output (Technology) | Outcomes | Metrics |
|---|---|---|---|
| • Need for more teaching aids<br>• Need for improved English education<br>• Need for more motivating factors to encourage students to learn English | • Computer game that helps students practice English grammar & vocabulary | • Short-term:<br>  • Improved student motivation<br>  • Technology adoption and acceptance by school<br>• Mid-to-long term:<br>  • Improved student English grammar<br>  • Increased English vocabulary among students | • Short-term:<br>  • Observed behavior changes<br>  • % of students and teachers who reported changes in student motivation post-intervention<br>  • proportion of school time spent using the technology; per day and per week<br>• Mid-to-long term:<br>  • Changes in student English grammar test scores<br>  • Changes in student English vocabulary test scores |

**Figure C4:** Sample Outcome Logic Model

## Reporting Project Results to Decision Makers

Typically, ICTD program directors and other decision makers will want to answer four major questions about a pilot project, before proceeding further with the work:

I. Is the technology useful or effective?
II. Will the target audience use the technology?
III. Can the technology be integrated and sustained within the pilot community?
IV. Should the project be scaled up, abandoned, or modified and re-launched?

Results of an ICTD pilot project evaluation should assist managers in answering these questions by reporting findings in a format that directly addresses these specific questions. The PREval framework provides a template for creating such a summary report.

## Summary Report Template

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# [Insert Project Name] Project Evaluation Findings: *Summary Report*

### Background

[Provide a summary of the project idea, field study location, target user(s) and the proposed technology.]

### Project Goals

[Describe the main goals of the project.]

### Process Evaluation Findings

[Summarize results of the process evaluation conducted for this project. Highlight any process changes made during the course of the project, processes that were executed well, and those activities that were not successfully carried out; including reasons (if known) for these findings. Listing findings in bullet-point form should be suitable here. Results can be organized based on the following categories of key processes.]

*a) Preparatory Work*

[Comment on assessment of activities conducted as preparation for the field work; e.g. conducting background research and establishing partnerships with local contacts.]

*b) On Site Research*

[Summarize evaluation of activities conducted once in the field; particularly focusing on the needs assessment and observation processes.]

*c) Technology Development*

[Comment on assessment of activities related to the technology development for the project; in particular, describe how well user input was incorporated into the technology design.]

*d) Project Sustainability Management*

[Summarize evaluation of activities directed towards enabling project sustainability. Specifically, describe steps taken for this endeavor and an assessment of whether these measures have been effective thus far.]

## Technology Assessment Findings

[Comment on the following topics based on findings regarding the technology innovation employed for this project.]

**Technology Name:**

[Provide the name given to technology involved in the project, if any. This will help when referring to the technology in further communications.]

**Technology Type:**

[Describe the technology in terms of whether it is software, hardware or a system involving both hardware and software.]

**Technology Purpose:**

[Summarize the main purpose(s) of the technology within the context of this project.]

**Technology Design:**

[Describe the design of the technology and its functions.]

**Technology Assessment:**

[Summarize results from the technology assessment conducted for this project, based on the following assessment criteria, in order of importance or pertinence for the given project.]

*I. Functionality*

[Summarize technology specifications and findings on how well the technology functions.]

*II. Reliability*

[Summarize findings on how consistently the technology functioned over the study period and during follow up checks, if any.]

*III. Usability*

[Summarize findings on how accessible the technology was to the user.]

*IV. Suitability*

[Summarize findings on how suitable the technology was to the given user community, project location and context.]

*V. Robustness*

[Summarize findings on how well the technology adapted to field work location dynamics and challenges.]

*VI. Maintainability*

[Summarize analysis of how easy or difficult it could be to maintain the technology in the long run within the given location.]

*VII. Cost*

[Summarize cost data related to the technology product itself, and its development, use and maintenance; juxtapose with estimates on what would be affordable to the target user(s). Also, include data on cost of practice that the technology was designed to replace or improve.]

## Outcome Evaluation Findings

[Summarize results of the outcome evaluation conducted for this project, focusing on the following topics. Note, that this section is dedicated to commenting on outcomes affecting the target community. However, if the audience for this summary report is interested in researcher outcomes (for example), or other outcomes of the project, include sections summarizing those results as well.]

### Evaluation Design

[Describe how this evaluation was designed, including information on how participants were selected and assigned, data collection techniques used, and field tests conducted, if any.]

### Quantitative Findings

[Provide a summary of quantitative findings, such as pre and post test scores. Also, describe the type of data analysis conducted using this data and the interpretation of those results.]

### Qualitative Findings

[Provide a summary of qualitative findings, such as user feedback. Also, describe how this information was analyzed and interpreted.]

## Conclusions

*Key Findings*

[Provide answers to the following key questions about the pilot study. If a question is unanswerable with available data, provide reasons as to why and avenues for how to find an answer or reach a conclusion about that question.]

1) **Will the target users actually use the technology?**
2) **Is there the necessary technical infrastructure to house and maintain the technology?**
3) **Does the technology effectively improve conditions in the given community?**
4) **Can user data and feedback be collected remotely from the field?**

5) **Were there any unique factors that contributed to the success and/or failure of any or all components of this pilot project?**

*Recommendations*

[Provide recommendations for how to continue this work, based on pilot project results as well as researchers' experiences in the field. In particular, comment on how the technology can be improved to be more effective and propose the next step for this project. Use the following sections and questions as a guide.]

**Technology Modifications**

*What modifications, if any, could improve the design and effectiveness of the technology?*

**Project Continuation**

*What should the next phase of this research endeavor entail, and why?*

a. Scale up
b. Gather more data/evidence prior to scaling up or down
c. Abandon the project

# PREval Appendix A: Tips on How to Conduct Key Activities

a) *Preparatory Work*

- *Identify stakeholders*
    1. Create a list of stakeholders and update it as more stakeholders are identified
    2. Contact stakeholders to ascertain their expectations of the project
    3. Work with program/project managers to reconcile any conflicts or significant disparities in expectations among different stakeholder groups
- *Establish a partnership with a local group or organization*
    1. Look into potential partners in the area – utilize media resources as well as recommendations and previous contacts in the area; a partner invested in community development or ICT work is most suitable
    2. Communicate project details with the chosen partner and solicit their feedback
    3. Form an agreement with the local partner, clearly outlining each party's role in the project
    4. Identify a key person within the local partner organization to be the main point of contact between researchers and the local partner
    5. Obtain information about the local community based on the experiences and expertise of the local partner
- *Conduct background research*
    1. Review literature and information on the target location and community.
    2. Gain an understanding of any prior ICTD efforts in that region. This will provide clues as to what steps are needed to successfully execute a pilot ICTD project in that location.
    3. Look into any other technology that is currently used within that locality, to gain insight into what type of technologies thrive in that community and also how local people respond to technology in general.
    4. Determine the target community's capacity to adopt technology. This involves gaining a better understanding of key aspects of the target community and environment, including the following:
        - Community access to computers, cell phones and other IT hardware
        - ICT infrastructure (e.g. cell phone coverage, Internet access, etc.).
        - Energy Infrastructure – determine what type of access is available to affordable power sources. For example, if power outages are frequent, generator or battery power may be used.
        - Locally available services for technical assistance and maintenance.

    - Environmental factors (e.g. temperature, humidity, dust, etc.), which may affect the function of technology.

- *Logistics and legalities*
  i. Make necessary travel arrangements, including obtaining any visas or other permits necessary to conduct research at the given location.
  ii. Comply with institutional level requirements; *e.g.* universities require their researchers to obtain Institutional Review Board (IRB) approval prior to beginning a study involving human subjects.
  iii. Look into any regulatory agencies in the project location and determine whether compliance documents are required by those institutions; *e.g.* some countries require special permission from a government board in order to work with public school students.
  iv. Vet site in order to approve it from a safety standpoint.
  v. Obtain immunizations, travel insurance and other health and safety necessities.
- *Identify and form agreements with data sources*
  i. List project outcome goals and associated metrics that can be used to measure progress towards achieving those goals
  ii. Think of possible sources who can provide data on those metrics
  iii. Contact data providers to determine whether they will be able to share or collect information for the project
  iv. Agree on some terms for the data collection process with these providers

*b) On Site Research*

- *Obtaining participant consent*
  i. Set aside time to discuss the project with the pool of potential participants.
  ii. Find out in advance whether an interpreter would be required and make arrangements accordingly. Someone within the participant group who knows the researchers' language and the local language would be an ideal interpreter.
  iii. If applicable, devise a method for recording consent from participants who are unable to write (e.g. illiterate or visually impaired participants). Consult with a local partner or the participants themselves on how this could be done. For example, blind participants typically stamp their fingerprint in lieu of a signature.
- *Needs assessment*
  i. Prepare interviews, questionnaires and/or focus group discussion material prior to site visits. Avoid questions that would solicit a simple yes/no answer, or ask participants to explain why they said yes or no.

ii. Try to interview/question two to three participants one-on-one, so as to identify any information that might be affected by group dynamics.
iii. Identify a key informant in the group of participants. This can be extremely valuable in gaining the group's trust and also in obtaining more detailed information about the user group from the perspective of an insider. However, verify information from your key source when possible to ensure s/he is credible.
iv. Listen carefully to participants and remember to always ask clarifying questions.
v. Take steps to make sure that participants do not feel intimidated when you ask them questions. For example, a formal setting may overwhelm some participants, in which case you could conduct interviews/focus group discussions in a more conversational manner.
vi. If audio or video recordings are permitted, utilize these tools to help transcribe findings. However, first ensure that participants are comfortable with the use of such devices.
vii. When conducting interviews, if recording devices are not acceptable, it is useful to assign two people to each interview so that one person can focus on note-taking while the other can focus more on conducting the interview. This eases the task of interviewers, improves the flow of the interview, and allows for a more accurate recording of findings.
viii. Once needs assessment results are compiled, obtain community feedback as to whether researchers' interpretation of findings is in line with their viewpoints.

- *Observations*
  i. Prior to introducing the technology intervention, observe participants to create a baseline profile of behavior and attitudes.
  ii. Post-technology intervention, record any changes detected since baseline observations were made.
  iii. Do not actively disrupt proceedings during observations.
  iv. Always carry a notepad during site visits to record any important observations.
  v. If permission is granted, video recordings might be useful in analyzing participant behavior and attitudes; although, keep in mind that video cameras can significantly alter behavior.

c) *Technology Development*

- *Technology design*
  i. Assemble a list of identified community needs.

ii. Brainstorm ideas on how any or all of these needs can be addressed via a technology solution.
iii. Determine whether an existing prototype, if available, is applicable in the given context and environment.
iv. Create a list of potential technology solutions, based on information from the field.
v. Contemplate a realistic timeline for development of a given design.
vi. Decide whether the given project's timeline is sufficient to develop the chosen technology design.
vii. Pick a solution that is feasible given the available time and resources; and/or determine a method for extending the project in order to develop a more involved technology design.

- *<u>Iterative development of technology</u>*
    i. Designate milestones for technology development and seek user feedback at each of those stages.
    ii. Consult with users on a regular basis (e.g. bi-weekly or every three weeks) to provide the community with a progress update and also obtain their input. This will help keep the end user actively involved in the project.
    iii. Be sure to regularly reevaluate development goals to ensure that they are realistic, given the project timeline and resources.
    iv. Manage community expectations of the technology by clarifying any misconceptions as they arise and continually reiterating the actual capability and function of the technology.
    v. Before meeting with users develop a list of types of modifications that can be realistically incorporated into the technology during the pilot phase. This will help guide the discussion with users.
    vi. Address all comments made by the community by providing an honest assessment as to whether that suggestion can be incorporated within the scope of the project.
    vii. Avoid making promises; limit discussions to what researchers hope to deliver on and be open about any obstacles that have arisen.
    viii. If possible, ask users to interact with the technology at each stage of development and record any significant observations made during those interactions.

*d) Field Research Wrap Up Work*

- *Post-Pilot Monitoring*

  Include the following in the plan to monitor progress post-pilot study:

  i. A communication plan – whereby researchers work with community members or local partners to decide on the mode and frequency of communication once researchers leave the field.
  ii. A data collection plan – to facilitate longer term assessment of outcomes resulting from use of the technology. For example, this can take the form of administering regular surveys, monitoring test scores at different intervals, and/or tracking usage levels post-pilot study.

- *Technology Integration*

  *i.* Brainstorm with local partner and community members on how the technology may be incorporated into their regular activities
  *ii.* Run trial sessions where the technology is used in different instances, if possible
  *iii.* Determine the best mode of use and plan to collect feedback on if and how the technology is used post-pilot study

- *Technology Maintenance*

  i. Identifying a local expert to provide technical support; also brief this expert on the technology so they are better equipped to assist users
  ii. Providing users with a method for contacting researchers when they experience technical problems or have questions about the technology
  iii. Developing a manual that users can refer to for questions on how to utilize the technology

**Table C3:** Process evaluation worksheet 1 – for activities that are monitored via checklists

| Process Evaluation Worksheet 1 | | | | | |
|---|---|---|---|---|---|
| **<u>Instructions:</u> Use this sheet to track whether key activities are being carried out and deadlines for these processes are being met. Also on this sheet, document any special circumstances or obstacles experienced while executing tasks as well as any modifications made to accommodate such situations. See explanations given in first row.** | | | | | |
| **<u>Checklist Monitoring Sheet</u>** | | | | | |
| **Activity** | **Checklist of Tasks to Complete** | **Expected Completion Date** | **Actual Completion Date** | **Field Researcher Notes** | **Task or Deadline Modifications** |
| Specify the key activity (*e.g. Logistics and legalities*) | List tasks needed to accomplish the given activity (*e.g. Buy airline tickets, Obtain visas or travel permits, Apply for IRB approval, and Obtain necessary immunizations*) | Assign a deadline for completing each specific task | Record the actual date by which a given task was completed | Document what researchers experienced during task execution (*e.g. Experienced delays in obtaining IRB approval due to changes in requirements*) | Record any changes made to the task or assigned deadline, due to experiences in the field (*e.g. Extended deadline for obtaining IRB approval by two weeks*) |
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**Table C4:** Process evaluation worksheet 2 – for activities with longitudinal indicators

# Process Evaluation Worksheet 2

**Instructions: Use this sheet to track progress made on key activities that are not single events. Also on this sheet, document any special circumstances or obstacles experienced while conducting processes as well as any modifications made to accommodate such situations. See explanations given in first row.**

## Longitudinal Process Indicator Monitoring Sheet

| Activity | Indicator | Expected Indicator Value/Status | Actual Indicator Value/Status | Expected Completion Date | Actual Completion Date | Field Researcher Notes | Process Modifications |
|---|---|---|---|---|---|---|---|
| Specify the key activity (*e.g. Needs assessment*) | Describe the process indicator designed to track progress on the given activity (*e.g. Percentage of participants who participated in needs assessment, of those who consented to take part in study*) | Set a target to achieve for the assigned indicator (*e.g. 80% of consented participants take part in needs assessment*) | Record the actual indicator value or status (*e.g. 60% of consented participants took part in needs assessment*) | Assign a deadline for completing each specific activity (*e.g. Complete needs assessment within two months of field research*) | Record the actual date by which a given activity was completed (*e.g. Needs assessment completed by week 6 of field research*) | Document what researchers experienced as they carried out the given activity (*e.g. Participants seemed reluctant to provide answers to questions during the needs assessment process*) | Record any changes made to the process, or assigned indicator or deadline, due to experiences in the field (*e.g. Initially hoped to obtain 100% participation for needs assessment, but given participant reluctance, changed target indicator value to 80%*) |
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## PREval Appendix C: Technology Assessment Worksheet

**Table C5:** Worksheet for technology assessment

<table>
<tr><th colspan="4">Technology (Output) Assessment Worksheet</th></tr>
<tr><td colspan="4"><u>Instructions:</u> In the section below, fill in details about the technology to provide some context for its assessment</td></tr>
<tr><td colspan="4"><u>Description of Technology</u></td></tr>
<tr><td>Name</td><td colspan="3">Indicate a name by which the technology can be addressed (e.g. Braille Writing Tutor)</td></tr>
<tr><td>Type</td><td colspan="3">State whether the technology is hardware, software or a combination of both</td></tr>
<tr><td>Purpose</td><td colspan="3">Describe what the technology is designed for (e.g. To assist visually impaired students in learning to write braille)</td></tr>
<tr><td>Target users and location</td><td colspan="3">Provide basic information about where the technology is intended to be applied and who will be using the tool (e.g. Visually impaired students at the School for the Blind in Colombo, Sri Lanka)</td></tr>
<tr><td colspan="4"><u>Instructions:</u> Use the section below to record how the technology performs based on the given assessment criteria and selected metrics. The assessment criteria and metrics listed are to serve as a guide; researchers may modify these based on the specific technology. In the second column assign a target or goal for the given metric and in the third column record the actual value/status of that metric. Use the last column to document any obstacles faced with the technology or important observations made by researchers regarding that specific metric (e.g. For the metric 'Set up time' researchers may want to note that the time it takes to set up is halved when the user becomes familiar with the process).</td></tr>
<tr><td colspan="4"><u>Assessment Criteria & Metrics</u></td></tr>
<tr><td colspan="4">I. Functionality</td></tr>
<tr><td>Metrics</td><td>Expected Metric Value/Status</td><td>Actual Metric Value/Status</td><td>Comments</td></tr>
<tr><td>Set up time</td><td></td><td></td><td></td></tr>
<tr><td>Time to power on or start</td><td></td><td></td><td></td></tr>
<tr><td>Power source options</td><td></td><td></td><td></td></tr>
<tr><td>Power usage</td><td></td><td></td><td></td></tr>
<tr><td>Performance level</td><td></td><td></td><td></td></tr>
<tr><td>Battery quality</td><td></td><td></td><td></td></tr>
</table>

| | | | |
|---|---|---|---|
| Output quality | | | |
| Working/Processing speed | | | |
| Technical specifications | | | |
| **II. Reliability** | | | |
| **Metrics** | **Expected Metric Value/Status** | **Actual Metric Value/Status** | **Comments** |
| Failure/Error rate | | | |
| Mean time to failure | | | |
| Up time | | | |
| Error density | | | |
| **III. Usability** | | | |
| **Metrics** | **Expected Metric Value/Status** | **Actual Metric Value/Status** | **Comments** |
| User complaints | | | |
| Learning time | | | |
| Mastery rate | | | |
| Comprehension failure rate | | | |
| Resource access | | | |
| **IV. Suitability** | | | |
| **Metrics** | **Expected Metric Value/Status** | **Actual Metric Value/Status** | **Comments** |
| User interface comprehension rate | | | |
| Infrastructure fit | | | |
| Technology applications | | | |
| Suitability rating | | | |
| Content rating | | | |
| **V. Robustness** | | | |
| **Metrics** | **Expected Metric Value/Status** | **Actual Metric Value/Status** | **Comments** |
| Material strength | | | |
| Failures in the field | | | |
| Corruptibility | | | |

| | | | |
|---|---|---|---|
| Vulnerability to damaging user manipulation | | | |
| Backup availability | | | |
| Hazardousness | | | |
| Portability | | | |
| **VI. Maintainability** | | | |
| **Metrics** | **Expected Metric Value/Status** | **Actual Metric Value/Status** | **Comments** |
| Monthly checks | | | |
| Potential problem ratings | | | |
| Local technical support | | | |
| Remote technical support | | | |
| Local technical expertise | | | |
| Problem solving resources | | | |
| Backup and spare part access | | | |
| Adaptability | | | |
| Environmental sustainability | | | |
| **VII. Cost** | | | |
| **Metrics** | **Expected Metric Value/Status** | **Actual Metric Value/Status** | **Comments** |
| Product/Component cost | | | |
| Maintenance cost | | | |
| Development labor cost | | | |
| Backup cost | | | |
| Power cost | | | |
| Repair cost | | | |

## PREval Appendix D: Additional Information on Common Practices in Outcome Data Collection and Analysis

### *Field Testing*

There are two conventional approaches to field test design: an experiment, which is widely accepted as the most scientifically rigorous approach, and a quasi-experiment, which requires less precision but is not as rigorous.

a. Experiments require the following elements:
    i. *Random assignment*: Where participants are randomly assigned to two groups, one of whom experiences the intervention (treatment group) and another that does not (control group).
    ii. *Pre-testing or using available prior data as a baseline measure*: This entails collecting outcome data on participants prior to the intervention, in order to establish baseline outcome levels.
    iii. *Post-testing*: After the intervention is implemented, outcome data for all participants is collected to compare to pre-intervention results.
    iv. *Statistical analysis*: Once data is collected, statistical methods can be utilized to measure the effect of the intervention.
b. Quasi-Experiments satisfy some but not all of the requirements for an experiment. For example a field test with the following criteria would be considered quasi-experimental:
    i. Non-random assignment
    ii. Pre-testing or using available prior data on outcome variable
    iii. Post-testing
    iv. Statistical analysis

Conducting an experiment is considered ideal because it is the most reliable way to associate outcomes to a particular intervention and minimize or eliminate the effect of biases. However, in field research controlling the environment enough to satisfy requirements of an experiment is not always possible. Therefore, most ICTD field tests tend to be quasi-experimental rather than experimental. However, outside of these approaches, researchers also have the option to conduct field testing by way of gathering constructive user feedback on the technology. While quantitative data is valuable, incorporating qualitative measures such as user viewpoints into the analysis can offer valuable information to help interpret the quantitative data.

### *Sample Selection*

In general there are two categories of sampling strategies:[36]

a. Probability sampling (e.g. simple or stratified random sampling), which involves randomly selecting participants from the population. This sampling method allows for generalization of results.
b. Non-Probability sampling (e.g. convenience sampling, heterogeneity sampling), which does not entail random selection. With this method results cannot be generalized.

When recruiting participants for an ICTD study, it is naïve to assume that everyone in the developing world will be enthusiastic about ICTD work in their community. Additionally, in smaller scale pilot studies (e.g. studies that focus on one school or one village) the number of participants needed for statistical significance may not be available due to the small population size. Often times the only plausible option is to select a convenience sample; that is, recruit those who are available.

### *Sample Size*

With larger samples, internal validity of findings is more robust and there are a greater number of appropriate statistical tests available. As the sample size increases so does the confidence that findings (significant or non-significant) are not a result of inadequate power. With smaller sample sizes it is more difficult to associate an effect with a specific intervention because of "noise" in the data. This leads to much greater statistical error and wider confidence intervals (i.e. less accuracy in findings). It is difficult to draw statistical inferences from samples sizes with an n smaller than 30. This is primarily because it has been noted that by the Central Limit Theorem, with a sample size of roughly 30 or higher, the sample mean approximates a normal distribution, regardless of the population distribution.[37] Refer to Cohen[38] for more guidance on this element of data collection and analysis.

The necessary sample size for a study will be determined based on the type of analysis to be conducted. For this calculation, the first steps are to estimate the variance of the measure, and decide on the probability of a type I error (i.e. $\alpha$, which is typically set at 0.05) and the power of the test (i.e. $1 - \beta$; 80% is usually the goal). In the case of testing difference in means, we would also want to know the means under the null and alternative hypotheses (or the expected

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[36] Research Methods Knowledge Base: http://www.socialresearchmethods.net/kb/sampprob.php
[37] Agresti, A. & Finlay, B., Statistical Methods for the Social Sciences, fourth edition, Prentice Hall Inc., 2009.
[38] Cohen, J., Statistical Power Analysis for the Behavioral Sciences, second edition, Routledge Academic, 1988.

difference in means). For example, when comparing two population means ($\mu_0$ and $\mu_1$) that have the same variance ($\sigma^2$), the formula for calculating the required sample size (n) for a two-tailed test is as follows:[39]

$$n = \frac{2\left(z_{1-\frac{\alpha}{2}} + z_{1-\beta}\right)^2}{\left(\frac{\mu_0 - \mu_1}{\sigma}\right)^2}$$

Note, z represents the z-score, and $z_\tau$ for example, would represent the z-score corresponding to an area $\tau$ under the Standard Normal curve. Similar formulae can be found for other types of analyses.39 Although these calculations can be useful, while in the field, researchers have to adapt to prevailing conditions and therefore may not be able to control sample size. However, having a target sample size in mind can aid the participant recruitment process.

### *Equivalent vs. Non-Equivalent Comparison Groups or No Comparison Group*

In order to successfully isolate a cause-and-effect relationship between a technology intervention and a given outcome, having access to equivalent comparison groups (control subjects) is required. The most rigorous method for selection of comparison groups is through random assignment, where subjects are randomly assigned to be in the control (not exposed to intervention) and treatment (exposed to intervention) groups. Groups ought to be equivalent in the sense that their background characteristics are similar enough to justify attributing changes in outcome to the intervention, rather than other factors. If random assignment is carried out correctly and the sample size is large, there would be no need to collect data on other variables that might also affect the outcome. Yet, even with random assignment there may be imbalances between the two groups such that there are, for example, disproportionately more weak students in one group than the other. Thus, checking for balance across certain criteria is important before testing so that control variables can be included in the analysis when necessary. In the event that random assignment is not possible, non-equivalent comparison groups are still useful, although in that case a multivariate analysis would be necessary to control for confounding variables that may also affect the measured outcome. If concurrent comparison groups are not available, past or secondary data from a similar group may be used as control data; for example, a previous class' scores on the same tests can serve as a control. On the other hand, if no comparison group is available then the selected analysis would have to

[39] van Belle, G., Statistical Rules of Thumb (Wiley Series in Probability and Statistics), Wiley-Interscience, 1st edition, March 22, 2002.

measure changes in participant outcomes within the single group by comparing scores before and after the intervention. This is an inferior design because it mixes the effect of the intervention with the learning that routinely occurs from other concurrent efforts.

### *Pre & Post vs. Post Testing Only*

Conducting a pre-test (or collecting pre-intervention data) allows researchers to gather baseline data, against which post intervention results can be assessed. Whether a comparison group is available or not, a pre test is extremely useful to understand the current or pre-intervention state of participants. When only a post test is possible (or only post-intervention data is available), attributing outcome effects to a specific intervention becomes almost impossible. In such an event one would have to compare post intervention results to comparable national averages or another standardized measurement that is available.

### *Accounting for Confounding Factors*

There may be outside factors or events that also influence measured outcomes of the project. Accounting for these confounders is important in summative analysis. For example, there might be some students whose life circumstances degraded drastically during the course of the project and as a result performed poorly on post-tests. Such an effect might be misconstrued as a failure on the part of the project, if not identified. Conducting interviews with participants is an effective method for understanding aspects in their lives that are not obvious but have a significant effect on project outcomes. Additionally, dividing the sample into strata (i.e. stratified sampling), based on important distinguishing factors can control for some confounding variables.

## PREval Appendix E: Outcome Evaluation Worksheet

**Table C6:** Worksheet to assist in carrying out an outcome evaluation

| Outcome Evaluation Worksheet | | | | |
|---|---|---|---|---|
| **<u>Instructions:</u> Use this sheet to map out basic elements needed in an outcome evaluation. See explanations given in first row.** | | | | |
| **Project Objectives** | **Metrics** | **Data Collection Technique** | **Method of Data Analysis** | **Comments** |
| List project objectives (*e.g. Significantly increase student English grammar within the next two years*). To assist in the evaluation, categorize these goals as short-term vs. mid-to-long-term. | Assign metrics to capture progress made towards achieving listed objectives (*e.g. Student scores on grammar questions included in English class tests*). | Describe how data on the given metrics will be collected (*e.g. Tests: record monthly student test scores pre-intervention and post-intervention*). | Based on the data, select methods for analyzing the information (*e.g. t-test: detect statistically significant changes in test scores after the implementation of technology*). | Document any special circumstances or obstacles experienced in the data collection and analysis processes, and comment on any modifications made to accommodate such situations (*e.g. For six months of the study the school needed to shut down so no test scores were obtained during those months; however, there was still sufficient data to perform a t-test analysis*). |
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# PREval Appendix F: External Resources

## *Supplementary Resources for Data Analysis Algorithm*

***Linear Data Analysis:***

Kleinbaum, D., Kupper, L., Muller, K., and Nizam, A., Applied Regression Analysis and Multivariable Methods, Duxbury Press, 3rd edition, September 15, 1997.
http://www.amazon.com/Applied-Regression-Analysis-Multivariable-Methods/dp/0534209106

***Time-To-Event Data Analysis:***

Kleinbaum, D. and Klein, M., Survival Analysis: A Self-Learning Text, Springer, 2nd edition, December 1, 2010.
http://www.amazon.com/Survival-Analysis-Self-Learning-Statistics-Biology/dp/1441920188/ref=sr_1_3?s=books&ie=UTF8&qid=1290916069&sr=1-3

***Count Data Analysis:***

Cameron, A. and Trivedi, P., Regression Analysis of Count Data, Cambridge University Press, 1st edition, October 15, 1998.
http://www.amazon.com/Regression-Analysis-Count-Colin-Cameron/dp/0521632013/ref=sr_1_1?s=books&ie=UTF8&qid=1290916695&sr=1-1

***Categorical Data Analysis:***

Agresti, A., Categorical Data Analysis, Wiley-Interscience, 2nd edition, July 22, 2002.
http://www.amazon.com/Categorical-Analysis-Wiley-Probability-Statistics/dp/0471360937/ref=sr_1_1?ie=UTF8&s=books&qid=1290916295&sr=1-1#

Kleinbaum, D. and Klein, M., Logistic Regression: A Self-Learning Text, Springer, 3rd edition, July 1, 2010.
http://www.amazon.com/Logistic-Regression-Self-Learning-Statistics-Biology/dp/1441917411/ref=sr_1_2?s=books&ie=UTF8&qid=1290916069&sr=1-2

### *Other Resources for Guidance on Project Evaluation*

The Norwegian Agency for Development Cooperation (NORAD). The Logical Framework Approach (LFA): Handbook for Objectives-Oriented Planning. 4th ed. 1999. http://www.ccop.or.th/ppm/document/home/LFA by NORAD Handbook.pdf

PASSIA Seminars. “Chapter 2: Monitoring and Evaluation as an Integral Component of the Project Planning and Implementation Process.” 2002. 2 Apr. 2011 http://www.passia.org/seminars/2002/ME/Chapter2.htm

Guijt, Irene, Mae Arevalo, and Kiko Saladores. “Participatory Monitoring and Evaluation: Tracking Change Together.” PLA Notes 31: Participatory Monitoring and Evaluation. IIED, 1998. 28-36. http://pubs.iied.org/pdfs/G01749.pdf

Davies, Rick, and Jess Dart. “The ‘Most Significant Change’ (MSC) Technique: A Guide to Its Use.” 2005. 4 Apr. 2011 http://www.mande.co.uk/docs/MSCGuide.pdf

W.K. Kellogg Foundation. Evaluation Handbook. 1998. http://www.ojp.usdoj.gov/BJA/evaluation/links/WK-Kellogg-Foundation.pdf

Frechtling, Joy. The 2002 User-Friendly Handbook for Project Evaluation. National Science Foundation, 2002. http://www.nsf.gov/pubs/2002/nsf02057/nsf02057_4.pdf

Wagner, D. et al. Monitoring and Evaluation of ICT in Education Projects: A Handbook for Developing Countries. 2005. 10 Apr. 2011 http://www.infodev.org/en/publication.9.html

Batchelor, S., and P. Norrish. Framework for the assessment of ICT pilot projects: Beyond Monitoring and Evaluation to Applied Research. 2005. 1 Apr. 2011 http://www.infodev.org/en/Publication.4.html

Mikkelsen, B., Methods for Development Work and Research: A Guide for Practitioners, Sage Publications Pvt. Ltd, September 13, 1995. http://www.amazon.com/Methods-Development-Work-Research-Practitioners/dp/0803992297