

UC Berkeley

UC Berkeley Electronic Theses and Dissertations

Title

Designing for Health Accessibility: Case Studies of Human-Centered Design to Improve Access to Cervical Cancer Screening

Permalink

<https://escholarship.org/uc/item/8dq9z2f5>

Author

Kramer, Julia

Publication Date

2020

Peer reviewed|Thesis/dissertation

Designing for Health Accessibility: Case Studies of Human-Centered Design
to Improve Access to Cervical Cancer Screening

by

Julia M. Kramer

A dissertation submitted in partial satisfaction
of the requirements for the degree of
Doctor of Philosophy

in

Engineering – Mechanical Engineering
and the Designated Emphasis

in

Development Engineering

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Alice M. Agogino, Chair

Professor Sara L. Beckman

Professor Coye Cheshire

Professor Andy Dong

Summer 2020

**Designing for Health Accessibility: Case Studies of Human-Centered Design
to Improve Access to Cervical Cancer Screening**

Copyright © 2020

by

Julia Kramer

Abstract

Designing for Health Accessibility: Case Studies of Human-Centered Design
to Improve Access to Cervical Cancer Screening

by

Julia Kramer

Doctor of Philosophy in Engineering – Mechanical Engineering

Designated Emphasis in Development Engineering

University of California, Berkeley

Professor Alice M. Agogino, Chair

Our world faces immense challenges in global health and equity. There continue to be huge disparities in access to health care across geographies, despite the massive strides that have been made to address health issues. In this dissertation, I explore the role of human-centered design to improve global health access and reduce disparities. Human-centered design, a cross-disciplinary creative problem-solving approach, has been applied and studied in both academic research and practice, but its role in improving global health access remains poorly understood.

In this dissertation, I present research on designing for health accessibility in the context of one particular disease: cervical cancer. Every year, 300,000 women around the world die of cervical cancer and ninety percent of these deaths occur in low- and middle-income countries. Cervical cancer is an illustrative example of the global disparities in access to health care, given that cervical cancer is preventable and the majority of global cervical cancer mortality is in low- and middle-income countries.

My research examines the work of two organizations that created unique solutions to improve access to cervical cancer screening in India and Nicaragua. I develop case studies of each organization grounded in ethnographic fieldwork, including over 250 hours of observation and 15 interviews over two years. Through these case studies, I show how early efforts to understand the barriers inhibiting cervical cancer screening access allow design practitioners to create novel and feasible ways to address these

barriers. This demonstrates the importance of design practitioners considering multiple dimensions of accessibility, including *availability*, *physical accessibility*, *accommodation*, *affordability*, and *acceptability*, while conducting design research in order to improve the potential impact of their ideas and prototypes. Overall, this dissertation establishes the foundation of a new paradigm to “design for accessibility” that can inspire further application and research across sectors to address the many social equity and accessibility challenges facing our world.

Dedicated to all those who have suffered from cervical cancer.
May we design a better world in your honor.

Table of Contents

List of Figures	vi
List of Tables	x
List of Abbreviations	xi
Acknowledgments	xii
Chapter 1: Introduction	1
1.1 Human-Centered Design	2
1.2 Global Health Care	4
1.3 Cervical Cancer	4
1.4 Research Questions	5
1.5 Roadmap for Dissertation	6
Chapter 2: Literature Review	7
2.1 Global Health Accessibility	7
2.1.1 Health Equity	9
2.1.2 Health Care Access and Quality	9
2.2 Cervical Cancer	12
2.2.1 Cervical Cancer Prevention, Screening, and Treatment	12
2.2.2 Cervical Cancer Burden	15
2.2.3 Focus on Cervical Cancer Screening	16
2.3 Human-Centered Design	18
2.3.1 A Brief History of Design	18
2.3.2 Human-Centered Design in Theory and Practice	20
2.3.2.a Human-Centered Design in Academic Theory	20
2.3.2.b Human-Centered Design in Practice	22
2.3.3 Applications of Human-Centered Design in the Creation of Products and Services	24
2.4 Applications of Human-Centered Design for Global Health Accessibility	25
2.4.1 Existing Work in Human-Centered Design for Global Health	26
2.4.2 Existing Work in Human-Centered Design for Accessibility	28
2.5 Conclusion	31
Chapter 3: Preliminary Work in Human-Centered Design for Accessibility: Visualize	32
3.1 An Overview of Visualize	32
3.2 The Visualize Design Process	33
3.3 Current Status and Future Plans of Visualize	37
3.4 Summary of Visualize	37

Chapter 4: Research Framework and Methodology	38
4.1 Research Questions	38
4.2 Research Method: Exploratory Case Study Approach	38
4.2.1 Getting Started	39
4.2.2 Selecting Cases	40
4.2.3 Crafting Instruments and Protocols	41
4.2.4 Entering the Field	42
4.2.4.a Conducting Research with InVia	42
4.2.4.b Conducting Research with Mujeres Móviles	42
4.2.4.c Summary of Data Sources	43
4.2.5 Analyzing Data	44
4.2.5.a Constructing and Coding the Corpus	44
4.2.5.b Analyzing the Case Studies	45
4.2.6 Shaping Hypotheses	45
4.2.7 Enfolding Literature	46
4.2.8 Closure	46
4.3 Limitations in the Research Methods	47
4.4 Locating Myself in the Research	47
Chapter 5: A Case Study of InVia Technologies	48
5.1 Indian Context	48
5.1.1 Context of Health in India	49
5.2 Description of InVia	51
5.2.1 Overview of InVia's Programs	51
5.2.1.a ccScreen	53
5.2.2 Personnel of InVia	55
5.2.3 Historical Timeline of InVia	58
5.3 InVia's Process of Human-Centered Design for Accessibility	60
5.3.1 Consideration of Accessibility 1: Accommodation, Availability, and Affordability	64
5.3.2 Consideration of Accessibility 2: Affordability	67
5.3.3 Consideration of Accessibility 3: Accommodation, Physical Accessibility, Availability, and Affordability	71
5.3.4 Consideration of Accessibility 4: Affordability	75
5.3.5 Consideration of Accessibility 5: Availability	76
5.4 Discussion and Evaluation of InVia's Process of Human-Centered Design for Accessibility	77
5.4.1 Discussion of InVia's Process of Human-Centered Design for Accessibility	77
5.4.2 Evaluation of InVia's Human-Centered Design Process	79
5.4.3 Evaluation of InVia's Considerations of Accessibility	83
5.5 Summary of the Case Study of InVia Technologies	88

Chapter 6: A Case Study of Mujeres Móviles	89
6.1 Nicaraguan Context	89
6.1.1 Context of Health in Nicaragua	91
6.2 Description of Mujeres Móviles	93
6.2.1 Overview of Mujeres Móviles' Programs	93
6.2.1.a Mobile Cervical Cancer Clinic	95
6.2.2 Personnel of Mujeres Móviles	103
6.2.3 Historical Timeline of Mujeres Móviles	106
6.3 Mujeres Móviles' Process of Human-Centered Design for Accessibility	109
6.3.1 Consideration of Accessibility 1: Physical Accessibility and Availability	111
6.3.2 Consideration of Accessibility 2: Availability, Accommodation, and Acceptability	113
6.3.3 Consideration of Accessibility 3: Accommodation and Availability	114
6.3.4 Consideration of Accessibility 4: Acceptability and Accommodation	116
6.3.5 Consideration of Accessibility 5: Affordability and Accommodation	118
6.3.6 Consideration of Accessibility 6: Accommodation	120
6.3.7 Consideration of Accessibility 7: Acceptability	122
6.4 Discussion and Evaluation of Mujeres Móviles' Process of Human-Centered Design for Accessibility	123
6.4.1 Discussion of Mujeres Móviles' Process of Human-Centered Design for Accessibility	124
6.4.2 Evaluation of Mujeres Móviles' Human-Centered Design Process	126
6.4.3 Evaluation of Mujeres Móviles' Considerations of Accessibility	130
6.5 Summary of the Case Study of Mujeres Móviles	138
Chapter 7: Cross-Case Analysis	140
7.1 Comparison of InVia and Mujeres Móviles	140
7.2 Comparison of ccScreen and the Mobile Cervical Cancer Clinic	143
7.2.1 Human-Centered Design Practices to Create ccScreen and the Mobile Cervical Cancer Clinic	145
7.2.1.a Assessment of Human-Centered Design Practices and Recommendations for Future Human-Centered Design Practices	149
7.2.2 Accessibility Considerations to Create ccScreen and the Mobile Cervical Cancer Clinic	154
7.2.3 Intersection of InVia's and Mujeres Móviles' Human-Centered Design Practices and Considerations of Accessibility	157

7.3 Best Practices of Human-Centered Design for Accessibility	159
7.4 New Frameworks of Human-Centered Design for Accessibility	160
7.4.1 Criteria of Human-Centered Design for Accessibility	160
7.4.2 Process of Human-Centered Design for Accessibility	161
7.4.3 Implications of the Criteria and Process of Human-Centered Design for Accessibility	162
7.4.4 Evaluating Human-Centered Design for Accessibility	163
7.5 Summary of Cross-Case Analysis of InVia Technologies and Mujeres Móviles	164
Chapter 8: Dissertation Summary and Future Work	166
8.1 Summary and Contributions of Dissertation	169
8.2 Future Work in Human-Centered Design for Accessibility	173
8.3 Broader Implications of Human-Centered Design for Accessibility	173
References	175

List of Figures

Figure 1-1	This dissertation focuses on the intersection of HCD and cervical cancer, linked to the broader intersection of design and health and equity.	2
Figure 1-2	The overarching goal of my dissertation is to assess the role of HCD to improve access to health care. I aim to study how applying HCD can improve health care access, and I aim to explore how an understanding of health care access can improve HCD.	3
Figure 1-3	Global age-standardized mortality rate of cervical cancer by country, 2018. Source: [23]	5
Figure 2-1	Global burden of death and disability, measured in disability-adjusted life years (DALYs), 2017. The majority of global death and disability is due to non-communicable diseases (blue), and a smaller portion of global death and disability is due to communicable, maternal, neonatal, and nutritional diseases (red), and injuries (green), Larger boxes indicate a larger proportion of DALYs. Darker colors indicate a more positive percent annual change (1990 to 2017). Source: [19]	8
Figure 2-2	Country income (gross domestic product per capita) versus life expectancy, 2019. High-income countries have a higher life expectancy than low-income countries. Larger bubbles indicate countries with larger populations. Source: [26]	8
Figure 2-3	HAQ index 1990 versus 2015. Nearly all countries improved HAQ from 1990 to 2015, indicated by most countries falling above the dashed line. South Korea, Maldives, Turkey, China, and Peru experienced the greatest gains. India and Nicaragua experienced modest gains. Source: [21]	11
Figure 2-4	Age versus disease prevalence. The progression of HPV infection early in life can lead to cervical precancer and cervical cancer later in life. Source: [33]	13
Figure 2-5	The steps to perform the Pap smear and VIA.	14
Figure 2-6	Facets of cervical cancer control.	15
Figure 2-7	HAQ (2015) versus log(Age-Standardized Rate of Cervical Cancer Incidence) [left] and versus log(Age-Standardized Rate of Cervical Cancer Mortality) [right]. Cervical cancer incidence and mortality both decrease as HAQ increases. Graphs created with data from [21], [24]	16
Figure 2-8	Countries with a national HPV vaccine program, 2018. Less than half of the countries around the world have introduced a national HPV vaccination program. Source: [33]	17

Figure 2-9	The Innovation Model presents HCD as a process of four phases (Observe and Notice, Frame and Reframe, Imagine and Design, and Make and Experiment) laid out on two axes (analysis-synthesis and concrete-abstract). Source: adapted from [74]	21
Figure 2-10	IDEO suggests that design thinking and HCD are at the intersection of desirability, feasibility, and viability. Source: adapted from [76]	22
Figure 2-11	IDEO created the first usable computer mouse for Apple. Source: All About Apple Museum	23
Figure 2-12	HCD with the addition of accessibility as a core principle. Source: adapted from [76]	30
Figure 3-1	The current version of Visualize built in Spring 2018.	34
Figure 3-2	A rendering of the paper tabs used in Visualize.	35
Figure 3-3	Theory of change for how Visualize will create impact at scale.	36
Figure 5-1	Burden of death and disability in India, measured in disability-adjusted life years (DALYs), 2017. The majority of death and disability in India is due to non-communicable diseases (blue), and a smaller portion of death and disability is due to communicable, maternal, neonatal, and nutritional diseases (red), and injuries (green). Larger boxes indicate a larger proportion of DALYs. Darker colors indicate a more positive percent annual change (1990 to 2017). Source: [118]	49
Figure 5-2	The journey map for how ccScreen is used, including interactions between CHWs, clinicians, and patients.	54
Figure 5-3	Theory of change demonstrating how InVia intends for ccScreen to create impact.	55
Figure 5-4	Timeline of InVia's design phases and considerations of accessibility.	61
Figure 5-5	Schematic for ccScreen v1. Source: InVia	68
Figure 5-6	One of the 115 Jhpiego flashcards that show images of a patient's cervix after acetic acid has been applied during the VIA procedure. Source: [124]	69
Figure 5-7	ccScreen v2 schematic [left] and 3D printed prototype [right]. Source: InVia	70
Figure 5-8	ccScreen v3 cervical scope, shown with approximate dimensions. The nose end of the device [left] measures 4.5 centimeters across. The camera in the middle of the nose is approximately 0.5 cm in diameter and is surrounded by lights. The handheld part of the device [right] is approximately 15 cm long from bottom to light switch, shown in black on the right side of the device. Source: InVia	74

Figure 5-9	InVia's design process plus their considerations of accessibility. Each blue arrow corresponds to a consideration of accessibility, as I describe in Section 5.3. The thicker the blue arrow, the more dimensions of accessibility considered.	78
Figure 6-1	Burden of death and disability in Nicaragua, measured in disability-adjusted life years (DALYs), 2017. The majority of death and disability in Nicaragua is due to non-communicable diseases (blue), and a smaller portion of death and disability is due to communicable, maternal, neonatal, and nutritional diseases (red), and injuries (green). Larger boxes indicate a larger proportion of DALYs. Darker colors indicate a more positive percent annual change (1990 to 2017). Source: [132]	91
Figure 6-2	A nurse on the Central Nicaragua team demonstrates women's reproductive anatomy.	96
Figure 6-3	The mobile cervical cancer clinic teams bring all the required cervical cancer screening supplies, including a gynecological table [right], cotton swabs, vinegar, and gloves.	97
Figure 6-4	Mujeres Móviles' cervical cancer screening guidelines.	98
Figure 6-5	The mobile cervical cancer clinic teams bring a tank of compressed carbon dioxide (shown in orange) to perform cryotherapy. The teams set up cryotherapy in the same manner as they set up screening, and bring a gynecological table, cotton swabs, vinegar, and gloves.	100
Figure 6-6	The journey map of Mujeres Móviles mobile cervical cancer clinics.	101
Figure 6-7	A Mujeres Móviles truck parked at a school during a mobile screening event.	102
Figure 6-8	Theory of change demonstrating how Mujeres Móviles intends for the mobile cervical cancer clinics to create impact.	103
Figure 6-9	Timeline of Mujeres Móviles' design phases and considerations of accessibility.	110
Figure 6-10	The power bracelet is a tool to help teach women at Mujeres Móviles mobile cervical cancer clinics about their menstrual cycle.	121
Figure 6-11	Mujeres Móviles' design process plus their considerations of accessibility. Each green arrow corresponds to a consideration of accessibility, as I describe in Section 6.3. The thicker the green arrow, the more dimensions of accessibility considered.	124
Figure 7-1	The iterative process of HCD for accessibility begins with an accessibility mindset. This mindset influences accessibility-minded research activities (Observe and Notice), which inform how the problem is framed (Frame and Reframe) and how ideas are generated (Imagine and Design). The ideas are then tested with accessibility in mind (Make and Experiment).	161

Figure 7-2 The approach of HCD for accessibility (inputs) is linked to the goal of improving accessibility (impacts). This theory of change can be used to evaluate the success of HCD for accessibility.

163

List of Tables

Table 2-1	Penchansky and Thomas' framework to evaluate a patient's satisfaction with access to health care [22].	10
Table 4-1	Total number of hours and pages of data collected with InVia and Mujeres Móviles.	43
Table 5-1	Personnel involved with InVia, including co-founders, team members, and collaborators.	57
Table 5-2	Adapted from Penchansky and Thomas' framework to evaluate a patient's satisfaction with access to health care [22]. These questions have been edited to address a patient's satisfaction with their access to cervical cancer screening through the ccScreen system.	86
Table 6-1	Personnel involved with Mujeres Móviles, including co-founders, team members, board members, and collaborators.	105
Table 6-2	Adapted from Penchansky and Thomas' framework to evaluate a patient's satisfaction with access to health care [22]. These questions have been edited to address a patient's satisfaction with their access to cervical cancer screening through the Mujeres Móviles mobile cervical cancer clinics.	136
Table 7-1	Comparison of key features of two organizations that created programs to address cervical cancer screening access: InVia and Mujeres Móviles.	141
Table 7-2	Comparison of project attributes of ccScreen and the mobile cervical cancer clinic.	144
Table 7-3	Comparison of HCD practices employed by InVia and Mujeres Móviles to create ccScreen and the mobile cervical cancer clinic (respectively).	146
Table 7-4	Comparison of "human-centeredness" of the design approach employed by InVia and Mujeres Móviles to create ccScreen and the mobile cervical cancer clinic (respectively).	149
Table 7-5	Comparison of considerations of accessibility employed by InVia and Mujeres Móviles to create ccScreen and the mobile cervical cancer clinic (respectively).	154

List of Abbreviations

BP: best practice
CDC: Centers for Disease Control
CHW: community health worker
DALYs: disability-adjusted life years
FSLN: *Frente Sandinista de Liberación Nacional*, the Sandinista National Liberation Front
GBD: Global Burden of Diseases, Injuries, and Risk Factors Study
HAQ: Healthcare Access and Quality index
HCD: human-centered design
HCD+D: human-centered design for development
HPV: human papillomavirus
ISO: International Organization for Standardization
LMICs: low- and middle-income countries
MINED: *Ministerio de Educación*, the Ministry of Education in Nicaragua
MINSAL: *Ministerio de Salud*, the Ministry of Health in Nicaragua
RQ: research question
SDI: Socio-Demographic Index
SILAIS: *Sistemas Locales de Atención Integral de Salud*, the Local Comprehensive Health Care Systems in Nicaragua
UNO: *Unión Nacional Opositor*, the National Opposition Union
US: United States
USAID: United States Agency for International Development
UX/UI: user experience / user interface
VIA: visual inspection with acetic acid
VILI: visual inspection with Lugol's iodine
WHO: World Health Organization

Acknowledgments

It's hard to believe this dissertation is actually done and now out in the real world. This document feels like a compendium of my life's work (so far), and the process of working on this dissertation has been an incredible and rewarding challenge. I cannot count everyone who has impacted my work and my journey, and the people I name here are only a small list of many more.

Thank you to the amazing people I worked with in InVia Technologies and Mujeres Móviles. My time in the field with you has changed how I view design and global health. I am so happy to be able to present your work in my research.

Thank you to Vivek Rao, without whom this dissertation would not have been possible. Vivek, I am incredibly grateful for your thought partnership on the analysis of this research. I quite literally could not have analyzed this on my own and I feel so lucky to have gotten the chance to work with you.

Thank you to the many collaborators and friends of Visualize, who inspired me to embark on this journey of research on cervical cancer screening. To Abdul Zurak and Zurak Cancer Foundation, thank you for being such thoughtful and dedicated partners. To our collaborators at Ridge Hospital, Global Cervical Charity Foundation, the Nursing and Midwifery Council, Ghana Health Services, Komfo Anokye Teaching Hospital, and Korle Bu Teaching Hospital, thank you for always providing honest feedback on Visualize and for working with us to improve cervical cancer screening training in Ghana. To Iris Hou and Hailey Windsor, thank you for the many semesters you dedicated to Visualize.

Thank you to Maria Young, my partner in Visualize and my soulmate in all things health and design. You rock, don't ever change, you're simply the best. Here's to a shared future of collaborating to address health inequities.

Thank you to Rachel Dzombak. I didn't expect to find a fellow Midwest diva in California and I am so grateful that I did. Let's always enjoy our intellectual conversations with a side of buffalo chicken dip.

Thank you to the many mentors and teachers who have guided me along my path. Mr. Jim Bezdek, you sparked my interest in engineering when I was only 11 years old and that has shaped the trajectory of my life since then. Ms. Kerry Rutigliano, you have been a consistent compass in my life and I hope my writing has improved since ninth grade English class. Dr. Lorelle Meadows, you first raised my social consciousness as a budding engineer and I cannot thank you enough. Professor Shanna Daly, I am so thankful you introduced me to engineering design research and gave me such a strong foundation to build upon. Professor Kathleen Sienko, you have tirelessly supported Visualize and you've shown me how to carve my own niche in global health and design. Professor Sara Beckman, I have learned so much from you and I continue to be awed by the breadth of your knowledge and interests. Professor Alice Agogino, you have been the

most wonderful advisor, advocate, and teacher for me throughout grad school. Thank you for helping me find and foster my interdisciplinary passions.

Thank you to all of my past and present labmates in BiD and BEST. You've made such a welcoming academic home for me at Berkeley. Thank you to my friends in Mechanical Engineering and Development Engineering: Hannah Budinoff, Katya Cherukumilli, Casey Finnerty, Audrey Ford, Sarah Frank, Zach Gima, Payton Goodrich, Pierce Gordon, Hannah Gramling, Bernard Kim, Euiyoung Kim, Max Micali, George Moore, Danielle Poreh, Celeste Roschuni, Drew Sabelhaus, Kate Schweidel, and Chengwei Zhang. Thank you to Yawo Akpawu in the Mechanical Engineering Department for helping me figure out how to start and finish a master of public health degree in my last year of grad school. Thank you to the Graduate Division, the Mechanical Engineering Department, and the InFEWS Fellowship (NSF Grant No. DGE-1633740) for funding me throughout grad school.

Thank you to my classmates and professors in the Interdisciplinary Master of Public Health program. You've pushed me to think deeply about the meaning of health equity and health accessibility.

Thank you to everyone who reviewed this dissertation through its many iterations: Andrew Barkan, Hannah Budinoff, Brian Cera, Deniz Dogruer, Elena Durán-López, Audrey Ford, Sarah Frank, Tomás Georgiou, George Moore, and Alan Zhang. Thank you to my dissertation committee members, Professors Alice Agogino, Sara Beckman, Coye Cheshire, and Andy Dong, who provided me with several rounds of thoughtful and engaged feedback. My work is better and more rigorous for your influence.

Thank you to all those who have kept me accountable during the writing process: Tracey Benson, Ela Ben-Ur, Christine Ortiz, and Susie Wise. You all kept me showing up day after day to write this thing and I'm so thrilled to say that I'M DONE.

Thank you to my Reflex Design Collective teammates, who have demonstrated what it looks like to practice equitable co-design while sticking true to our core values. Julia Kong, Brooke Staton, Briana Evans, Hiroko Kurihara, and rita zhang, I'm so grateful.

Thank you to everyone who kept me level-headed through this dissertation. To my friends from Cleveland, Michigan, California, and elsewhere, you have brought so much joy and fun to my life. To the Pereiras, you have offered me so much support and encouragement. To my grandparents, Melvyn Goldstein, Dorothy Goldstein, Rose Goldstein, Frieda Kramer, and John Kramer, thank you for your infinite love and wisdom.

And finally, the biggest thank you to my family, Nancy and Herb Kramer, Annalise and Wade Friedel, and Brandon Pereira. Mom and Dad, you have instilled in me a strong work ethic and sense of empathy. Thank you for always supporting me through this rollercoaster of a dissertation. Annalise and Wade, you've been such energetic cheerleaders and I'm so grateful to have such positive forces in my life. Brandon, you've been unbelievably patient, encouraging, and loving. This was just the beginning; onto the next adventure!

Chapter 1

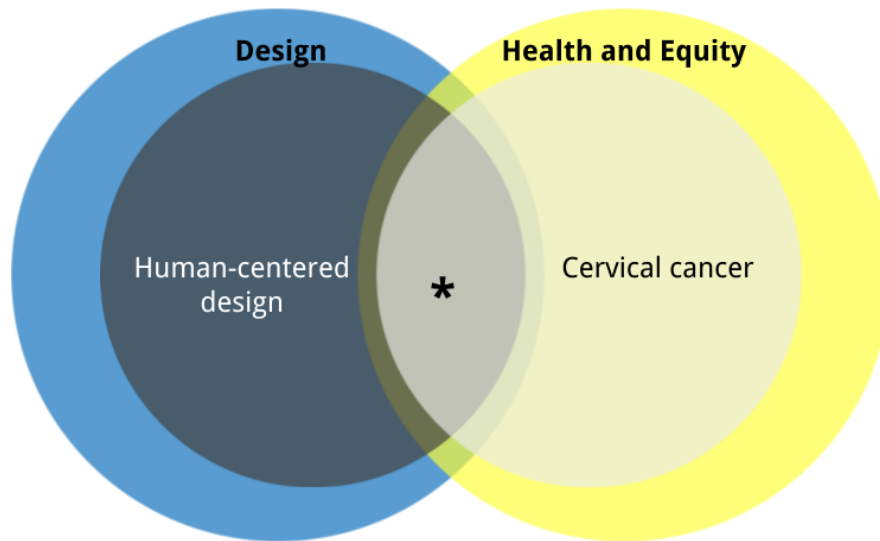
Introduction

Our world faces immense challenges in global health and equity. The challenges in health today are not simple, linear, or one-dimensional. We're facing massively complex challenges of health care infrastructure, health care delivery, and implementation of promising health care technologies and therapies. I am writing this dissertation in the midst of the COVID-19 pandemic, a global health crisis that has illustrated and exacerbated global disparities in access to health care [1], [2]. The World Health Organization (WHO) acknowledges the importance of equitable access to health products, including vaccines and medications to combat COVID-19 [3], [4].

COVID-19 has refreshed our collective awareness of the importance of effective global health infrastructure. We have seen the complex challenge of global disparities in access to health care, and we are now seeing the impacts of those global disparities. To begin to address the daunting challenge of global inequities in health care access, we need creative solutions. Design is a promising approach to call to task.

This dissertation seeks to understand the role of design in improving health. I focus on cervical cancer as an example of disparities in global health access. Therefore, I explore the applications and practices of human-centered design (HCD) in addressing the global health issue of cervical cancer (Figure 1-1).

In this introduction, I present the practice of "human-centered design," explore global health care access, and discuss the burden of cervical cancer mortality. I then introduce the research questions (RQs) of my dissertation and the contribution I intend to make. I close with a roadmap for the rest of the dissertation.



* What is the role of HCD in improving access to cervical cancer screening?

Figure 1-1. This dissertation focuses on the intersection of HCD and cervical cancer, linked to the broader intersection of design and health and equity.

1.1 Human-Centered Design

HCD is a cross-disciplinary problem-solving approach where design practitioners develop a deep understanding of stakeholders in their design context, and use this understanding to drive an iterative process of framing the problem to solve, generating ideas to solve the problem, experimenting with prototypes of these ideas, and implementing solutions.

HCD is applied in both academic theory and practice, but there are limited links between the academic world and the translation to practice. HCD practice does not tend to draw upon existing academic HCD research, while HCD research does not tend to refine and develop HCD theories in light of practice [5].

Recently, researchers and practitioners across industry, government, and academia have begun to call for HCD in addressing challenges of poverty and global health. For example, IDEO.org, the non-profit arm of global design firm IDEO, was established with the explicit mission to “*use human-centered design to create products, services, and experiences that improve the lives of people living in poverty*” [6]. IDEO.org boasts a number of global health projects, including their Diva Centres project to provide reproductive health services to girls in Zambia [7]. The United States Agency for International Development (USAID), a government agency, applies HCD across their global health work [8]. USAID created the EngageHCD website and the Design for Health portal to explore how HCD can be used in global health work [9], [10]. To understand the role of HCD in global development within academia, I previously

conducted a systematic literature review of HCD for development (HCD+D). In this review, my collaborators and I found 78 academic publications practicing HCD for a range of global development challenges in HCD+D's foundational decade between 2004 and 2014 [11], [12]. Twenty-four of these publications focused specifically on addressing a global health challenge. While this review provided a broad overview of how HCD has been applied to address global development challenges, foundational work has been conducted at the University of California, Berkeley to theorize how HCD is part of a new academic discipline called "Development Engineering" [13].

While there are clearly many examples of solutions developed with HCD to address poverty and to improve global health [14], much of the work done in HCD for global development and health has been driven by practice, not theory. In this dissertation, I aim to understand the role of HCD in improving access to health care and I aim to propose new frameworks of HCD for accessibility. Improved accessibility may be an outcome of HCD work, but the existing processes and theories in HCD have not been updated to reflect the utility of HCD in improving accessibility. Current HCD frameworks consider only a limited view of accessibility, with a focus on the desirability and usability of a solution for a target group of stakeholders. Without an accessibility-informed framework for HCD, we cannot generate or test hypotheses about the role of HCD in improving accessibility. It is therefore my goal to extend HCD theory by generating new frameworks about HCD and accessibility, which can be applied and tested in a broad range of domains.

The emerging intersection of HCD in health offers an opportunity to develop new HCD practices that are tailored to health applications. This, in turn, has the potential to improve both HCD as a whole and the health outcomes it seeks to affect (Figure 1-2).

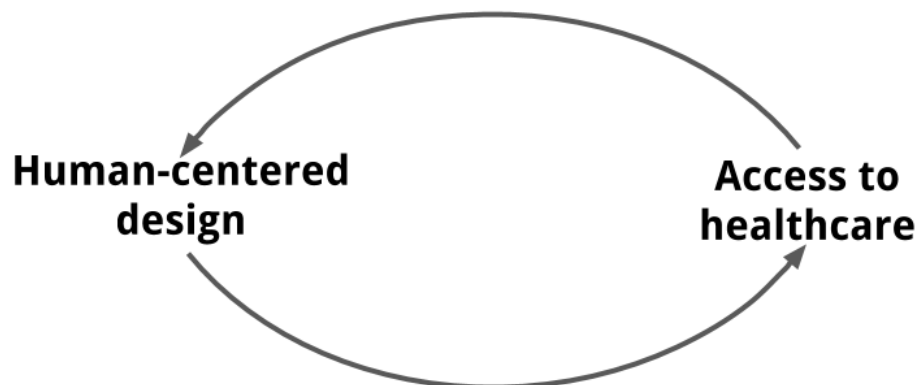


Figure 1-2. The overarching goal of my dissertation is to assess the role of HCD to improve access to health care. I aim to study how applying HCD can improve health care access, and I aim to explore how an understanding of health care access can improve HCD.

In this dissertation, I aim to contribute to the literature around design and access to health care by studying the role of HCD in creating and implementing accessible cervical cancer screening programs.

1.2 Global Health Care

Improving health care is a global priority, and is recognized in both the Millennium Development Goals [15] and the Sustainable Development Goals [16]. Major strides have been made in improving global health, including reducing childhood mortality, improving vaccination coverage, and controlling many infectious diseases (e.g., the eradication of smallpox) [17], [18]. Yet, these improvements in global health bring new challenges. For example, the majority of death and disability in the world today is due to non-communicable diseases [19].

Today, the disparities in life expectancy across the world are stark. There is over a 30 year gap between the lowest life expectancy (Lesotho: 51.1 years expected at birth) and the highest life expectancy (Japan: 84.2 years expected at birth). A person's life expectancy depends on where that person is born and raised.

The WHO views health as a fundamental human right, and states that the right to health includes the right to accessible quality health care [20]. Access to health care is limited for a range of individual, community, and health system reasons. Healthcare quality and access is improving, yet still remains disparate between high-income countries and low-income countries [21]. Access is a multidimensional concept that refers to the *acceptability, physical accessibility, accommodation, affordability, and availability* of health services to patients [22].

In this dissertation, I aim to develop a new way of thinking about the role of HCD in health access. Specifically, I aim to explore and develop new frameworks to push forward the emerging intersection between HCD and health access. To do so, I focus on one particular health issue: cervical cancer. Cervical cancer is one particular global health issue that highlights the disparities in global access to health care.

1.3 Cervical Cancer

Every year, 300,000 women around the world die of cervical cancer and ninety percent of these deaths occur in low- and middle-income countries (LMICs) [23], [24]. Figure 1-3 shows a map of cervical cancer mortality.

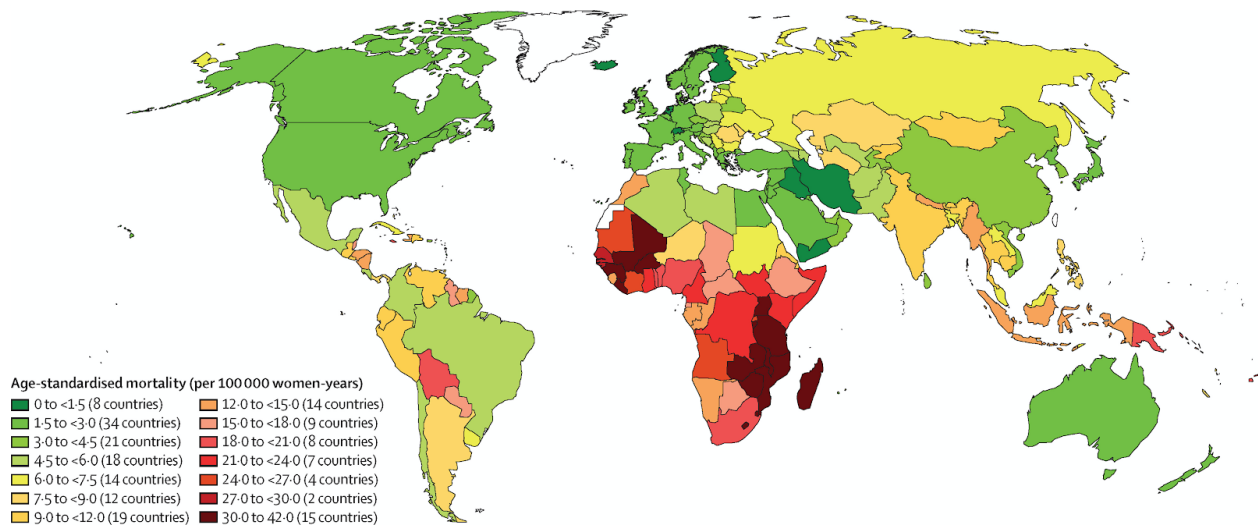


Figure 1-3. Global age-standardized mortality rate of cervical cancer by country, 2018. Source: [23]. *Reused per Creative Commons BY 4.3 license.*

Regular screening procedures, like the Pap smear and visual inspection with acetic acid (VIA), can identify abnormal cervical cells before they become cancerous, therefore preventing the progression of cervical cancer [25]. However, cervical cancer screening is not accessible everywhere – particularly in LMICs – and more accessible cervical cancer screening can result in lower rates of cervical cancer incidence and mortality around the world.

1.4 Research Questions

In this dissertation, I aim to contribute to the literature around design and access to health care by studying the role of HCD in creating and implementing accessible cervical cancer screening programs.

The main question guiding this dissertation is: what is the role of human-centered design in improving access to cervical cancer screening? In particular, this dissertation addresses two RQs and their intersections:

RQ1. How and why do organizations consider **accessibility** in creating and implementing programs to address cervical cancer screening?

RQ2. How and why do organizations use **human-centered design** to create and implement these cervical cancer screening programs?

1.5 Roadmap for Dissertation

This dissertation contributes to the literature around design and health care access by studying the role of HCD in creating programs to improve access to cervical cancer screening. In this dissertation, I provide a background literature review and an example of my own work in cervical cancer screening that continues to motivate my work. I then document two case studies of organizations who have created programs to improve access to cervical cancer screening. These case studies and a comparative analysis across case studies reveals the practices these organizations took to create accessible cervical cancer screening programs.

Chapter 2: Literature Review reviews background literature of the topics I explore in this dissertation, including HCD, health care access, cervical cancer screening, and global development.

Chapter 3: Preliminary Work in Human-Centered Design for Accessibility: Visualize explores an application of HCD in cervical cancer screening I am involved in that has motivated me to explore, from a more theoretical perspective, the ways in which HCD is used to address cervical cancer screening access.

Chapter 4: Research Framework and Methodology presents the research methods and data sources I use in undertaking this research.

Chapter 5: A Case Study of InVia Technologies will present a case study of InVia, an organization that has created a new medical device to improve VIA in India.

Chapter 6: A Case Study of Mujeres Móviles will present a case study of Mujeres Móviles, an organization that has created a system of mobile health clinics to deliver cervical cancer education and screening in parts of rural Nicaragua.

Chapter 7: Cross-Case Analysis compares and contrasts the two previous case studies. This analysis will provide more context to understand the findings and implications of each study. Additionally, this chapter introduces new frameworks to understand the practice of HCD for accessibility.

Chapter 8: Conclusions and Future Research closes the dissertation by summarizing key findings, discussing limitations and broader implications, and highlighting areas of future work.

Chapter 2

Literature Review

This literature review is intended as a broad overview of the fields I integrate in this dissertation: design and global health equity. First, I explore the state of global health today and present cervical cancer as an illustrative example of a global health inequity. I then present design as a tool to address global health inequity. Therefore, I dive into the history of design, including the birth of human-centered design (HCD) and I discuss the emerging applications of HCD in global health.

2.1 Global Health Accessibility

As I discuss in Section 1.2, the world has seen major improvements in the state of global health. Major international bodies, like the United Nations and the World Health Organization (WHO), recognize and promote the improvement of global health. Yet, improvements in global health bring new challenges. Consider, for example, the wide global successes of controlling many infectious diseases, like smallpox. This, indeed, is a triumph in the global health community. And yet, the burden of infectious (or communicable) diseases is being replaced by the burden of non-communicable diseases. Today, the majority of death and disability in the world is due to non-communicable diseases (Figure 2-1).

Health disparities are not only a function of a person's health characteristics, but also where that person lives. The global trends of life expectancy illustrate this point clearly: life expectancy is correlated with a country's income (Figure 2-2).

Disparities in health status across the world depend on the level of access to quality health care in different parts of the world. Disparities in health also relate to health equity. I explore these notions in the subsections below.

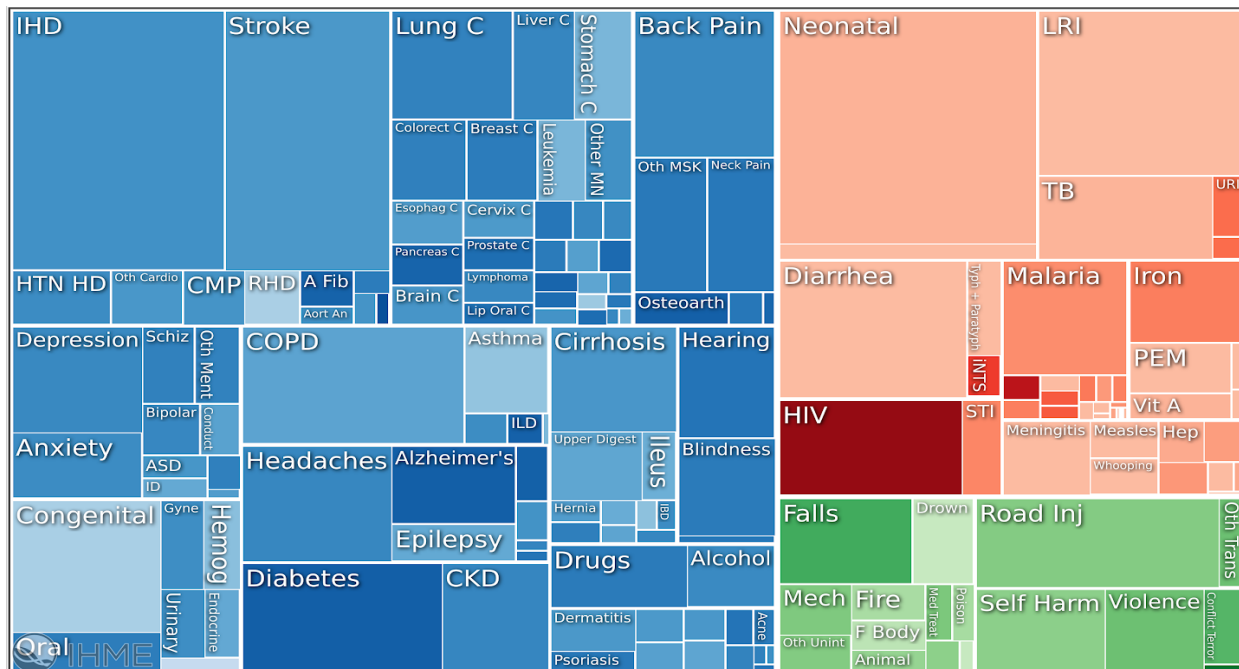


Figure 2-1. Global burden of death and disability, measured in disability-adjusted life years (DALYs), 2017. The majority of global death and disability is due to non-communicable diseases (blue), and a smaller portion of global death and disability is due to communicable, maternal, neonatal, and nutritional diseases (red), and injuries (green). Larger boxes indicate a larger proportion of DALYs. Darker colors indicate a more positive percent annual change (1990 to 2017). Source: [19]. *Reused per Creative Commons CC BY-NC-ND 4.0 license.*

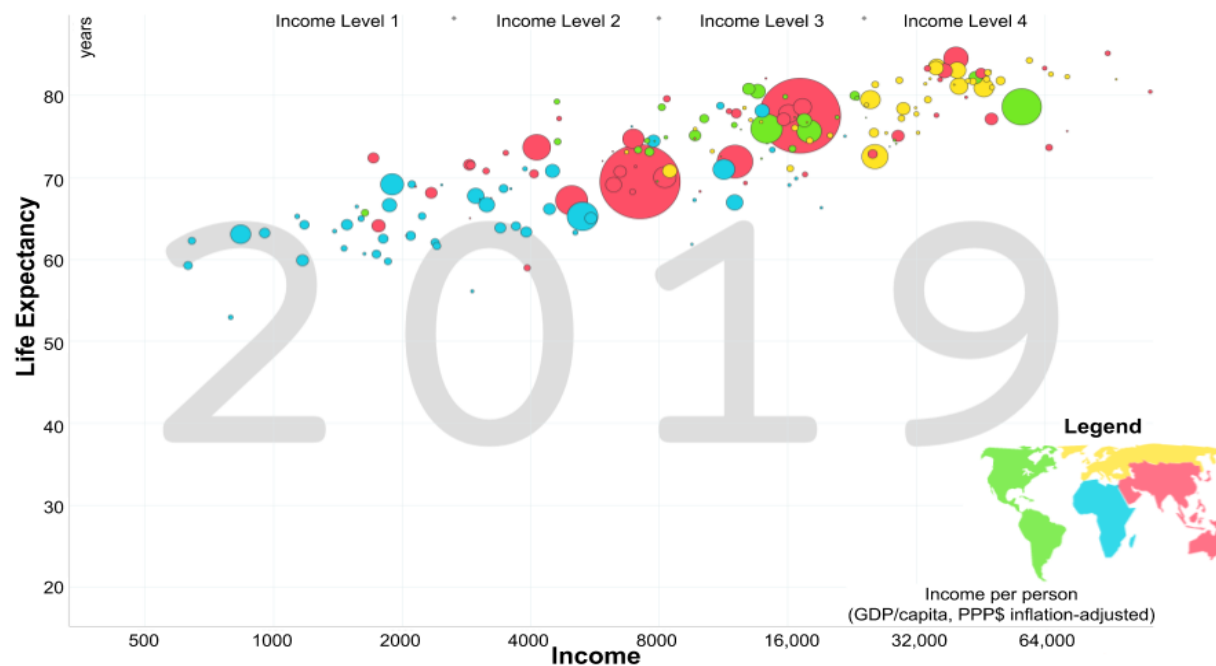


Figure 2-2. Country income (gross domestic product per capita) versus life expectancy, 2019. High-income countries have a higher life expectancy than low-income countries. Larger bubbles indicate countries with larger populations. Source: [26]. *Based on free material from gapminder.org, Creative Commons BY 4.0 license.*

2.1.1 Health Equity

Paula Braveman [27] defines health equity as *“the principle underlying a commitment to reduce — and, ultimately, eliminate — disparities in health and in its determinants, including social determinants.”* In this definition, Braveman calls out the notion of *social determinants of health*. The WHO defines and explores the social determinants of health further [28]:

“The social determinants of health are the conditions in which people are born, grow, live, work and age. These circumstances are shaped by the distribution of money, power and resources at global, national and local levels. The social determinants of health are mostly responsible for health inequities — the unfair and avoidable differences in health status seen within and between countries.”

Braveman [27] goes on to say that *“pursuing health equity means striving for the highest possible standard of health for all people and giving special attention to the needs of those at greatest risk of poor health, based on social conditions.”*

Therefore, health equity goes beyond just eliminating health disparities, or differences in health. Health equity explicitly carries an element of human rights and social justice. As I discuss in Section 2.1, inequities in health access lead to inequities in health outcomes.

2.1.2 Health Care Access and Quality

Health care access can be thought of as the degree of “fit” between patients and the healthcare system [22]. Roy Penchansky and J. William Thomas [22] conceive of health care access on five dimensions: *availability, (physical) accessibility, accommodation, affordability, and acceptability*. Note that the addition of “physical” is my own. According to the Penchansky and Thomas, these dimensions are defined as:

- **Availability:** *“the relationship of the volume and type of existing services (and resources) to the clients’ volume and types of needs.”*
- **(Physical) Accessibility:** *“the relationship between the location of supply and the location of clients.”*
- **Accommodation:** *“the relationship between the manner in which the supply resources are organized to accept clients and the clients’ ability to accommodate to these factors.”*
- **Affordability:** *“the relationship of prices of services and providers’ insurance or deposit requirements to the clients’ income, ability to pay, and existing health insurance.”*
- **Acceptability:** *“the relationship of clients’ attitudes about personal and practice characteristics of providers to the actual characteristics of existing providers, as well as to provider attitudes about acceptable personal characteristics.”*

I show Penchansky and Thomas' framework to evaluate patient satisfaction with health care access in Table 2-1. In a later paper, Thomas and Penchansky [29] applied the questions in Table 2-1 to measure patient satisfaction with health services and to relate patient satisfaction to the utilization of health services. Thomas and Penchansky found that patient satisfaction with access did significantly correlate to utilization of health services, albeit weakly. The correlations between access satisfaction and utilization were stronger when stratified to look at homogenous demographic groups.

Table 2-1. Penchansky and Thomas' framework to evaluate a patient's satisfaction with access to health care [22]. These questions are assessed through a patient survey where patients respond on a five-point Likert scale, ranging from "very satisfied" (1) to "very dissatisfied" (5)

Dimension of Accessibility	Question to Evaluate Patient Satisfaction
Availability	All things considered, how much confidence do you have in being able to get good medical care for you and your family when you need it?
	How satisfied are you with your ability to find one good doctor to treat the whole family?
	How satisfied are you with your knowledge of where to get health care?
	How satisfied are you with your ability to get medical care in an emergency?
Physical Accessibility	How satisfied are you with how convenient your physician's offices are to your home?
	How difficult is it for you to get to your physician's office?
Accommodation	How satisfied are you with how long you have to wait to get an appointment?
	How satisfied are you with how convenient physicians' office hours are?
	How satisfied are you with how long you have to wait in the waiting room?
	How satisfied are you with how easy it is to get in touch with your physician(s)?
Affordability	How satisfied are you with your health insurance?
	How satisfied are you with the doctors' prices?
	How satisfied are you with how soon you need to pay the bill?
Acceptability	How satisfied are you with the appearance of the doctor's offices?
	How satisfied are you with the neighborhoods their offices are in?
	How satisfied are you with the other patients you usually see at the doctors' offices?

Penchansky and Thomas [22], [29] conceived of “access” in the context of a full healthcare system, as opposed to a particular health program or offering. Therefore, when they evaluate patient satisfaction with health care access, they evaluate how satisfied a patient is with access to health care as a whole as opposed to one particular health program. In Section 5.4.3 and Section 6.4.3, I adapt Table 2-1 for use to evaluate the access afforded by InVia’ and Mujeres Móviles’ cervical cancer screening programs.

In a 2017 paper, a large group of authors (collectively, the “Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2015 Healthcare Access and Quality Collaborators”) developed a Healthcare Access and Quality (HAQ) index and analyzed the relationship between a country’s HAQ and “development” status, represented by the Socio-Demographic Index (SDI) [21]. As expected, the GBD 2015 Healthcare Access and Quality Collaborators found that low-SDI (“developing”) countries had lower HAQ than high-SDI (“developed”) countries over time, but they also found a general positive trend where HAQ globally improved between 1990 and 2015 (Figure 2-3).

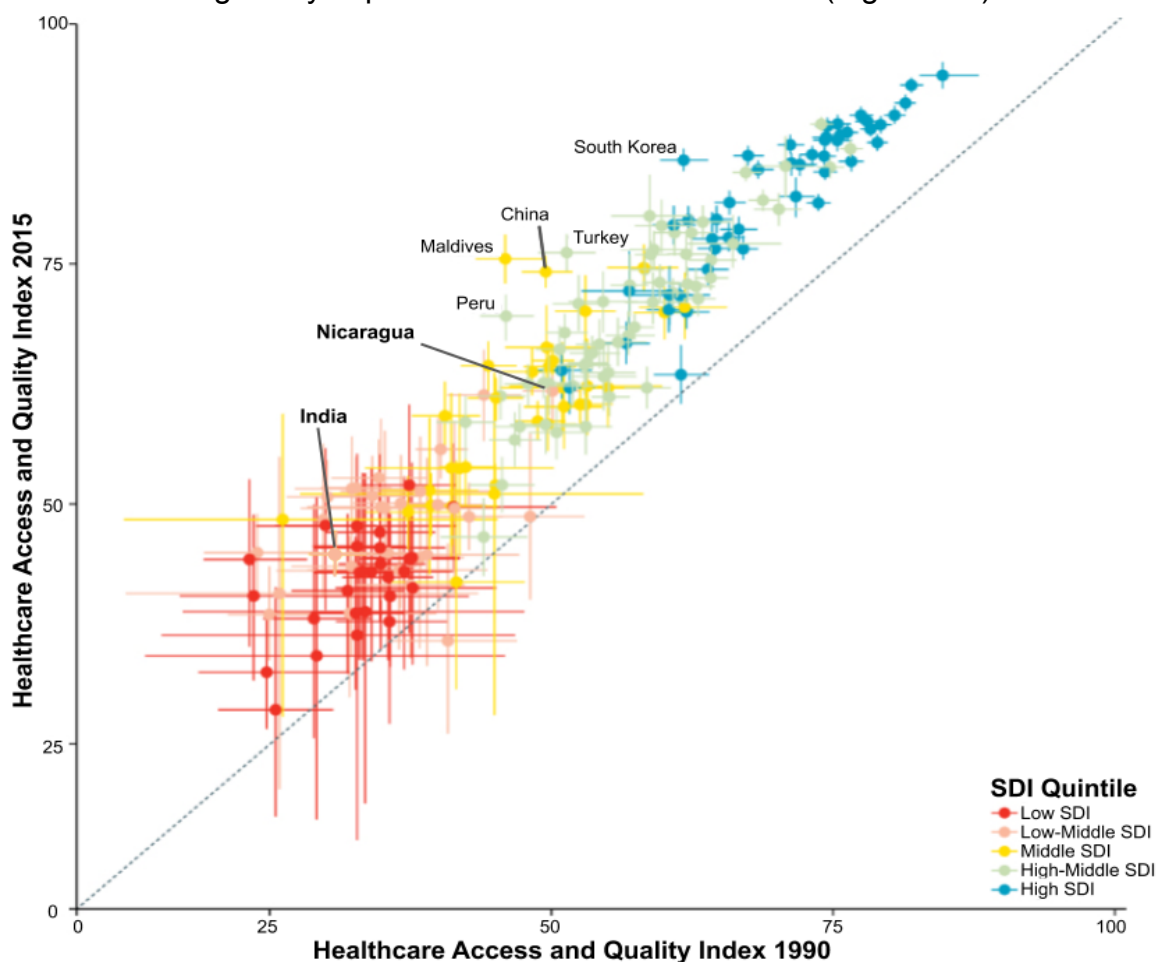


Figure 2-3. HAQ index 1990 versus 2015. Nearly all countries improved HAQ from 1990 to 2015, indicated by most countries falling above the dashed line. South Korea, Maldives, Turkey, China, and Peru experienced the greatest gains. India and Nicaragua experienced modest gains. Source: [21]. *Reused per Creative Commons BY 4.0 license.*

The GBD 2015 Healthcare Access and Quality Collaborators determined HAQ by measuring the mortality rates of health conditions that are amenable to care. They define the *amenable burden* as “[the] disease burden that could be avoided in the presence of high-quality personal health care.” Therefore, a high amenable disease burden indicates low healthcare access and quality [21]. Although the authors mention “quality” and “access” separately, Penchansky and Thomas’ framework suggests that quality is part of access. Specifically, Penchansky and Thomas refer to the idea of “*good medical care*” and “*good doctor[s]*” within the *availability* dimension of accessibility (Table 2-1). Therefore, although the GBD 2015 Healthcare Access and Quality Collaborators do not discuss the various dimensions of access, I consider the HAQ index to be a cumulative measure of all five of Penchansky and Thomas’ dimensions.

2.2 Cervical Cancer

Cervical cancer is an illustrative example of global health (in)equity, given that it is a largely preventable disease and the majority of the disease burden is located in low- and middle-income countries (LMICs). In the following subsections, I present an overview of cervical cancer including strategies to control the disease and global trends in the disease burden.

2.2.1 Cervical Cancer Prevention, Screening, and Treatment

There are three facets of cervical cancer control: *primary prevention*, *secondary screening*, and *treatment* [30]. Nearly all cases of cervical cancer are caused by human papillomavirus (HPV). HPV is an extremely common sexually transmitted infection [31]. Half of all HPV strains are high-risk and untreated cases of high-risk HPV can result in long-term cell changes and cancer. HPV causes nearly all cases of cervical cancer, and also causes the majority of anal, vaginal, oropharyngeal, vulvar, and penile cancers [32]. As Figure 2-4 shows, there is a high global prevalence of HPV around the age of sexual debut which can lead to cervical precancer and cervical cancer over time.

There are several types of HPV vaccines that can *prevent* several high-risk HPV strains and therefore cervical cancer. The bivalent (Cervarix), quadrivalent (Gardasil), and nonavalent (Gardasil 9) HPV vaccines prevent infection for (respectively) two HPV strains, four HPV strains, and nine HPV strains [34]. The availability of these vaccine types varies by country and facility. The HPV vaccination is most effective when administered to a person before they are sexually active, and the WHO recommends adolescent girls (between 9 and 14 years old) as the priority group for HPV vaccination [35]. The Centers for Disease Control (CDC) also recommends HPV vaccination for

adolescents and young adults (including boys and men) between 15 and 26 years old [36]. The HPV vaccine is safe and effective at preventing a person from contracting high-risk HPV, and the vaccine is predicted to reduce up to 76% of cervical cancer deaths [37], [38]. There are several barriers to HPV vaccine access, including the affordability and the challenge of reaching the target 9 to 14 year old age group [33].

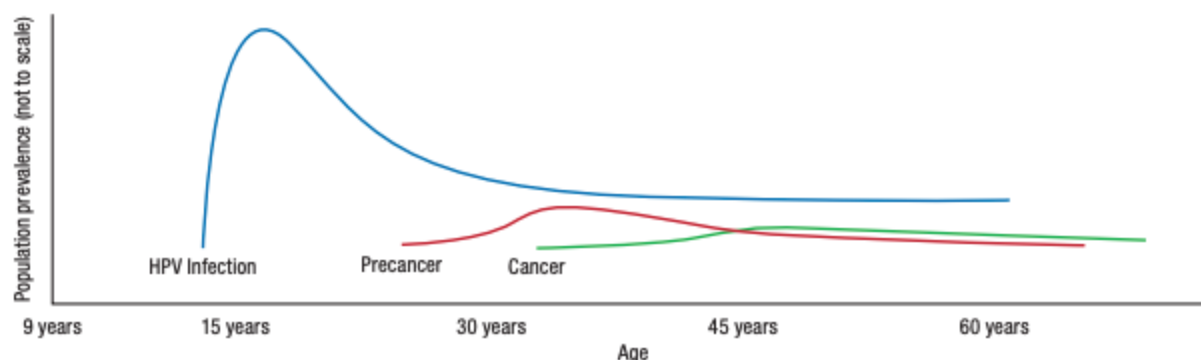


Figure 2-4. Age versus disease prevalence. The progression of HPV infection early in life can lead to cervical precancer and cervical cancer later in life. Source: [33]. Reused per Creative Commons BY-NC-SA 3.0 IGO license.

There are three types of cervical cancer *screening* methods, including cytology tests, DNA tests, and visual tests. The Pap smear is a cytology test that involves the sampling of cells from a patient's cervix and the testing of these cells in a laboratory to determine if they are precancerous. The Pap smear is performed as follows (Figure 2-5): (1) a healthcare provider (often a nurse, midwife, or doctor) performs a standard pelvic examination and inserts a speculum into the patient's vagina, (2) the healthcare provider uses a spatula and brush to take a sample of cells from the patient's cervix and transfers the cell sample onto a glass slide, (3) the healthcare provider sends the glass slide to a laboratory where a cytologist examines the cells under a microscope, and (4) the cytologist informs the healthcare provider who informs the patient if precancerous cells were detected and if further testing is required [39]. HPV DNA testing involves the sampling of cells from a patient's cervix — in the same manner as the Pap smear — and the testing of these cells to see if they carry high-risk HPV. HPV DNA screening can be performed on the same sample of cervical cells collected from a patient in a process known as cotesting [40]. Both the Pap smear and HPV DNA screening are limited by their dependence on laboratory testing. There are three main types of visual tests: colposcopy, visual inspection with acetic acid (VIA) and visual inspection with Lugol's iodine (VILI). During a colposcopy procedure, a healthcare provider uses a high-powered microscope (a colposcope) to view a patient's cervix in search of precancerous cells. Colposcopy is often done as a follow-up to an abnormal Pap smear or HPV DNA test [41]. VIA and VILI are also visual screening methods, but unlike colposcopy, VIA and VILI do not require specialized equipment. Instead, a practitioner

applies acetic acid (in VIA) or Lugol's iodine (in VILI) and then inspects the patient's cervix with their naked eye to see if any color changes are evident on the cervix. Such color changes indicate the presence of precancerous cells. VIA is performed as follows (Figure 2-5): (1) a healthcare provider (often a nurse, midwife, or doctor) performs a standard pelvic examination and inserts a speculum into the patient's vagina, (2) the healthcare provider visually inspects the patient's cervix for any existing abnormalities and then applies acetic acid (or white table vinegar) to the cervix, (3) the healthcare provider visually inspects the cervix one minute after application of acetic acid for any acetowhite lesions (or regions on the cervix that appear white upon application of acetic acid) that may appear, signifying precancerous cells, and (4) upon visualization of acetowhite lesions, the healthcare provider either refers the patient to specialized medical care or performs cryotherapy to remove the precancerous cells [42].

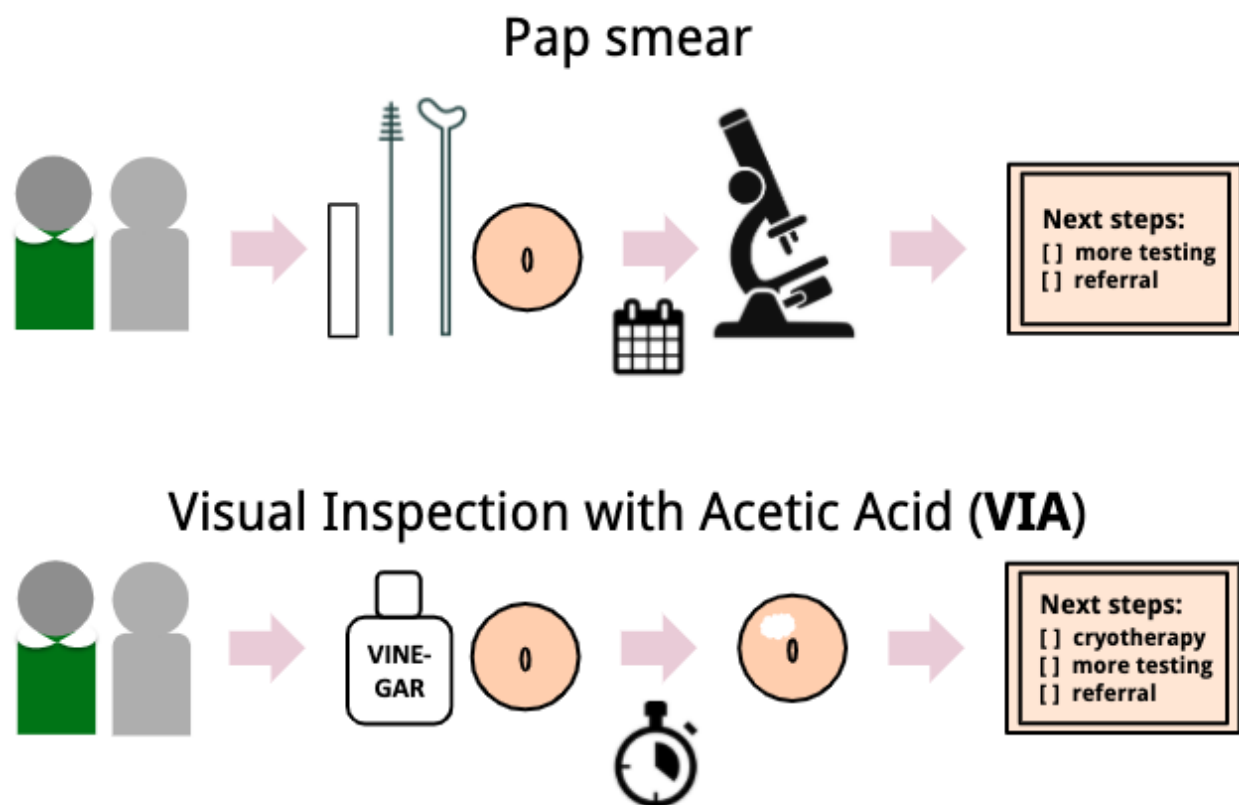


Figure 2-5. The steps to perform the Pap smear and VIA. Figure created by the author.

Figure 2-5 above illustrates how the Pap smear and VIA are performed. I focus on Pap smear and VIA as these are the methods used by both InVia and Mujeres Móviles.

If a person gets cervical cancer (i.e., it is too late to prevent the disease with either a vaccination or a screening procedure), there are options for treatment. Cervical cancer treatment options are similar to other types of cancer treatment: surgery,

chemotherapy, and radiation. Figure 2-6 below shows the various facets of cervical cancer control: primary prevention, secondary screening, and treatment. Both primary prevention and secondary screening methods prevent the onset of cervical cancer.

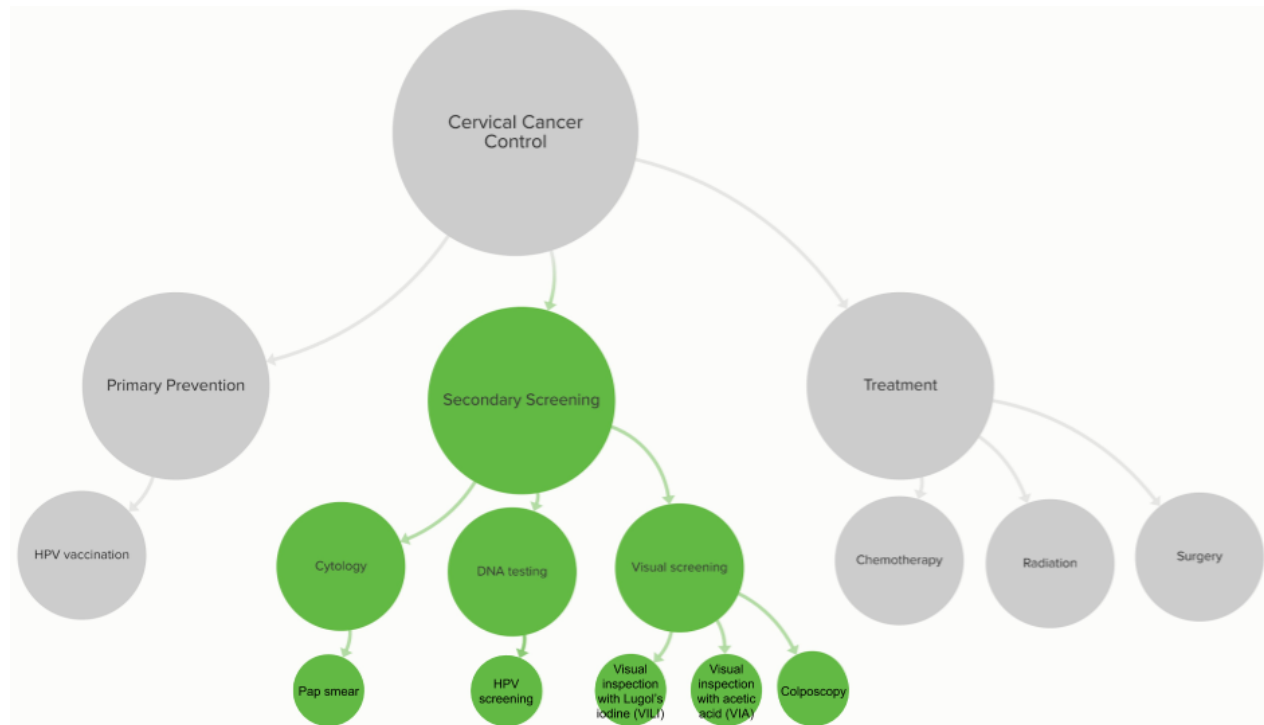


Figure 2-6. Facets cervical cancer control.

2.2.2 Cervical Cancer Burden

Every year, 300,000 women die from cervical cancer, and ninety percent of these cases occur in LMICs [24], [30]. Unsurprisingly, cervical cancer incidence and mortality is correlated with healthcare access and quality. Figure 2-7 below shows that as healthcare access and quality increases, cervical cancer burden decreases.

Cervical cancer is an undue burden in LMICs for three main reasons: (1) LMICs lack the traditional infrastructure for cervical cancer screening and treatment [43], (2) people in LMICs tend to lack awareness of cervical cancer [44], [45]; and (3) hospitals in LMICs tend to lack sufficient numbers of trained healthcare providers [44], [45].

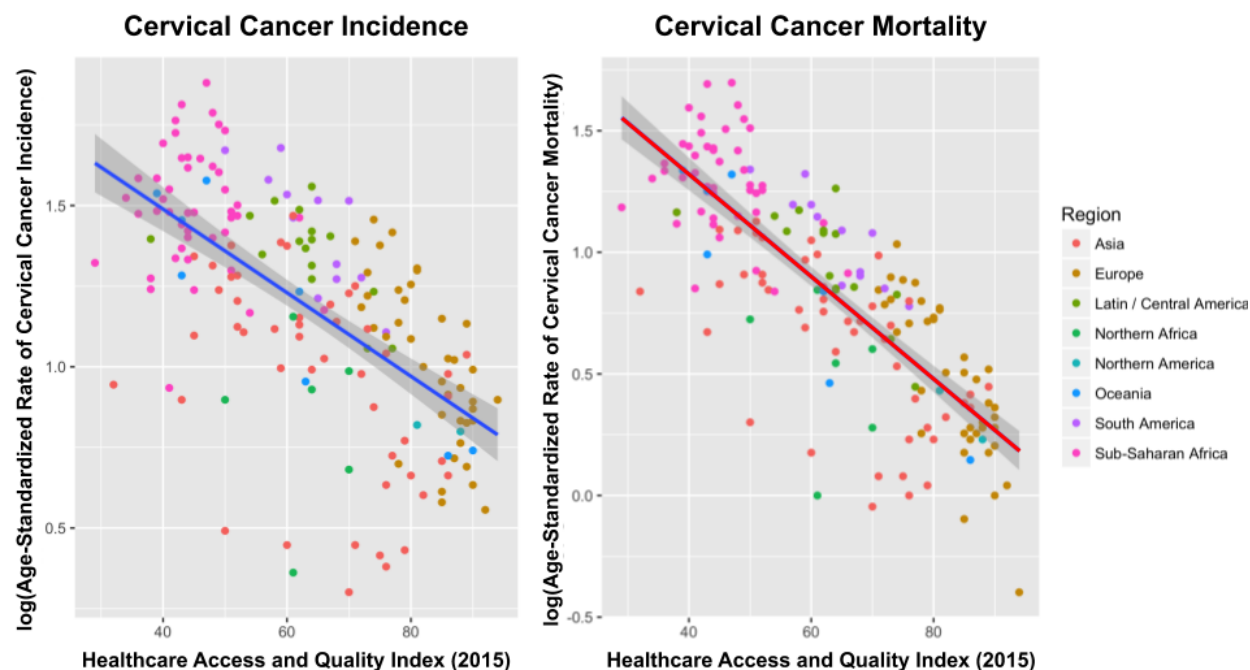


Figure 2-7. HAQ (2015) versus log(Age-Standardized Rate of Cervical Cancer Incidence) [left] and versus log(Age-Standardized Rate of Cervical Cancer Mortality) [right]. Cervical cancer incidence and mortality both decrease as HAQ increases. Graphs created with data from [21], [24].

Cervical Cancer Incidence: R-squared = 0.4014, R = 0.6336. **Log(Age-Standardized Rate of Cervical Cancer Incidence)** = $2.007 - 0.01296 * (\text{HAQ Index})$

Cervical Cancer Mortality: R-squared = 0.6473, R = 0.8045. **Log(Age-Standardized Rate of Cervical Cancer Mortality)** = $2.164 - 0.0211 * (\text{HAQ Index})$

It is worth noting that cervical cancer can be globally eliminated through a combination of prevention and screening [46]. In fact, at least two countries — Australia and Rwanda — could eliminate cervical cancer in the next several decades [47], [48]. Despite this, cervical cancer mortality is still inequitable, not only between high-income countries and LMICs but also within high-income countries. In Australia, cervical cancer death rates among Aboriginal women are three times higher than non-Aboriginal women [46]. In the United States (US), Black women are twice as likely to die from cervical cancer than white women [49]. Therefore, although I focus on the undue burden of cervical cancer mortality in LMICs, I acknowledge how much work must still be done in high-income countries to ensure equitable access to cervical cancer prevention and screening.

2.2.3 Focus on Cervical Cancer Screening

Both HPV vaccination and cervical cancer screening can prevent the onset of cervical cancer. The WHO prioritizes screening, particularly in low-income areas of the world

[50], [51]. HPV vaccination is a laudable goal and a long-term necessity for our global health system. However, there is a limited time frame during which a person can be vaccinated, and few countries have a large-scale HPV vaccination campaign effectively aimed at the target age group (Figure 2-8). According to the WHO, over 80% of high-income countries include HPV vaccination in a national immunization program, but only 20% of lower middle-income countries and 13% of low-income countries provide a national HPV vaccination program [33]. LMICs face additional constraints in implementing HPV vaccination, including the challenge of creating vaccine delivery programs within existing health systems and of ensuring the long-term sustainability of HPV vaccine programs [52], [53].

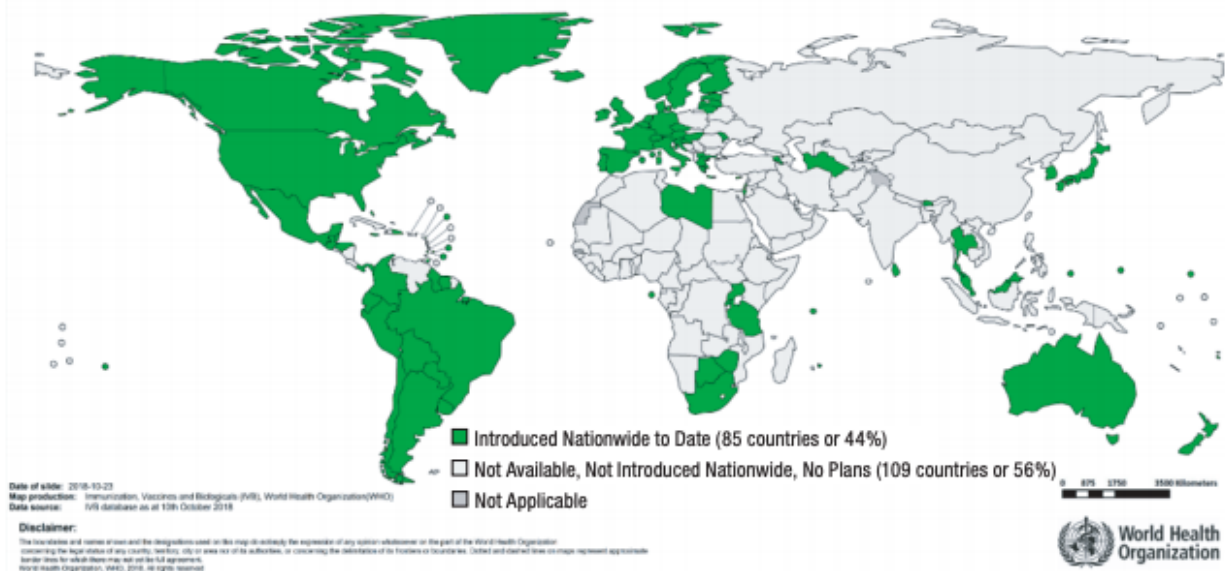


Figure 2-8. Countries with a national HPV vaccine program, 2018. Less than half of the countries around the world have introduced a national HPV vaccination program. Source: [33]. *Reused per Creative Commons BY-NC-SA 3.0 IGO license.*

Even if HPV vaccination were to become the global standard tomorrow, there is a significant and unignorable population who have not previously been vaccinated and therefore may be at risk of contracting HPV and developing cervical cancer. There is a need to create effective cervical cancer screening programs in the near-term to complement vaccination campaigns to eradicate cervical cancer in the long-term.

Because there is a lag between HPV contraction and invasive cervical cancer, screening procedures like Pap smear and VIA identify abnormal cervical cells before they become cancerous. However, many people lack access to cervical cancer screening, and are therefore less likely to identify cervical abnormalities before they become cancerous. Therefore, I have chosen to focus on cervical cancer screening, instead of primary prevention (i.e., vaccination) or treatment, in this dissertation.

2.3 Human-Centered Design

As I show in Sections 2.1 and 2.2, our world faces massive challenges in global health equity. While the global health community has made significant progress in addressing diseases, much more work needs to be done and new ways of problem-solving are needed. As I discuss in Chapter 1, HCD is a cross-disciplinary problem-solving approach where designers and stakeholders frame a problem, generate ideas to solve this problem, test these ideas through prototypes, and implement solutions. In the subsections below, I explore the history of design (Section 2.3.1), I present how HCD has been applied in both academic research and in practice (Section 2.3.2), and I discuss how HCD has been applied to address complex social challenges like health care access (Section 2.4).

2.3.1 A Brief History of Design

The terminology among “human-centered design” and its relatives, including “design thinking,” “participatory design,” “co-design,” and “user-centered design” is contested and not broadly consistent. I aim to clarify the definitions of these design approaches. To do so, I provide in this section a brief history of design.

Design, as an academic discipline and a practice, has been formally documented for years. Ulla Johansson-Sköldberg, Jill Woodilla and Mehves Çetinkaya [5] present two main schools of thought within design: *designerly thinking* (academic theory) and *design thinking* (professional practice). Within the “designerly thinking” school of thought, Johansson-Sköldberg et al. identify five unique discourses over time:

1. The creation of artefacts [54]
2. Reflexive practice [55]
3. Problem-solving activities [56], [57]
4. Ways of reasoning and making sense of things [58]–[60]
5. The creation of meaning [61]

To briefly summarize these *designerly thinking* discourses within academic design theory, Herbert Simon first posed design as a particular way of thinking in 1969. He noted the similarities in the “*intellectual activity*” underlying engineering, architecture, business, education, law, and medicine as “*the process of design*” [54]. Donald Schön [55] critiqued Simon’s view of design as a strictly cognitive activity, and prompted designers to consider the role of “*artistry*” in their research and practice. Design and urban planning scholars Horst Rittel and Melvin Webber [57] introduced the idea of

“wicked problems,” writing that social policy problems are wicked in that they are ill-defined, complex, and lack a unique solution. This formulation of wicked problems inspired Richard Buchanan [56] to discuss designerly thinking as a way of dealing with and solving wicked problems. Brian Lawson [58] and Nigel Cross [59], [60] both sought to characterize the ways designers conduct design through a process of abductive (synthetic) reasoning and presented a “*science of design*” and design practices [5]. While Lawson and Cross were concerned with a designer’s practices, Klaus Krippendorff [61] was concerned with a more meta-level creation of meaning, positing that the core of the design profession is in making meaning, and artifacts are articulations of meaning.

Within the “design thinking” school of thought, as it refers to professional design practice, Johansson-Sköldberg et al. [5] present three unique discourses:

1. Design consultancy IDEO’s way of working with design and innovation [62]–[65]
2. A way to approach indeterminate organizational problems, and a necessary skill for practicing managers [66], [67]
3. Part of management theory [68]

To briefly summarize these *design thinking* discourses within professional design practice, global design consultancy IDEO brought design thinking into the mainstream through several publications outlining IDEO’s design practice and lessons learned in creativity and management [62]–[65]. Broadening the scope to management education as a whole, Roger Martin and David Dunne discuss design thinking as an essential skill for managers in all fields, not just design consulting [66], [67]. Similar to Dunne and Martin, Richard Boland and Fred Collopy [68] integrate design into management theory and education, focusing on the cognitive design skills managers need.

Johansson-Sköldberg et al. [5] wrap up their discussion by connecting *designerly thinking* to *design thinking*. Designerly thinking, given its academic roots, is more theory-driven than design thinking. *Design thinking* can be thought of as a translation of designerly thinking, boiling down academic thought and discussion into key takeaways for practitioners. In this process, Johansson-Sköldberg et al. [5] posit that two omissions are made: (1) design thinking is incorrectly made synonymous to creativity, when design thinking should actually refer to the larger competence and practice required of design work; and (2) design thinking is incorrectly analogized to a toolbox, focusing exclusively on design methods and not on the skills and competence a practitioner must have to correctly apply these design methods.

2.3.2 Human-Centered Design in Theory and Practice

In this section, I explore the historical roots of HCD within both the academic *designerly thinking* and the practice-based *design thinking* schools of thought.

2.3.2.a Human-Centered Design in Academic Theory

Richard Buchanan [69] ties the practice of design to the promotion of human rights and human dignity, reminding fellow researchers and practitioners to not simply practice design for “users” or for usability. Buchanan expresses that HCD “*is an ongoing search for what can be done to support and strengthen the dignity of human beings as they act out their lives in varied social, economic, political, and cultural circumstances.*” Joseph Giacomini [70] echoes the notion that HCD transcends usability, and that the best examples of design address the five “*classical rhetorical questions*”: human factors (Who), activities, tasks and functions (What), interactivity (When), semiotics, communication and discourse (How), and meaning (Why).

Marc Steen [71] posits that HCD is an umbrella term for a range of design approaches that include stakeholders as participants in the design process. The practice of design that includes stakeholders as participants is known as “participatory design”. Eric Reynolds Brubaker, Carl Jensen, Sunday Silungwe, Sheri D. Sheppard, and Maria Yang [72] present a spectrum of participatory design that ranges from stakeholder-centered design (i.e., stakeholders are primarily involved for their perspectives on usability, but external designers lead the design process) to co-design (i.e., stakeholders and external designers engage equally in the design process) to stakeholder-led design. Marie K. Harder, Gemma Burford, and Elona Hoover [73] expand this spectrum, building a typology of participatory design relationships:

- **Level -1: Denigration.** External designers make design decisions without stakeholders’ involvement or perspective to the direct detriment of stakeholders.
- **Level 0: Neglect.** External designers ignore or dismiss stakeholders’ involvement or perspective when making design decisions.
- **Level 1: Learning About.** External designers ask stakeholders for opinions but do not feel compelled to address these opinions when making design decisions.
- **Level 2: Learning From.** External designers ask stakeholders for opinions and do consider these opinions seriously when making design decisions.
- **Level 3: Learning Together.** External designers and stakeholders practice design activities together and make most design decisions as a group.
- **Level 4: Learning As One.** External designers and stakeholders share common goals, jointly contribute their knowledge and skills to achieve these goals, and make all design decisions together.

In this typology, Levels -1 and 0 are non-participatory, Levels 1 and 2 are “user”-centered, in that they typically are only concerned with consulting stakeholders for their perspective on usability, Level 3 is co-design, and Level 4 is stakeholder-led design. In this dissertation, I align with Steen’s [71] view of HCD as an umbrella term that encompasses a range of levels of participation between stakeholders and the design team. I consider HCD to incorporate participation between Level 1 and Level 4 of Harder, Burford, and Hoover’s typology [73].

HCD is a process that follows Sara Beckman and Michael Barry’s Innovation Model [74]. The HCD process has four key phases laid out along two axes: activities of analysis to activities of synthesis, and concrete activities to abstract activities. The HCD process consists of four phases laid out on these two axes: *Observe and Notice*, *Frame and Reframe*, *Imagine and Design*, and *Make and Experiment* (Figure 2-9). The design team iterates and jumps between these phases multiple times during a design process.

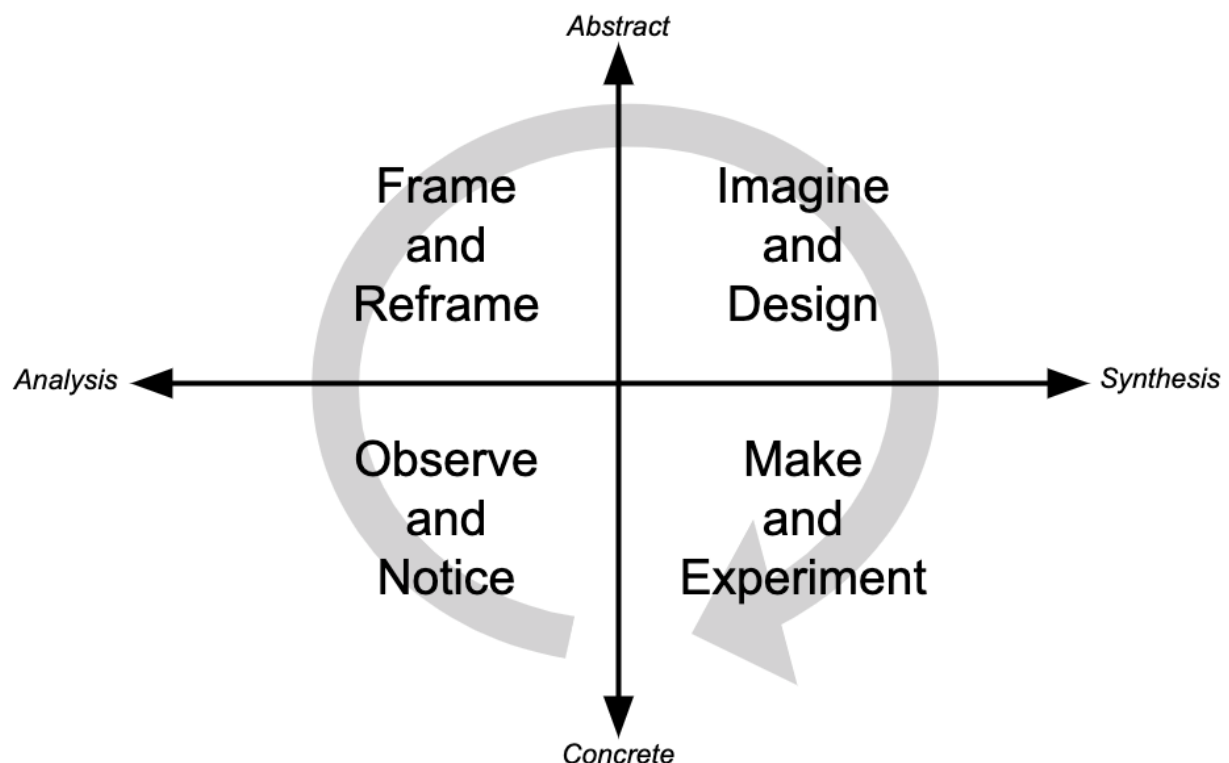


Figure 2-9. The Innovation Model presents HCD as a process of four phases (*Observe and Notice*, *Frame and Reframe*, *Imagine and Design*, and *Make and Experiment*) laid out on two axes (*analysis-synthesis* and *concrete-abstract*). Source: adapted from [74]. Reused with gratis reuse permission from SAGE Publications.

In this Innovation Model, HCD is able to identify and address gaps and challenges. A designer *Observes and Notices* the experiences of stakeholders, *Frames and Reframes* these experiences to identify the key gaps or challenges in the stakeholders’ experiences, *Imagines and Designs* new ideas to fill these gaps and address these

challenges, and *Makes and Experiments* solutions to see if they do in fact fill gaps and address challenges.

2.3.2.b Human-Centered Design in Practice

Design consultancy IDEO relates design thinking to HCD through the following definition proposed by chair Tim Brown [75]:

“Design thinking is a human-centered approach to innovation that draws from the designer’s toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success.”

As Figure 2-10 shows, IDEO suggests that design thinking and HCD are situated at the intersection of desirability (what do end-users desire?), feasibility (what is technically feasible?), and viability (what is commercially viable?) [63].

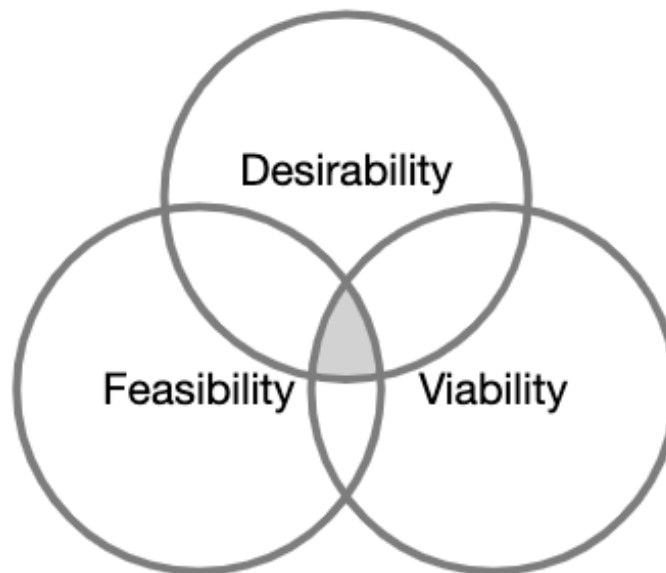


Figure 2-10. IDEO suggests that design thinking and HCD are at the intersection of desirability, feasibility, and viability. Source: adapted from [76]. *Reused with permission.*

In practice, there is a broad range of design consciousness. IDEO was one of the early design consultancies, responsible for a swath of high-profile projects including the design of the first Apple computer mouse in 1980 [77] (Figure 2-11). Since then, countless other design firms have sprung up across sectors and around the world. Many design firms, like frog design, Acorn, and Smart Design, function as their own consulting companies, seeking projects from a range of clients. Design consultancies also operate in the social sector: for example, Reboot and Greater Good Studios apply HCD to design solutions that address pressing societal issues.

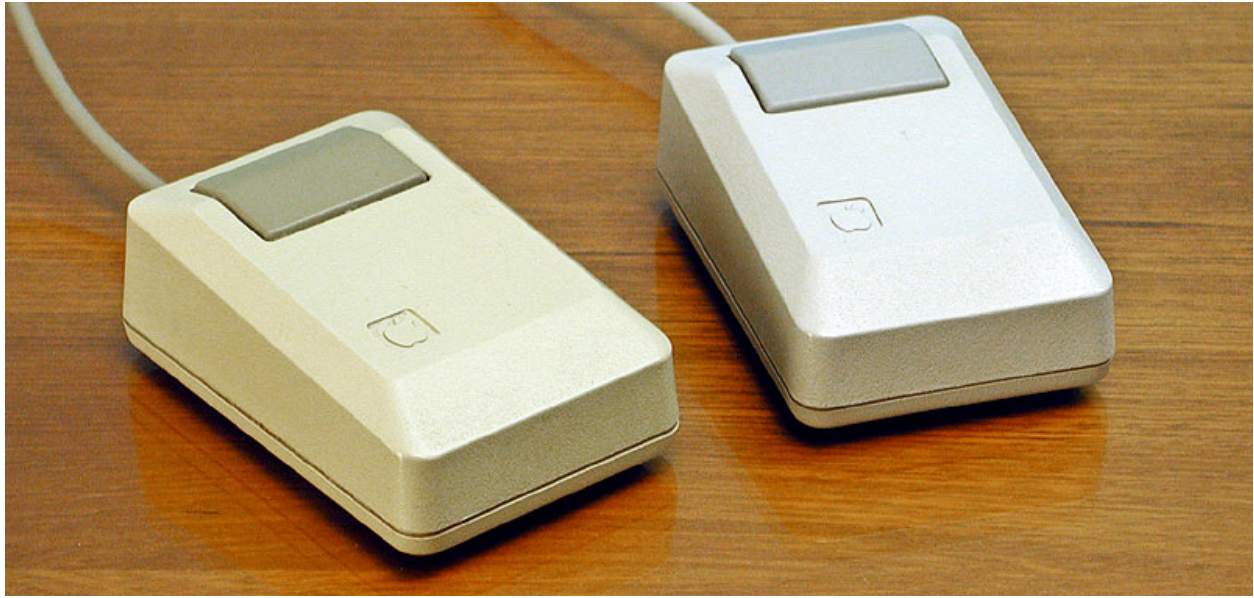


Figure 2-11. IDEO created the first usable computer mouse for Apple. Source: All About Apple Museum. *Reused per Creative Commons BY-SA-2.5-IT license.*

Other design firms, like Gravity Tank, Lunar, and Adaptive Path, have been acquired by larger companies. For example, Capital One – a national bank – acquired Adaptive Path in 2014 [78], McKinsey & Company – a global management consulting firm – acquired Lunar in 2015 [79], and Salesforce – a massive company building software tools for customer management – acquired Gravity Tank in 2016 [80].

Even more organizations not traditionally focused on design are building out their in-house design capacities: IBM has a dedicated design research team [81], Kaiser Permanente boasts “*the largest health care innovation center in the country*” [82], the University of California, San Francisco Hospital System has a “*clinical innovation center*” [83], and even the US Office of Personnel Management has a service design team [84].

The International Organization for Standardization (ISO) has put forth a set of criteria of HCD. According to ISO 9241-210:2010, “*human-centred design is an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques*” [85]. This ISO standard is specifically concerned with computer-based interaction systems, although I consider its scope to be much broader and to include both products and services. ISO 9241-210 puts forth six characteristics of HCD:¹

¹ The original ISO 9241-210 characteristics focus on “users”. I have edited all mention of “users” to be “stakeholders”, given that my research is concerned with more than just the immediate users of a system.

1. Adoption of multidisciplinary skills and perspectives
2. Explicit understanding of stakeholders, tasks and environments
3. Stakeholder-centred evaluation driven/refined design
4. Consideration of the whole stakeholder experience
5. Involvement of stakeholders throughout design and development
6. Iterative process

2.3.3 Applications of Human-Centered Design in the Creation of Products and Services

As I mention in Section 2.3.2, HCD is applicable for both the design of products and the design of services. In this section, I discuss the similarities of human-centered product design and human-centered service design.

Ammon Salter and Bruce S. Tether outline the history of product design and service design, pointing out four “*generations*” of service design [86]. First, before the 1980s, services had been neglected in the broader research on innovation. Most of the work to study innovation was concerned with innovations in technology and manufacturing (i.e., product innovation). Second, research on innovation began to assimilate services into the existing frameworks and theories of product innovation. Third, in the mid-1990s, service innovation began to become its own distinct field of research and researchers began to call for innovation frameworks that were specific to services. Fourth, most of the current work in service innovation today focuses on studying the synthesis of products and services. This current synthesis acknowledges how services and products are increasingly bundled together into solutions.

As Salter and Tether point out, there is an increasing focus on product-service systems [86]. Indeed, Lucy Kimbell argues that everything, including products, are part of a service [87]. Instead of designers focusing solely on creating a product that is desirable and functional, Kimbell suggests that designers focus on how a product creates value for a stakeholder.

In a later paper, Kimbell makes four observations of how designers create services [88]:

“[1] designers paid detailed attention to both the artefacts and experience of a service; [2] they made artefacts such as the customer journey diagram that rendered the service tangible and visible; [3] they assembled humans and non-humans into sets of relations; and [4] the designers were also involved in considering and proposing business model innovation.”

As is evident in these four observations, service design includes an attention to both products and services. Additionally, service design is concerned with the ways that

people interact with other people and with “*artefacts*”. The design of a service is closely related to the design of the service’s business model. Given Kimbell’s assertion that everything is a service, I assert that HCD in general includes these four practices.

To explore how a technology-centric process includes features of service design, consider the example of “biodesign”. Biodesign is a process to develop innovative medical technologies [89]. The biodesign process includes three phases: (1) identify, (2) invent, and (3) implement. Within each phase are two stages: (1a) needs finding, (1b) needs screening, (2a) concept generation, (2b) concept screening, (3a) strategy development, and (3b) business planning [89]. From these stages, we can see that a core focus of biodesign is on developing a strategy and a business plan, both elements of service design. Even though the core focus of biodesign is on creating a new *technology*, the process includes an understanding of how the technology will fit into a *service*, especially when it enters the phase of implementation.

Learning from the biodesign example, we can see that the process of designing a new technology incorporates aspects of service design. In fact, the HCD process — with its focus on the stakeholder environment and the whole stakeholder experience — explicitly includes service design aspects. HCD does not consider the development of products in isolation, but rather in relation to the stakeholders who will use and benefit from products.

Therefore, in the rest of this dissertation, I do not draw a further distinction between the process used to design a new technology and a service to accompany it (as InVia does, in Chapter 5) versus the process to solely design a service (as Mujeres Móviles does, in Chapter 6).

2.4 Applications of Human-Centered Design for Global Health Accessibility

HCD, with roots in both the designerly and design thinking traditions, has been gaining traction in the global health field [90]. Practitioners of HCD believe in its utility to understand and address human challenges.

In this section, I discuss existing HCD work in the field of global health (Section 2.4.1) and I discuss how the existing frameworks of HCD address accessibility (Section 2.4.2). The purpose of this section is to highlight the key area where I aim to contribute new knowledge through this dissertation: the role of HCD in improving global health accessibility.

2.4.1 Existing Work in Human-Centered Design for Global Health

Alessandra N. Bazzano, Jane Martin, Elaine Hicks, Maille Faughnan, and Laura Murphy [91] conducted a review of HCD in global health to understand the current themes in the field along with the areas of future research. In their review, Bazzano et al. highlight a number of examples of HCD in global health from both academic research and practice. Within academic research, for example, Vechakul et al. applied HCD to *“develop concepts for stimulating a vibrant local economy in the Oakland Best Babies Zone,”* an initiative to reduce infant mortality inequities [92]. Catalani et al. applied HCD to *“[understand] the problem of tuberculosis among people living with HIV, [create] an innovative system for improving the TB [tuberculosis] prevention and treatment practices among HIV providers, and [deploy] a solution in clinics across rural western Kenya”* [93]. van Hoof et al. applied co-design to involve bed-ridden nursing home residents in the *“exploration and generation of innovative environmental enrichment scenarios”* [94]. Within the practice sphere, for example, IDEO [95], frog design [96], and Dalberg Design [97] all engage in a portfolio of global health and wellness work.

Despite these many examples of HCD in global health, Bazzano et al. note that there is limited data on how HCD impacts health outcomes [91]. Additionally, Bazzano et al. observe that the outcomes of importance in design are often different than in health [91]. For example, the outcome of interest in a design project is the solution that is designed (e.g., the product or service). In health, however, the outcome of interest is the health impact of the artifact that is designed. Michael J. Roy, Cam Donaldson, Rachel Baker, and Susan Kerr echo these notions through their study of social enterprises (*“businesses with social objectives whose surplus revenue is reinvested for these purposes”*) working on projects to improve health and well-being [98]. Roy et al. find that social enterprises currently do not understand or study the causal mechanisms by which their activities influence health outcomes or health inequities. Therefore, there is a need to better understand how innovation approaches like HCD can causally influence the outcomes they seek to create, including health accessibility outcomes.

In addition to the many applied examples of HCD in global health, funders are increasingly dedicated to driving forward the practice of HCD in health. Design for Health was created by the United States Agency for International Development (USAID) and the Gates Foundation to integrate design and global health. Design for Health is a community of practice comprising funders, implementers, and designers applying design to achieve global health goals [99].

With all of the emerging work in HCD and global health, there are a number of evident tensions between the two fields. Myra Altman, Terry T.K. Huang, and Jessica

Breland highlight four tensions [90]. First, there is often a difference between what stakeholders want (the concern of HCD) and what healthcare providers believe is most beneficial to stakeholders (the concern of the health field). Second, design prioritizes a full needs assessment including literature reviews, stakeholder interviews, and stakeholder observations while practitioners in the health field tend to rely solely on literature and extant clinical evidence when developing new solutions. Third, design research often focuses on studying small samples of outliers or “extreme” users while health research focuses on studying large, generalizable samples of stakeholders. Fourth, design prioritizes rapid prototyping to test iterative hypotheses (*“fail faster to succeed sooner”* [100]) but health prioritizes research that is driven by an evidence-based hypothesis to mitigate the risk of failure, which can bring serious health consequences [101].

Despite these tensions, researches, funders, and practitioners seem to agree that there is merit to the application of HCD in global health and that health projects can be improved through the application of HCD [90], [91], [101], [102]. To summarize how HCD can be applied in global health, the Design for Health community poses a set of ten Common Principles of Design & Global Health [101]. These principles, listed below, capture the growing intersection of the design and global health fields:

1. **Take a holistic view.** *“We design for the relationships between actors and the ways in which they will impact each other within a health system. We listen to and design for stakeholders at every level within the health system, as well as influencers who sit outside the system, not just the end-user.”*
2. **Embrace complexity, adapt, and learn.** *“We understand that health systems sit at the intersection of complex global, national, regional, and local culture and politics. We elevate contextual factors through rich user engagement and use an iterative approach to help adapt solutions to different cultures and ensure a good fit to national, regional, and local contexts.”*
3. **Tap into the creative power to engage and motivate.** (the description for Principle 3 is currently missing from the Common Principles of Design & Global Health documentation)
4. **Collaborate with many and diverse perspectives.** *“We co-create across disciplinary boundaries and traditional silos within global health systems in a respectful and collaborative manner. We ensure that diverse perspectives and experiences are illustrated to technical experts as a means to understand root causes more deeply and create solutions that are more responsive to end user needs at every level within the health system.”*
5. **Build capacity by engaging communities.** *“We engage the community and other stakeholders as equal participants in creative problem-solving so that they have an increased sense of ownership over the solutions that emerge. We use design to increase the quality of solutions, as well as to build capacity in individuals and*

institutions to more effectively collaborate in addressing challenges and barriers to improved health outcomes.”

6. **Test and iterate, over and over.** *“We rapidly test solutions by putting them in the hands of end users early and often to make assumptions and learnings tangible early in the design process. We iteratively adapt and refine these prototypes with users (and other stakeholders) to reduce the risks associated with introducing new solutions, whether products, services, communications, or other interventions.”*
7. **Anchor on the existing evidence.** *“We start our inquiry with what is known and review the established evidence base. Drawing on user insights, we build on the work of global health experts and incorporate the knowledge of the communities and institutions with which we work to strengthen understanding and challenge existing assumptions. We employ a structured, creative process that connects insights to action in a transparent and rigorous manner.”*
8. **Make solutions accessible, usable, and inclusive.** *“We design inclusively; that is, we make design choices that support widespread adoption across diverse needs and priorities, including those of the individuals and communities who are most disenfranchised from the health system. Good design is accessible, and accessible design is good design.”*
9. **Create solutions that evoke positive emotions.** *“We realize that healthcare products and services that are usable or functional are simply not enough to encourage behavior change and sustained use. We aim to increase the quality of health experiences through thoughtful consideration of the needs, emotions, and constraints of stakeholders at all levels of the system. Our goal, even in resource-constrained environments, is to create feasible, viable solutions that evoke positive emotions for increased uptake and sustained use.”*
10. **Empower users as equal participants.** *“We use a collaborative process that seeks to give communities greater influence over their day-to-day health experiences. We co-design new experiences that take into account, and fit within, existing health behaviors, norms, and beliefs rather than expecting users to change their lives to suit the processes and provisions of the health system.”*

2.4.2 Existing Work in Human-Centered Design for Accessibility

My goal in this dissertation is to understand how HCD can improve health accessibility and to understand how understanding health accessibility can improve HCD. In Section 2.4.1, I describe how HCD has been applied to global health. In this subsection, I describe why HCD needs to better consider accessibility and why health offers the field an opportunity to do so.

To understand how HCD currently considers accessibility, I map efforts within HCD to address the five dimensions of accessibility proposed by Penchansky and

Thomas: *availability, physical accessibility, accommodation, affordability, and acceptability* [22]. This accessibility framework from the health literature offers a specific and holistic understanding of what accessibility is. By mapping how HCD does or does not address Penchansky and Thomas' five dimensions of accessibility, I aim to uncover the areas where HCD can improve how it considers accessibility.

The HCD approach addresses *availability* for some stakeholders: HCD practitioners seek to understand what stakeholders need and then make solutions available to stakeholders. Traditionally, HCD focuses on target stakeholder groups and does not consider the needs of other groups of stakeholders. The *availability* dimension calls for all stakeholders and users to be provided solutions to their needs, so HCD can better address *availability* by considering the needs of many different types of stakeholders and users.

Within HCD, there is a specific “universal design” approach that addresses *physical accessibility* and *accommodation*. Universal design is a broad umbrella term that captures similar approaches, including “inclusive design”, “design for all”, and “barrier-free” design [103]. According to Molly Follette Story, universal design is “*the design of products and environments that can be used and experienced by people of all ages and abilities, to the greatest extent possible, without adaptation*” [104]. There are seven principles of universal design [104]:

1. **“Equitable Use:** *The design is useful and marketable to people with diverse abilities.*
2. **Flexibility in Use:** *The design accommodates a wide range of individual preferences and abilities.*
3. **Simple and Intuitive Use:** *Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.*
4. **Perceptible Information:** *The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.*
5. **Tolerance for Error:** *The design minimizes hazards and the adverse consequences of accidental or unintended actions.*
6. **Low Physical Effort:** *The design can be used efficiently and comfortably and with a minimum of fatigue.*
7. **Size and Space for Approach and Use:** *Appropriate size and space is provided for approach, reach, manipulation, and use regardless of the user's body size, posture, or mobility.”*

While the HCD process in and of itself addresses a few dimensions of accessibility, universal design represents how HCD researchers and practitioners explicitly think about accessibility. However, not all HCD researchers and practitioners engage in universal design and “*much of the work that has been done so far in this area [universal design] has focused on defining groups with different types of disabilities and treating them as entities separate from society in general*” [103]. Additionally, universal design

focuses on people with disabilities, but not on the different abilities and needs of all people. There is therefore a need for HCD to prioritize *physical accessibility* and *accommodation* for all people, and not to single out groups of people with disabilities.

The HCD approach addresses *affordability* through its focus on considering the viability of solutions developed (see Figure 2-10). However, there is a difference between solutions that are commercially viable and solutions that are affordable to all stakeholders and users who need the solutions. Therefore, HCD would benefit from including an approach to explicitly understand what is considered *affordable* for a variety of different groups of stakeholders, not just the target stakeholder groups.

The HCD approach addresses *acceptability* by focusing on the desirability of solutions developed (see Figure 2-10). The core principle of HCD is to develop solutions that meet stakeholder needs and that are desired to be used in practice. However, as I note in my discussion of how HCD addresses *availability*, the traditional HCD process focuses on a limited number of stakeholder groups. There is therefore a need for HCD to consider the *acceptability* of solutions to a broader range of stakeholders.

Although HCD does address the various dimensions of accessibility in some way, accessibility is not a core focus of the HCD process. Specifically, accessibility within HCD is conceived as addressing the accessibility needs of a small group of stakeholders, but not explicitly considering the accessibility needs of all people who may interact with or benefit from the solution. In order to understand how HCD can create more broadly accessible solutions, HCD must better integrate a holistic understanding of accessibility, as I propose in Figure 2-12 below.

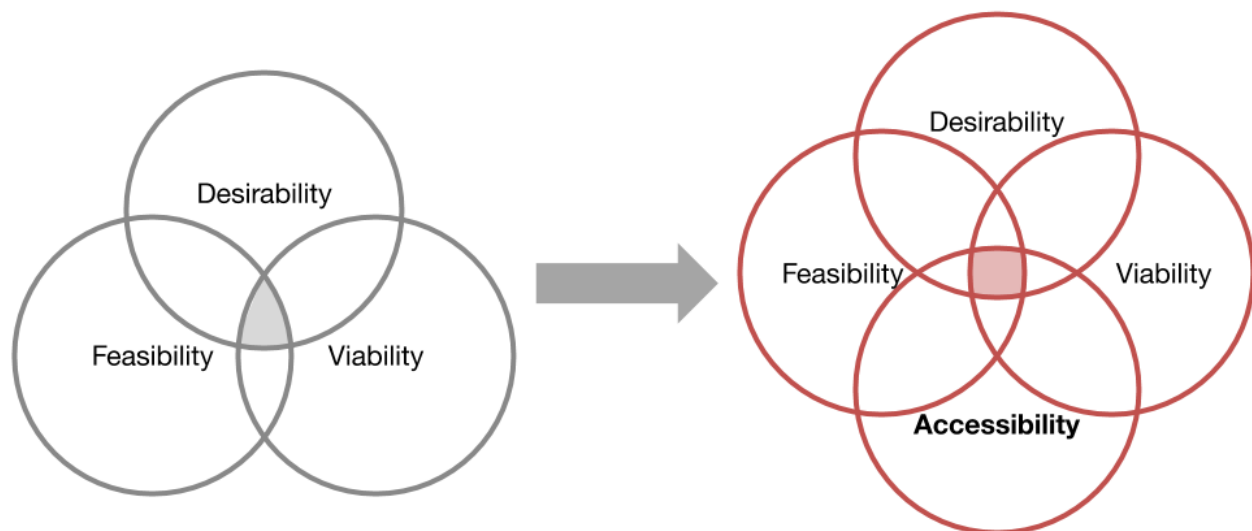


Figure 2-12. HCD with the addition of *accessibility* as a core principle. Source: adapted from [76].

It is my goal in this dissertation to study how HCD has been applied by two organizations seeking to improve access to cervical cancer screening. Through this

study, I aim to propose a new understanding of how HCD can incorporate accessibility as a core principle.

2.5 Conclusion

Global inequities in health access have led to global inequities in health outcomes. The global burden of cervical cancer illustrates this trend clearly: limited access to HPV vaccination and to cervical cancer screening has led to a disproportionate burden of cervical cancer incidence and mortality in LMICs. HCD has a rich history of research to draw upon and is increasingly being applied to complex societal challenges. In order for HCD to address global health accessibility, we need to understand how HCD should incorporate a focus on accessibility. The integration of HCD and accessibility has merit in addressing major global health equity challenges, including cervical cancer. Additionally, integrating accessibility into HCD can improve the overall field of HCD, as considerations of accessibility are not limited to health care.

The rest of this dissertation will present examples of organizations that engage in the creation of new solutions to improve access to cervical cancer screening. In the next chapter, Chapter 3, I present an overview of my previous work on this space: designing and implementing a training tool to support midwives in Ghana learning to screen for cervical cancer. In the remaining chapters, Chapter 4 through 7, I present findings from two case studies I documented of other organizations engaging in design to create new solutions for cervical cancer mortality. In presenting these case studies, I explore the practices that each organization undertakes in developing, testing, and implementing their artifacts within their communities.

Chapter 3

Preliminary Work in Human-Centered Design for Accessibility: *Visualize*

In this chapter, I describe previous applied work I have engaged in at the intersection of human-centered design (HCD) and cervical cancer screening. Visualize, Inc. is a non-profit organization I co-founded that is dedicated to training midwives to screen for cervical cancer [105]. We developed a cervical cancer screening training device called *Visualize* that aids midwives and other healthcare providers in learning how to screen for cervical cancer using visual inspection with acetic acid (VIA).

My intention in presenting this work is threefold: (1) to provide a concrete example of the application of HCD to cervical cancer screening, (2) to describe how my motivation to study HCD and cervical cancer screening came about and how I am situated within HCD, health accessibility, and cervical cancer screening, and (3) to provide context for the importance of considering accessibility in HCD. My work on *Visualize* represents my practical experience applying HCD to improve access to cervical cancer screening. This work has motivated me to explore from a theoretical perspective how HCD is more generally used to address cervical cancer screening access.

3.1 An Overview of *Visualize*

I began to work on *Visualize* in May 2013 as part of a collaboration between the University of Michigan (my undergraduate alma mater), Komfo Anokye Teaching Hospital in Kumasi, Ghana and Korle Bu Teaching Hospital in Accra, Ghana. Today, Visualize, Inc. is a 501c3 non-profit, and my team and I continue our work with partners in Ghana to improve cervical cancer screening education.

A range of dedicated team members and collaborators have been involved in *Visualize*. I broadly acknowledge that all of this work was done in collaboration and thought partnership with Maria Young, co-founder of Visualize, Inc. and co-creator of *Visualize*. We have enjoyed our ongoing collaboration with midwives in Ghana at Komfo

Anokye Teaching Hospital, Korle Bu Teaching Hospital, Global Cervical Charity Foundation, Ridge Hospital, and Pantang Nursing and Midwifery Training College. Our recent work has been conducted in collaboration with Zurak Cancer Foundation, a non-profit organization in Ghana focused on advocacy work related to cervical, prostate, and other cancers.

Visualize is a cervical cancer screening training device that aids midwives and other healthcare providers in learning how to screen for cervical cancer. The training device itself consists of a simulated vaginal cavity, a set of cervical images and a microcontroller plus LCD screen to provide feedback that guides the user through the simulated screening procedure. *Visualize* is a novel approach to addressing cervical cancer mortality in Ghana. A number of people and organizations have attempted to address the issue of cervical cancer detection and early treatment before using VIA and their results have been very positive. However, none of these programs have focused specifically on developing and distributing an effective training method for teaching VIA. This is the gap *Visualize* aims to fill.

3.2 The *Visualize* Design Process

My team and I followed the Innovation Model [74] (Figure 2-9) as we developed our ideas for *Visualize*. We started with an initial problem frame (*Frame and Reframe*) of designing a medical intervention to address a need in maternal and child health in Ghana. This frame was provided by our professor, Kathleen Sienko, at the University of Michigan [106]. We then traveled to Ghana for eight weeks in the summer of 2013 (*Observe and Notice*) to conduct “design ethnography” [107]: observing obstetrics and gynecology departments, family planning clinics, and other health posts; interviewing doctors, nurses, midwives, and health administrators; and conducting a literature review on health care challenges in Ghana.

Our research in Ghana showed us that less than three percent of women in Ghana have had a Pap smear, even though cervical cancer is the number one cause of cancerous death for Ghanaian women [108]. When we interviewed healthcare providers in family planning clinics, we learned that few women in Ghana could afford to get a Pap smear and we learned that community health clinics were often not equipped to perform Pap smear. Optimistically, however, we also learned about VIA, a low-cost alternative to the Pap smear. As I describe in Section 2.2.1, VIA is a method where a healthcare provider applies table vinegar to a patient’s cervix and then examines the cervix to see if any white lesions have appeared, signifying the existence of pre-cancerous cells. In Ghana, midwives are the healthcare providers most likely to perform cervical cancer

screening, yet we learned that midwives in Ghana were not trained to perform VIA, and therefore the method was not widely used in Ghana. Based on this research, we narrowed in on our project focus (*Frame and Reframe*): to improve training for VIA among midwives in Ghana.

With this project frame in mind, we began to generate and synthesize ideas to improve VIA training in Ghana during Fall 2013 (*Imagine and Design*). We developed the idea to create a physical training device to teach midwives in Ghana how to perform VIA. In late Fall 2013 and throughout Spring 2014, we built and tested various versions of a physical training device (*Make and Experiment*). We tested our device with healthcare providers in the United States (US) and in Ghana. A summary of our early work is provided in [109]. Since 2014, we have continued to test and iterate various versions of *Visualize*, eventually creating the most recent version (Figure 3-1).

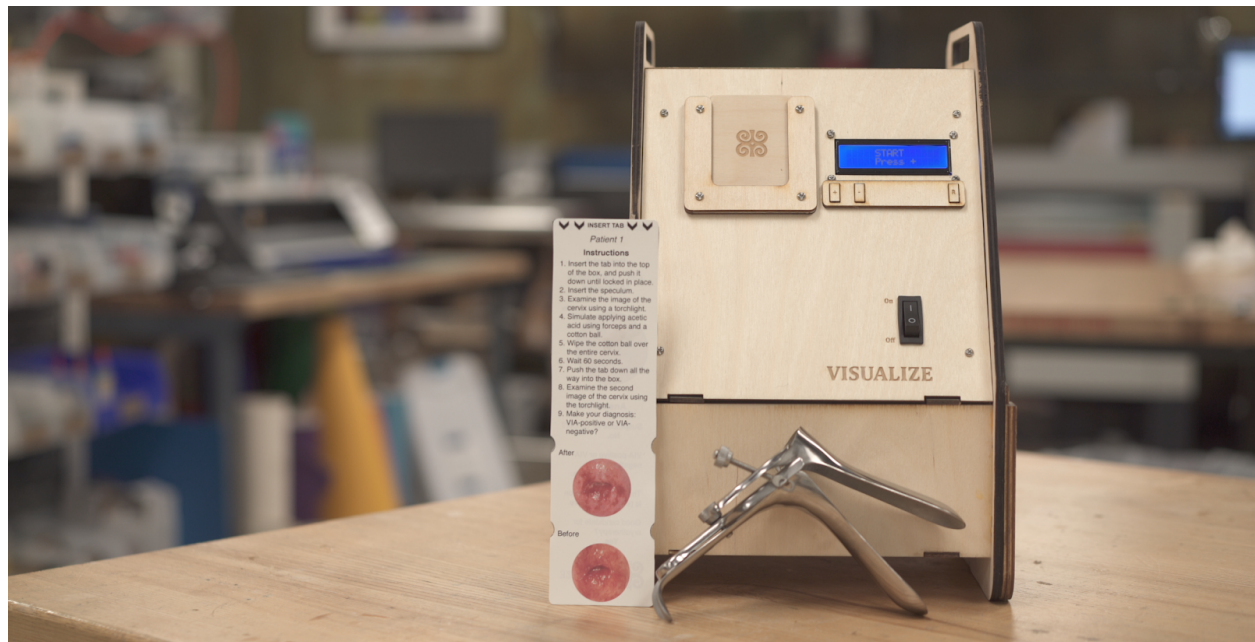


Figure 3-1. The current version of *Visualize* built in Spring 2018.

The *Visualize* training device allows a midwife to practice performing VIA in a low-risk yet realistic environment. Therefore, midwives can improve their VIA skills before they actually screen patients. *Visualize* features a simulated vaginal cavity (behind the covering on the left side of the device) that allows a midwife to pass a speculum and examine a pictured cervix. The midwife is guided through the process by the Arduino microcontroller and LCD screen (on the right side of the device). The midwife turns on the device using the power switch (on the bottom right of the device) and then advances through a series of instructions and prompts using the buttons underneath the LCD screen.

Images of cervixes before and after applying acetic acid are shown on a set of paper tabs (Figure 3-2). These tabs can be inserted into the top of the training device and are visible behind the simulated vaginal cavity. The front of the tab includes instructions for how to use the tab and images of a cervix before and after acetic acid is applied. The back of the tab includes a magnified view of the cervix after acetic acid is applied, pointing out the areas indicative of precancer, if applicable. Currently, we have created eleven tabs and continue to seek more photos of cervixes from collaborators around the world.

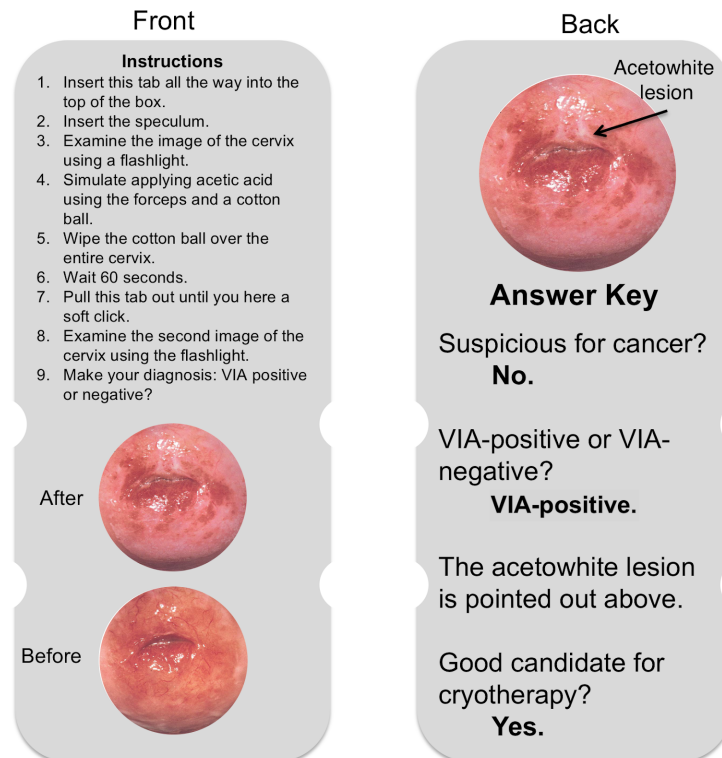


Figure 3-2. A rendering of the paper tabs used in *Visualize*.

Throughout our early work, we applied HCD to create the most functional, usable, and cost-effective device possible. After creating early versions of the *Visualize* prototype, we realized that in order to make sure our device would be used by those who need it the most, we had to think of our design process as broader than just the device itself. We began to consider questions of accessibility like *which healthcare providers in Ghana can access the training? what other educational materials do we need? how do we create awareness of the training? and how do we work with hospitals and health centers to make the training accessible?* Therefore, as we were testing the physical prototypes we developed, we added a new focus to our project: how to implement our training device within existing midwifery curricula in Ghana (*Frame and Reframe*).

To think about how to create and measure impact, we fleshed out our theory of change, or our “*comprehensive description and illustration of how and why a desired change is expected to happen in a particular context*” [110] showing how Visualize ultimately aims to reduce cervical cancer mortality (Figure 3-3). Our hypothesis is that distributing the training model plus an educational curriculum will result in more midwives becoming proficient in VIA. These midwives will then go on to perform more VIAs. As more women are screened, fewer women will die of cervical cancer.

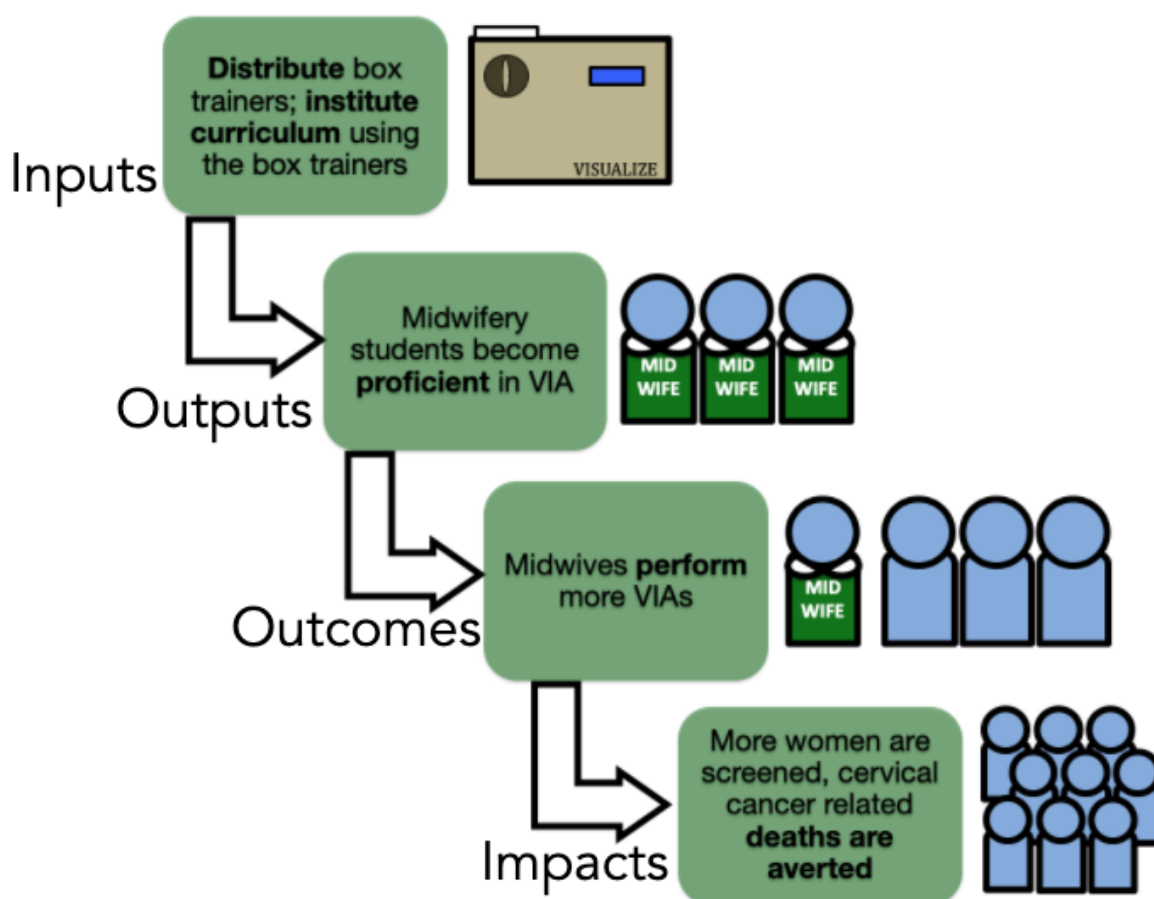


Figure 3-3. Theory of change for how *Visualize* will create impact at scale.

To accompany the *Visualize* device, we worked with midwives in Ghana to develop a curriculum for midwives learning to perform VIA and for trainers who are teaching midwives to perform VIA. The curriculum includes (1) a facilitator’s guide for conducting VIA training with *Visualize*, including theoretical lecture materials on cervical cancer and VIA, plus instructions on the structured use of *Visualize*; (2) an instruction guide for midwives to use *Visualize*; and (3) a maintenance guide to fix small damages and breakages of *Visualize*.

3.3 Current Status and Future Plans of *Visualize*

Currently, our team is in the ongoing process of testing the *Visualize* device and curriculum (*Make and Experiment*) and of conducting research on how to manufacture and implement *Visualize* in Ghana (*Observe and Notice*). *Visualize* is ready to be implemented into midwifery curriculum in Ghana. The device is certified by Ghana Standards Authority for use in Ghana, and we are now looking forward to working with various regulatory bodies in Ghana (e.g., the Nursing and Midwifery Council) to implement *Visualize* with midwifery trainees learning how to perform VIA.

Zurak Cancer Foundation, our implementation partner, is deeply involved in the day-to-day work of speaking with regulatory partners and curriculum stakeholders. We intend to pursue two routes of implementing *Visualize*: (1) incorporating *Visualize* into midwifery schools (“pre-service” education), and (2) incorporating *Visualize* into continuing education for practicing midwives (“in-service” education).

In collaboration with Zurak Cancer Foundation, Visualize, Inc. looks forward to implementing *Visualize* within midwifery training and evaluating the successes and the areas for improvement.

3.4 Summary of *Visualize*

The *Visualize* training device aims to enable midwives in Ghana to perform and teach others to perform VIA, a proven screening method that is affordable and accessible for women. By detecting precancerous cells early, these women can get the treatment they need in time to save their lives. By engaging with Ghanaian collaborators and partners early and often in our design process, the hope of our program is to be locally managed and sustained.

I invoke *Visualize* as an example of how I have previously engaged in HCD applied to cervical cancer. By working on *Visualize*, I learned of the need to apply HCD to consider factors that impact the accessibility of the solution. After seeing the ways in which this type of approach was effective, *Visualize* has motivated me to understand how other organizations apply design methods, tools, and mindsets to their own work in cervical cancer. This work highlights the importance of understanding how HCD can be applied to improve health care access and has led me to study the role of HCD in cervical cancer screening in my dissertation work.

Chapter 4

Research Framework and Methodology

The goal of this dissertation is to assess if and how human-centered design (HCD) improves access to cervical cancer screening. In Chapter 3, I discuss my experience applying HCD to improve cervical cancer screening access. The focus of my dissertation is to extend my practical experience by studying the role of HCD applied to cervical cancer screening from a theoretical perspective. In this chapter, I lay out my guiding research questions (RQs), my research methods, my data sources, and my methods of data analysis.

4.1 Research Questions

Two RQs guide this dissertation:

RQ1. How and why do organizations consider **accessibility** in creating and implementing programs to address cervical cancer screening?

RQ2. How and why do organizations use **human-centered design** to create and implement these cervical cancer screening programs?

The bolded words in the above RQs demonstrate the key topic of each RQ.

4.2 Research Method: Exploratory Case Study Approach

To answer these RQs, I took an exploratory case study research approach. The case study approach is the most appropriate to address my RQs for several reasons. First, a case study research approach lends itself to answering questions of “how” and “why” [111]. Second, case studies allow researchers to holistically study the context

surrounding the unit of analysis, study the dynamics present within a single case setting, and combine several types of data collection to triangulate findings [111], [112].

An exploratory research approach is useful to empirically generate theory. A contribution of this dissertation is to empirically generate nascent and testable frameworks about HCD in health care screening. My dissertation lends itself to an exploratory approach because there are currently no theories regarding the role of HCD in improving access to health care.

According to Yin and Eisenhardt, there are eight steps to exploratory case research [111], [112]:

1. Getting started
2. Selecting cases
3. Crafting instruments and protocols
4. Entering the field
5. Analyzing data
6. Shaping hypotheses
7. Enfolded literature
8. Reaching closure

I describe each of these steps in the subsections below.

4.2.1 Getting Started

The first step in exploratory case study research is to define RQs and to define any *a priori* constructs. I present the RQs I defined in Section 4.1. Before beginning data collection, I specified two constructs to guide my research.

The first construct I specified was the “theory of change”. According to The Center for Theory of Change, a theory of change is “*a comprehensive description and illustration of how and why a desired change is expected to happen in a particular context*” [110]. A theory of change links the inputs of a program to its outputs, outcomes, and impacts:

- **Inputs** are the resources and actions put into the program.
- **Outputs** are the things accomplished immediately because of the program.
- **Outcomes** are the benefits and changes apparent on a longer time scale because of the program.
- **Impacts** are the long-term consequences of the program.

The second construct I specified was the dimensions of health care access defined by Penchansky and Thomas. Health care access is “*a concept representing the degree of ‘fit’ between the clients and the [health] system*” and there are five specific dimensions

of health care access [22]. In the list below, I include the definition from Penchansky and Thomas (in quotations) and I provide a summarizing question to define each dimension:

- **Availability:** *“the relationship of the volume and type of existing services (and resources) to the clients' volume and types of needs.”* This dimension asks the question: are services available for all patients who need them?
- **Physical Accessibility:** *“the relationship between the location of supply and the location of clients.”* This dimension asks the question: are services located near patients?
- **Accommodation:** *“the relationship between the manner in which the supply resources are organized to accept clients and the clients' ability to accommodate to these factors.”* This dimension asks the question: are there known entry points for patients to use the services?
- **Affordability:** *“the relationship of prices of services and providers' insurance or deposit requirements to the clients' income, ability to pay, and existing health insurance.”* This dimension asks the question: are the services affordable, considering income, liquidity, and insurance of patients?
- **Acceptability:** *“the relationship of clients' attitudes about personal and practice characteristics of providers to the actual characteristics of existing providers, as well as to provider attitudes about acceptable personal characteristics.”* This dimension asks the question: are the services and the providers socially acceptable to patients?

4.2.2 Selecting Cases

After defining RQs and *a priori* constructs, I then defined the unit of analysis. In this dissertation, the unit of analysis in each case study is a specific cervical cancer screening program created by an organization.

Next, I selected the cases. First, I identified the following criteria to choose appropriate case studies:

- The organization created a cervical cancer screening program located in a low or middle-income country with a high burden of cervical cancer.
- The organization's cervical cancer screening program is still active today.
- The organization's program has a different primary goal and approach to addressing cervical cancer screening access compared to other organizations already selected.
- The organization applied a human-centered approach to design and implement their solution.

I first searched online and through my professional network to identify organizations addressing cervical cancer screening around the world. Eisenhardt [76] suggests that four to ten cases are necessary to build theory. After attempting to contact more than five organizations, I successfully contacted and held a preliminary conversation about my research with two organizations. Based on these initial conversations and on my

background research, I learned that both organizations fit the criteria above and were interested in participating in this research. These two organizations are my two case studies:

- InVia Technologies
- Mujeres Móviles

In Section 4.2.8, I discuss my decision to close this study at two case studies. For the purposes of this research, I consider InVia and Mujeres Móviles to be *exemplars* of organizations applying HCD to improve cervical cancer screening access. The intention of my research is to explore the current successful practices of HCD in cervical cancer screening accessibility and to develop new frameworks of HCD for accessibility based on these current best practices.

4.2.3 Crafting Instruments and Protocols

Within each case, I collected data in three categories: (1) the **context** of the cervical cancer screening program, (2) the **process** to create and implement the program, and (3) the **outcomes** of the program.

To explore the **context** in which each cervical cancer screening program was created, I sought to understand the organizations' motivations to create and implement the program and to understand the current state of health and cervical cancer screening access in each case's country. I conducted interviews with the program creators and I performed a literature review of cervical cancer screening in each case's country.

To explore the **process** to develop each cervical cancer screening program, I sought to understand the programs' approaches to improving accessibility (i.e., which dimension(s) of accessibility they targeted) and the design processes each organization employed to create their program. I conducted interviews with the program creators, I reviewed documents and artifacts provided by the organizations, and I observed the programs in action.

To explore the **outcomes** of each cervical cancer screening program, I sought to understand how well the programs succeeded in meeting their cervical cancer screening goals. I conducted interviews with the program creators, I reviewed documents and artifacts provided by the organizations (including any prior evaluation studies), and I observed how stakeholders interacted with the programs in action.

All instruments and protocols were approved by the University of California, Berkeley's Institutional Review Board 2018-10-11520.

4.2.4 Entering the Field

4.2.4.a Conducting Research with InVia

I first contacted InVia in April 2017. At the time, I was conducting fieldwork with *Visualize* in Ghana (Chapter 3) and I came across InVia's website. After sending an introductory email to the InVia team, I eventually began to collaborate with InVia in my capacity as co-founder of Visualize, Inc. The purpose of our collaboration was to learn from each other's approaches to increasing cervical cancer screening. Specifically, I began to work with members of the InVia team to understand how to train healthcare providers to screen for cervical cancer. This topic is the core of Visualize, Inc.

Between April 2017 and December 2018, I was introduced to InVia, including four co-founders and three additional team members. None of these co-founders or members of InVia live in India, and are instead distributed across the United States (US). I worked with several of these co-founders and team members to develop a training protocol. Through this ongoing collaboration, I learned that InVia was planning a trip to India to test their most recent prototype with clinicians and to gain feedback from other collaborators. I asked InVia if I could join this trip and therefore include InVia as one of the case studies in my dissertation. The members of InVia agreed and paid for my trip, including flights and accommodations, to India.

In December 2018, I traveled to India with two members of InVia, Co-Founder A and Co-Founder B. I spent two weeks in the field with InVia, conducting interviews with key members and stakeholders of InVia and performing daily observations of InVia's in-country operations.

After returning to the US, I continued to collect observational data from InVia's weekly team meetings, convened on a video conference call. I continued to join these meetings through April 2019.

4.2.4.b Conducting Research with Mujeres Móviles

I first contacted Mujeres Móviles in September 2017. I discovered Mujeres Móviles' work through my Visualize, Inc. co-founder, Maria Young. At the time, Maria worked at the University of Michigan — Maria's and my undergraduate alma mater — and knew of a group who had worked with Mujeres Móviles. Maria connected me with members of the group who then connected me with the Mujeres Móviles co-founders.

I began a series of phone interviews with the Mujeres Móviles co-founders beginning in September 2017. I originally planned to travel to Nicaragua in May 2018 but postponed my trip due to political unrest in Nicaragua [113]. I continued to keep in

touch with Mujeres Móviles and eventually re-scheduled my trip to Nicaragua for June 2019. I received funding for my travel and accommodations in Nicaragua from the University of California, Berkeley's Innovations at the Nexus of Food, Energy, and Water Systems Fellowship.

In June 2019, I traveled to Nicaragua to meet the Mujeres Móviles team. I spent two weeks in the field, moving between towns in Central Nicaragua and Northwestern Nicaragua where the two main Mujeres Móviles teams are located. I interviewed Mujeres Móviles team members and co-founders and performed daily observations of Mujeres Móviles' operations, including their mobile cervical cancer clinics.

4.2.4.c Summary of Data Sources

In Table 4-1, I summarize the data I collected from both InVia and Mujeres Móviles. Note that each "page" of documentation corresponds to a 8.5" x 11" page consisting of content typed at 12 point font.

Table 4-1. Total number of hours and pages of data collected with InVia and Mujeres Móviles.

	InVia	Mujeres Móviles
Participant observation	2 weeks full time - Observations of usability tests and internal team conversations 4 months of weekly meetings - Remote observation of team check-in calls 150 hours of observation, corresponding to 81 pages	2 weeks full time - Observations of mobile cervical cancer clinics, education, outreach, and internal team conversations 100 hours of observation, corresponding to 28 pages
Organization-specific documentation	- Organization website - Organization blog 12 pages of documents analyzed	- Organization website - Organization blog - 2017 and 2018 annual reports - News articles about organization 83 pages of documents analyzed
Interviews	- 3 co-founders 3.5 hours of interviews, corresponding to 65 pages	- 3 co-founders (interviewed as a group) - 8 mobile cervical cancer clinic team members - 1 education team member 5.5 hours of interviews, corresponding to 84 pages
Total	158 pages	195 pages

4.2.5 Analyzing Data

4.2.5.a Constructing and Coding the Corpus

To analyze the data I collected, I first typed and transcribed all observation notes and interview transcripts. I constructed a full corpus of data consisting of de-identified participant observation notes, organization-specific documentation, and interview transcripts (Table 4-1). For the case study of InVia, there were 158 pages in the corpus. For the case study of Mujeres Móviles, there were 195 pages in the corpus. Therefore, the full corpus was 353 pages.

Another researcher and I began by coding this corpus separately and inductively, a process of tagging portions of the text in the corpus related to how the organization designed their cervical cancer screening program to be accessible. We then organized these inductive codes into themes, which included the organizations' phases of the design process, motivations to start or join the organization, relationships with collaborators, team member dynamics, and ways of navigating systems and context. These inductive codes captured the organization's HCD for accessibility activities plus the demographics and context of the organization. We then met to create a preliminary codebook pairing our inductive codes with *a priori* deductive codes: the theory of change and the five dimensions of access. A small subset (~7%) of the full corpus was selected to test the preliminary codebook. In MaxQDA 2018, we each coded the small subset of the corpus with our preliminary codebook, noting the difficulties we faced in applying the codes and developing inclusion and exclusion criteria for each code. We then met to resolve differences in how we applied the codes. We repeated this process four times on four additional small subsets of the corpus, totaling 25% of the full corpus.

After coding and revising our codebook on these five subsets of the corpus, our final codebook totaled 89 codes. Our original goal was to achieve intercoder reliability of at least 80% (i.e., we applied the same codes to the same content 80% of the time) yet we were unable to do so in any of our five rounds of coding the subsets of the corpus. We found that due to the expansive nature of the corpus and the exploratory nature of the study, we could not consistently come to agreement on how or where to apply each code. Therefore, instead of dividing up the remainder of the corpus to be coded individually, we chose to each fully code the remainder of the corpus.

With our final codebook, we each coded the remaining 75% of the corpus. After doing so, we again met to resolve any differences in our coding. At the end of this process, the entire 353 page corpus was coded and reviewed by two independent coders.

4.2.5.b Analyzing the Case Studies

Analysis is “*both the most difficult and the least codified part of the process*” [112]. To move through the massive set of codes applied in the corpus, I first conducted a *within-case* analysis of each organization followed by a *cross-case* analysis of both organizations.

Within each case (Chapters 5 and 6), I summarized the application of codes to compile a description of the organization and their program to improve access to cervical cancer screening. First, I summarized each organization, including the context of the country the organization operates in, the range of programs the organization operates, the personnel in the organization, and the historical timeline of the organization. Next, I summarized the design practices within each organization, including the design process they employed and a comparison of their process to the International Organization for Standardization (ISO) 9241-210 [85] standard to assess the “human-centeredness” of their approach. Then, I summarized the ways the organization addresses accessibility of cervical cancer screening. I sent the descriptive portion (i.e., the organizational summary and the design process employed) of my analysis to each organization to fact check. InVia requested small clarifications while Mujeres Móviles did not request any changes. From these fact-checked descriptions of the organizations, their design practices, and their considerations of accessibility, I then analyzed how each organization’s design practices and considerations of accessibility overlapped and how their cervical cancer screening program was designed to improve accessibility.

In the cross-case analysis (Chapter 7), my goal was to look at data in many divergent ways and to go beyond my initial impressions of the data. To do so, I applied a range of tactics suggested by Eisenhardt [112] and Yin [111]:

- List the similarities and differences between cases
- Identify key themes for each code that attend to all data in the corpus
- Evaluate the causes and effects within cases and compare these chains across cases

I then developed two frameworks to capture the similarities in the design approach employed by InVia and Mujeres Móviles. These frameworks are the emergent “hypotheses” I put forth for future study, as I describe below.

4.2.6 Shaping Hypotheses

The within-case and cross-case analyses were highly iterative with the goal of shaping hypotheses to explain patterns in the data [112].

Eisenhardt [112] and Yin [111] suggest strategies to shape and refine hypotheses within and across cases:

- Develop hypotheses of patterns in the data based on within-case and cross-case analyses
- Identify evidence in support of these emergent hypotheses
- Identify rival hypotheses that would explain the patterns in the data, and then refute or consider these hypotheses
- Revise hypotheses into a proposed theory, concept, or construct
- Assess the fit between proposed theory, concept, or construct and data from each case considered individually
- Put forth future work to test the theory, concept, or construct

The hypotheses I developed are frameworks to capture the characteristics and process of HCD for accessibility. These frameworks (Section 7.4) are elaborations of existing HCD frameworks that account for the process of considering multidimensional health care access.

4.2.7 Enfolding Literature

Again, the within-case and cross-case analyses, the process of shaping hypotheses to explain patterns in the data, and the process of comparing emergent theory to existing literature are all highly iterative [112].

Throughout the process of analyzing the cases and developing explanations, I searched for existing work by health and design researchers noting similar or different patterns in their findings. In Section 2.4, I present work that scholars and practitioners have done at the intersection of design and health. In Section 7.4, I develop the frameworks of HCD for accessibility by comparing the findings from the two case studies to existing HCD frameworks.

4.2.8 Closure

Mujeres Móviles and InVia each represent a particular archetype of an organization seeking to improve access to health care: a service-providing non-profit founded in the country of implementation, and a technology-driven for-profit founded in the US remote from the country of implementation, respectively. By comparing these exemplary cases, I develop a set of frameworks to describe HCD for accessibility.

Given the exploratory nature of this research, I chose to conduct two case studies and to put forth my emergent frameworks for future testing and refinement through the study of additional case studies.

4.3 Limitations in the Research Methods

In this study, I assume that both InVia and Mujeres Móviles are exemplars from which to build best practices and a new understanding of HCD for accessibility. A limitation of this assumption is that I do not conduct an impact evaluation of either InVia or Mujeres Móviles in this work, so I do not formally check whether or not both cases are successful in reaching their goals. Notably, InVia has not yet implemented their solution in practice but Mujeres Móviles has implemented their solution. A key area of future research will be in studying the impact of HCD for accessibility on health outcomes.

Another key limitation of this work is that I collect retrospective accounts of the design process from the InVia team and the Mujeres Móviles team. There is likely bias in what team members remember of their past work that I ask them to recall in the interviews. To address this limitation in future research, I can conduct a longitudinal study where I observe and interview design teams “live” from the initiation of their project to the implementation of their solution.

4.4 Locating Myself in the Research

As a participant observer with InVia and Mujeres Móviles and in carrying out two qualitative case studies, I must acknowledge my identity and my philosophical assumptions of research. I am educated primarily as an engineer and much of my education has been rooted in a positivist tradition. Previously, the majority of my education focused on applying the scientific method to study phenomena in the world. Today, my research is more concerned with humans, and specifically with how humans create and interact with solutions that are designed (e.g., products and services).

I believe in the existence of multiple truths, with meaning being created by individual people based on their interactions with artifacts within the world they inhabit. I believe in transdisciplinary research, where collaboration across or between disciplines can generate novel insights not possible to be created by only a single discipline. I personally am an interdisciplinary scholar, formally trained in mechanical engineering (BSE, MS, PhD) and public health (MPH). I am a White, cisgender woman living in a high-income country (the US) and raised in an upper middle class family. These identities inform my dissertation research and therefore my findings are interpreted through my lenses.

Chapter 5

A Case Study of InVia Technologies

In this chapter, I present a case study of an organization designing a new technology to improve accessibility to cervical cancer screening in India: InVia Technologies. To set the stage for this organization's work, I first provide an overview of the demographic and health care context in India (Section 5.1), including the burden of disease and the healthcare system in India. I then provide a descriptive overview of InVia (Section 5.2) including the programs InVia has created, the personnel involved in InVia, and the historical timeline of InVia. After presenting this descriptive context, I then present an analysis of how InVia applied human-centered design (HCD) and considered accessibility as they created ccScreen, their program to improve access to cervical cancer screening (Section 5.3). Then, I discuss and evaluate InVia's HCD process and InVia's ways of considering accessibility (Section 5.4).

InVia is the first of two case studies I present in this dissertation of organizations who are applying HCD to improve access to cervical cancer screening. InVia is a technology-driven for-profit organization founded in the United States (US) remote from India, the country of implementation. I consider InVia to be an exemplar of best practices in HCD for product design. In Chapter 7, I will compare the case study of InVia that I present in this chapter to the case study of Mujeres Móviles that I present in Chapter 6. By comparing these two exemplary cases, I develop a set of frameworks to describe the process and the characteristics of HCD for accessibility in Chapter 7.

5.1 Indian Context

In order to understand why InVia developed their programming to address cervical cancer screening access, it is important to first understand the historical and demographic context that the InVia team considered while crafting their solution. The team created their cervical cancer screening program as a response to the lack of reliable and affordable cervical cancer screening services in India, which is influenced

by the broader political context and health system in the country. These contextual factors continue to play a role in how InVia develops and implements their services.

India is the second most populous country in the world — behind China — with a population of more than 1.35 billion people [114]. India is the largest democracy in the world and the seventh largest economy, behind the US, China, Japan, Germany, the U.K., and France [115]. The U.K. controlled the Indian subcontinent from 1765 to 1947, draining vast economic resources during this time [116]. The Indian independence movement began in 1857 and culminated in 1947, when the Indian subcontinent was declared independent from the U.K. and was divided into two countries: India and Pakistan [117].

5.1.1 Context of Health in India

Figure 5-1 shows the general burden of disease in India. Slightly more than half of disease and disability in India is due to non-communicable diseases. Communicable, maternal, neonatal, and nutritional diseases are responsible for more death and disability in India than in the world as a whole (see Figure 2-1).

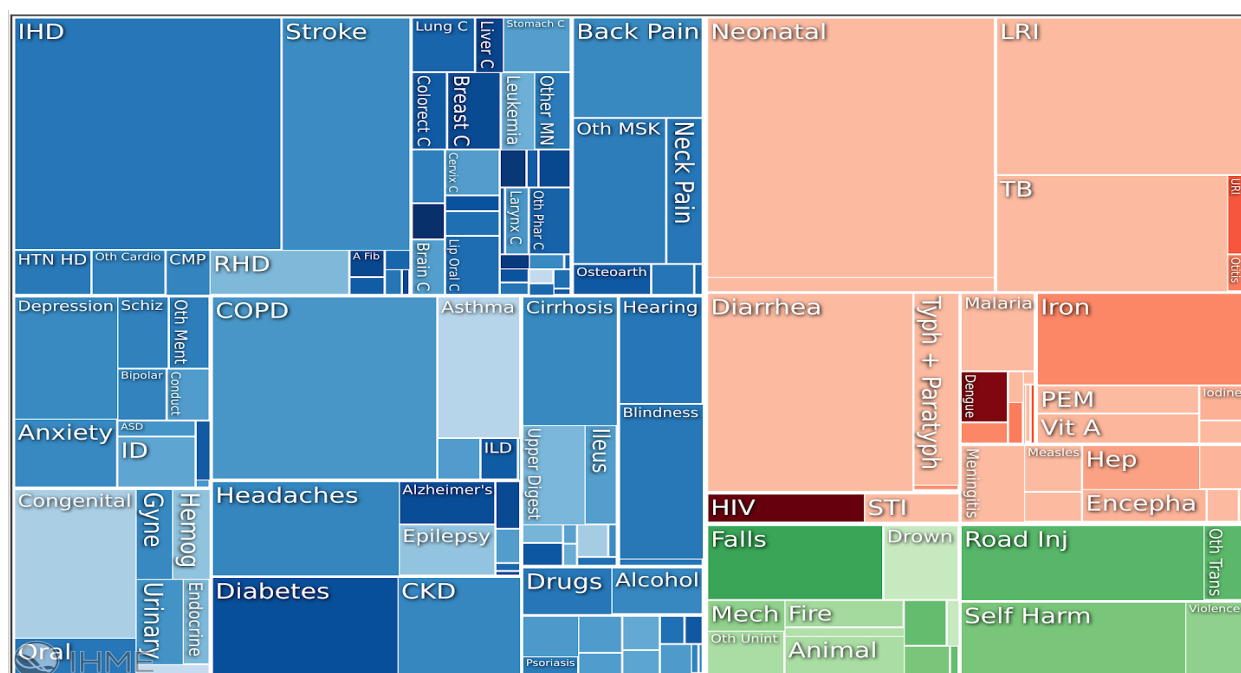


Figure 5-1. Burden of death and disability in India, measured in disability-adjusted life years (DALYs), 2017. The majority of death and disability in India is due to non-communicable diseases (blue), and a smaller portion of death and disability is due to communicable, maternal, neonatal, and nutritional diseases (red), and injuries (green). Larger boxes indicate a larger proportion of DALYs. Darker colors indicate a more positive percent annual change (1990 to 2017). Source: [118]. Reused per Creative Commons BY-NC-ND 4.0 license.

The public health system in India includes three tiers: primary, secondary, and tertiary facilities. This three tier structure is meant to connect people across India with a primary community health center that can then refer the person to more specialized care at secondary and tertiary facilities. However, India faces a shortage of medical staff and medical supplies [119]. The urban poor in India tend to have more limited access to health care than the rural poor due to extremely high population density and limited numbers of primary community health centers in urban areas.

India offers tax-financed health insurance to the public. Citizens can access public insurance through a variety of schemes, most stemming from their employer. Wealthy individuals and families can purchase private insurance instead of public insurance, but uptake of private insurance is limited. One particular public insurance scheme offers insurance outside of the employer to families whose income falls below the poverty line. Despite this range of insurance schemes, less than 20% of the Indian population had health insurance in 2014 [119].

India does not rank highly in terms of health quality and access. As I discuss in Section 2.1.2, a group of authors constructed a Healthcare Access and Quality (HAQ) index based on data from the 2015 Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) [21]. This index, which ranges from zero to 100, approximates healthcare access and quality by measuring the mortality rates of health conditions that are amenable to care. I consider the HAQ index to be a cumulative measure of all five of Penchansky and Thomas' dimensions of health care accessibility. India's HAQ index is only 45. The authors who constructed the HAQ index divide each of the world's countries into quartiles based on the Socio-Demographic Index (SDI). A country's SDI is a composite metric of a country's income, education, and fertility [120]. Out of 38 countries in the third SDI quartile (i.e., lower middle SDI countries), India ranks 28th in terms of HAQ. This means that when comparing India to other countries with similar socio-demographic contexts, India's healthcare quality and access is poor. For comparison, Nicaragua's (third SDI quartile) HAQ index is 64 while the US's (first SDI quartile) HAQ index is 81.

Cervical cancer, a non-communicable disease, is a major problem in India. Behind breast cancer, cervical cancer is the second most common and second deadliest cancer among women in India [121]. In 2018, 14.7 per 100,000² women in India were diagnosed with cervical cancer and 9.2 per 100,000 women in India died of cervical cancer. Translated to raw numbers, in 2018 96,922 women in India were diagnosed with cervical cancer and 60,078 women in India died of cervical cancer.

² The incidence rate of 14.7 per 100,000 women and the mortality rate of 9.2 per 100,000 women are both age-standardized rates.

5.2 Description of InVia

InVia was founded in 2015 as the result of a class project in an undergraduate engineering design course. The four co-founders of the organization met while students at a US university and teamed up for a biomedical engineering senior design course. During the course, the co-founders engaged in “biodesign,” a process to create new and innovative medical technologies [89]. As a result of this class, the team developed a technology, ccScreen, to improve the standardization of the visual inspection with acetic acid (VIA) screening procedure. I describe the details of this technology in Section 5.2.1.a. After developing the initial version of their technology in 2015, the team chose India as their initial target implementation site. Given the vastness and the complexity of the Indian healthcare system (Section 5.1), the team believes that if they can first implement ccScreen in India, then they can implement ccScreen anywhere.

Over the past five years, the co-founders graduated from their university and officially formed a for-profit LLC, InVia Technologies, to continue their work. In that time, the organization has developed solutions to meet their overarching vision: to leverage technology to improve the standardization and automation of health procedures.

The core focus of InVia is on leveraging technology towards health and societal benefit. The first project (and the impetus for the organization) is around cervical cancer screening. However, the future plans for the organization (specifically, the two other programs they are currently planning as I describe in Section 5.2.1) are not directly in the topic area of cervical cancer. Co-Founder A of InVia relates the organization’s vision to the topic of cervical cancer: *“[The ultimate goal in my mind is] enabling mobile health technologies to transform health care for low-income individuals around the world. I think the way we do that is we have to learn how a mobile health solution can get implemented. That’s through cervical cancer screening.”*

5.2.1 Overview of InVia’s Programs

Today, InVia has developed one program focused on cervical cancer screening and is in the process of developing two other programs unrelated to cervical cancer screening: a mobile health ecosystem and a biometric identity authentication system.

In their first program, the primary focus of this chapter, InVia developed a technology to improve cervical cancer screening called ccScreen. The vision for this technology is to provide accessible, accurate, and standardized cervical cancer screening for clinics and hospitals in low- and middle-income countries (LMICs) around the world. There are two key features of ccScreen: a hardware component and a

software component. On the hardware side, ccScreen includes a handheld cervical scope with a digital camera surrounded by lights. The camera-end of the cervical scope can sit flush on the end of a speculum, therefore allowing the camera to view the patient's cervix during a pelvic examination. On the software side, ccScreen includes an Android app that prompts the healthcare provider using the cervical scope to take images of the patient's cervix before and after acetic acid is applied during the VIA procedure. The software is connected to the hardware, so the images taken through the camera on the handheld cervical scope are seen on the app. Then, a machine learning algorithm is applied to the cervical images before and after acetic acid is applied, outputting a new cervical image that shows the healthcare provider where suspected lesions are located on the cervix, thus indicating the location of precancerous cells. The team has already developed the cervical scope and the mobile phone application, and they continue to work on developing the machine learning algorithm. Further technical details, including a walkthrough of how ccScreen is envisioned for use in practice, is provided in Section 5.2.1.a.

In their second program, InVia envisions a mobile health ecosystem that connects mobile health companies together to create a central, universal data hub for coordinated data access by healthcare providers and patients alike. This program is inspired by the fact that India is experiencing a digital surge, with millions of new internet users and smartphone users each year. As of March 2019, only forty percent of Indian citizens were connected to the internet, but this portion is expected to significantly increase as internet infrastructure continues to be built across the country and as smartphones and data plans become less expensive. As India becomes more digitized, the Indian healthcare system stands to benefit immensely from technologies that will address the limited access, low quality, and low patient satisfaction of the Indian healthcare system [122]. InVia has not finalized the details of this mobile health ecosystem yet, but it will likely consist of a mobile phone application that aggregates patient data across other mobile health apps to create a centralized and personalized patient profile.

In their third program, InVia envisions a biometric system to authenticate a person's identity, which can be used by health administrators to provide community health workers (CHWs) in the field with transient and secure access to patient information. Therefore, this biometric authentication system allows for patient privacy to be maintained among the range of healthcare providers they may encounter in the field. Only high-level health administrators would have the access needed to view the patient's full medical and personal portfolio. InVia has developed a prototype of this system, using a small device that takes an image of the peripheral vein in a person's finger. The image of this peripheral vein is unique in every person and therefore can be

used to authenticate a person's identity. InVia has not yet finalized the integration of this technology with the other programs and technologies they have developed.

In this chapter, I focus specifically on InVia's first program: ccScreen. This program is most directly related to the improvement of access to cervical cancer screening, which is the subject of this dissertation. Therefore, this program is the most comparable to the work of Mujeres Móviles (Chapter 6). In Section 5.2.1.a below, I provide further details on the ccScreen system in practice.

5.2.1.a ccScreen

The typical use of ccScreen includes four groups of people: a CHW out in the field, a remote clinician, a health administrator, and a patient.

A CHW is the primary user of the ccScreen system. Before using the ccScreen system, the CHW is first trained by a clinician on the basics of cervical cancer screening, including how to conduct a pelvic examination, use a speculum, identify cervical abnormalities, conduct VIA, use ccScreen, counsel a patient, and record their findings in the ccScreen app. Upon finishing training, the CHW can go into the field to screen patients using ccScreen. A health administrator manages the logistics of screening events and grants access to the CHW to access relevant patient records. On the ccScreen app, the CHW enters the patient's information and records any concerns or changes in general health the patient may have. Then, the CHW conducts the pelvic examination and the VIA procedure. Using the ccScreen app, the CHW takes images of the patient's cervix before and after acetic acid is applied and then uses ccScreen to generate a map of areas suspicious for pre-cervical cancer. The CHW can make a negative diagnosis themselves but must await confirmation from a trained clinician to make a positive diagnosis. To accommodate this, the app then sends the images taken by the CHW to a remote clinician, and the clinician makes a diagnosis and a treatment plan. If treatment is necessary (i.e., if the patient is VIA-positive), the CHW and the clinician schedule a time for the patient to come back and receive treatment from the clinician. Once the clinician provides the CHW with the next steps, the CHW counsels the patient through these steps.

The patients do not directly interact with the ccScreen system, but do so through their interactions with a CHW who performs screening.

The journey map in Figure 5-2 shows these interactions.

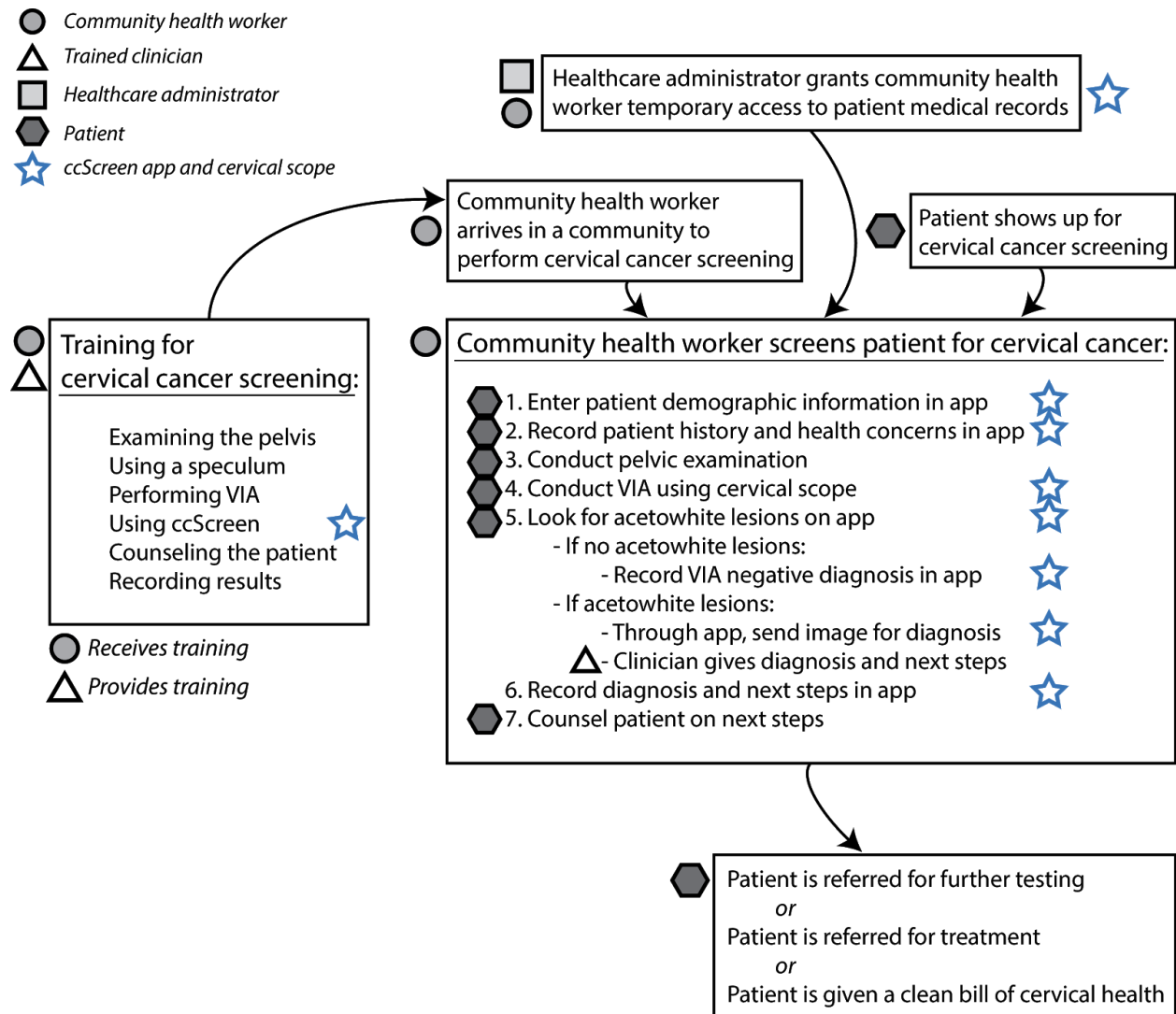


Figure 5-2. The journey map for how ccScreen is used, including interactions between CHWs, clinicians, and patients.

The vision of ccScreen is to “*provide automated, accurate and accessible cervical cancer screening for clinics and hospitals in LMICs worldwide.*” To understand how ccScreen seeks to enact this vision, I have created a theory of change for ccScreen, where the goals of ccScreen are categorized as *inputs, outputs, outcomes, and impacts*. This theory of change is critical in thinking about how InVia envisions that ccScreen will create impact on cervical cancer mortality.

Figure 5-3 below shows the theory of change for ccScreen.

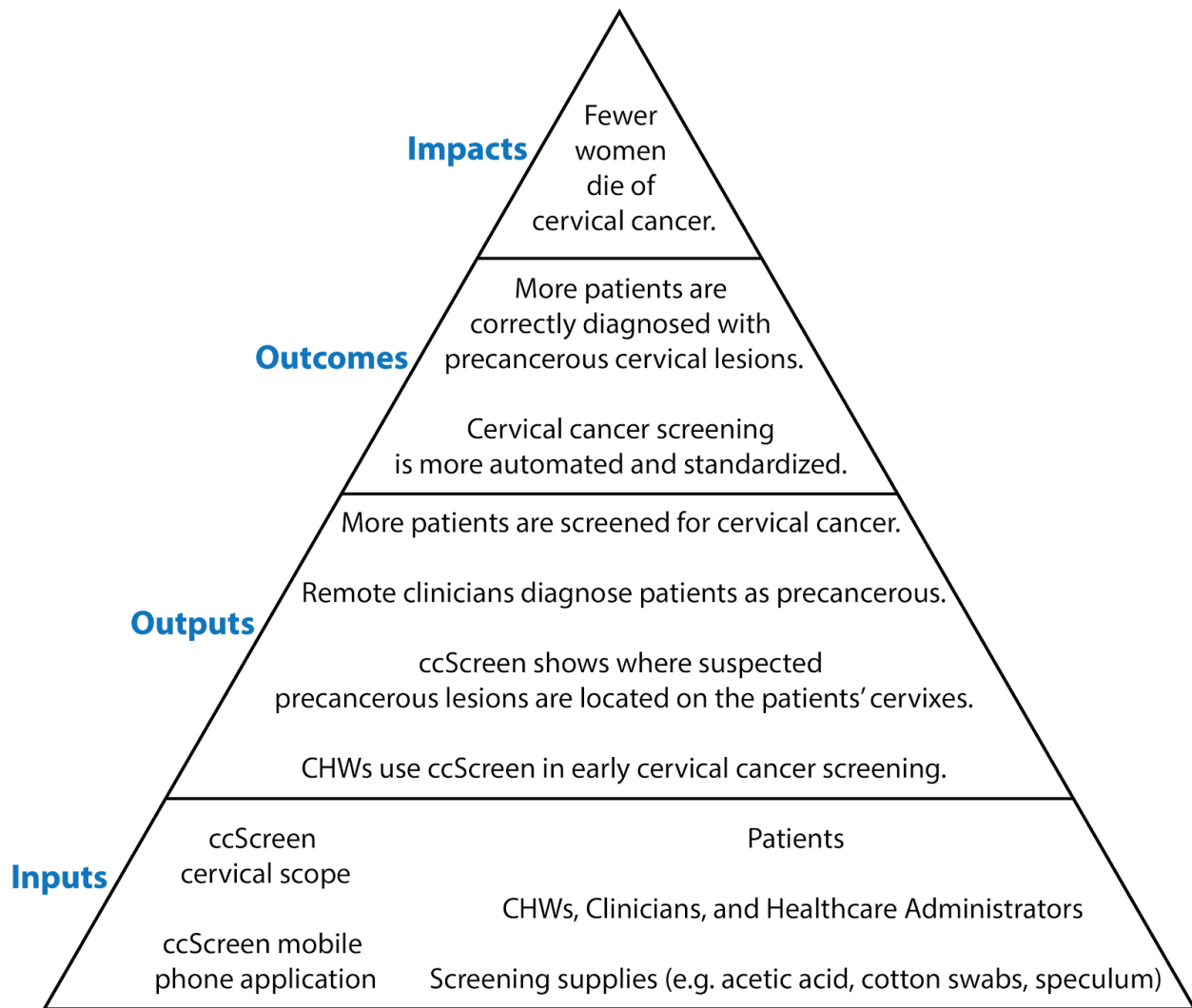


Figure 5-3. Theory of change demonstrating how InVia intends for ccScreen to create impact.

5.2.2 Personnel of InVia

In 2015, the four co-founders of InVia worked together on a university biomedical engineering class project to initiate their work on ccScreen. Currently, the co-founders work with three team members, three advisors, and a range of collaborators. All co-founders and team members work on InVia part-time.

Co-Founder A is the Chief Executive Officer of InVia and he leads the funding, the India operations, the overall strategy, and the emerging mobile health ecosystem program of InVia. Co-Founder A is currently a PhD student in bioengineering. Co-Founder B is the Chief Technical Officer of InVia and he leads both the circuit design of the ccScreen cervical scope and the back-end development of the ccScreen app, including the app database and storage. Co-Founder B is currently a joint medical

student and PhD student. Co-Founder C is the Chief Operating Officer of InVia and she leads the front-end development of the ccScreen app, with a focus on the user experience / user interface (UX/UI) of the app. Co-Founder C is currently a PhD student in bioengineering. Co-Founder D is the Chief Medical Officer of InVia and she leads both the hardware design of ccScreen and the clinical trials strategy. Co-Founder D is currently a medical student.

Currently, InVia is composed of three team members. Team Member 1 is an undergraduate at the co-founders' alma mater, and she leads the ongoing efforts to develop a survey to assess the nationwide need for cervical cancer screening in India. Team Member 1 also assists with managing the mobile application's data storage. Team Member 2 is a PhD student with Co-Founder A and he assists with the technical development of ccScreen along with the InVia business model development. Team Member 3 is a graduate of the co-founders' alma mater and she works with Co-Founder D on the ccScreen hardware design and the clinical trials strategy.

Three advisors have supported InVia since its founding. InVia's Engineering Advisor is a university professor and he was the instructor for the biomedical engineering design course where the four co-founders first started to work on ccScreen. The Engineering Advisor continues to advise the team on product development and design processes. InVia's Prototyping and Development Advisor is a staff member at the four co-founders' alma mater where she works on biomedical engineering innovation and entrepreneurship. The Prototyping and Development Advisor advises the team on their prototype development and clinical trial strategies. InVia's Implementation Advisor is a health care entrepreneur and he originally met the team in early 2016 during a Lean Launchpad immersive bootcamp. The Implementation Advisor continues to provide the team with feedback on their implementation strategies, including legal, manufacturing, and commercialization considerations.

Four organizations and two individuals collaborate with InVia. Visualize, the non-profit organization that I co-founded and describe in Chapter 3, collaborates with InVia to develop training for the ccScreen system. India Health Innovations Organization is a non-profit organization that works to deliver preventive health services to their members, who are people of marginalized communities in India. India Health Innovations Organization works with InVia to implement ccScreen within their member network. India Institute for Cancer Prevention is a non-profit organization focused on cancer eradication. India Institute for Cancer Prevention works with InVia to both provide clinical feedback on ccScreen and to implement ccScreen among its network of clinicians. Prototype Manufacturing Company is an American company that supports hardware-focused startup organizations. Prototype Manufacturing Company provides InVia with feedback on the manufacturability of the ccScreen cervical scope and 3D prints prototypes of ccScreen's cervical scope for testing. Medical Doctor A works with

InVia to evaluate the ccScreen system in a clinical setting. Finally, the team's Biometric Device Collaborator is an undergraduate engineering student and is the brother of Co-Founder A. He leads the development of the biometric authentication system.

Table 5-1 shows the range of people and organizations involved with InVia.

Table 5-1. Personnel involved with InVia, including co-founders, team members, and collaborators.

Role	Name	Description of Work with InVia
Co-founder	Co-Founder A	Chief Executive Officer. Leads the funding, India operations, overall strategy, and emerging mobile health ecosystem program of InVia
	Co-Founder B	Chief Technical Officer. Leads both the circuit design of the ccScreen cervical scope and the back-end development of the ccScreen app, including the database and storage
	Co-Founder C	Chief Operating Officer. Leads the front-end development of the ccScreen app focusing on UX/UI
	Co-Founder D	Chief Medical Officer. Leads both the hardware design of ccScreen and the clinical trials strategy
Team member	Team Member 1	Leads the efforts to develop a survey assessing the need for cervical cancer screening in India. Assists with app storage
	Team Member 2	Assists with the technical development of ccScreen along with the InVia business model
	Team Member 3	Assists with ccScreen hardware design and the clinical trials strategy
Advisor	Engineering Advisor	Advises on product development and design processes
	Prototyping and Development Advisor	Advises on prototype development and clinical trial strategies
	Implementation Advisor	Advises on implementation strategies
Collaborating organization	Visualize	Collaboratively develops ccScreen training
	India Health Innovations Organization	Plans to implement the ccScreen system within member network
	India Institute for Cancer Prevention	Provides clinical feedback on ccScreen and plans to implement ccScreen among its network of clinicians
	Prototype Manufacturing Company	Provides manufacturing feedback on the ccScreen cervical scope and builds prototypes for testing
Collaborating individual	Medical Doctor A	Evaluates the ccScreen system in a clinical setting
	Biometric Device Collaborator	Leads the development of the biometric authentication system

5.2.3 Historical Timeline of InVia

In the Fall 2015 academic semester, the four co-founders teamed up for their biomedical engineering senior design course, taught by Engineering Advisor. The four co-founders had a range of interests within biomedical engineering: Co-Founder A and Co-Founder B focused on bioimaging, Co-Founder C focused on cell and tissue engineering, and Co-Founder D focused on biomechanics. The course brought together students in all biomedical engineering concentrations and taught students how to identify clinical needs, develop solutions to meet those needs, and build and test those solutions. During the first semester of this two-semester course, the team members first identified a range of clinical needs they could address, then decided to focus on women's global health, and then narrowed further to focus on cervical cancer.

In early 2016, before the start of the Spring 2016 academic semester, the four co-founders engaged in a Lean Launchpad immersive bootcamp [123] where they met their Implementation Advisor. During this bootcamp, they interviewed over a hundred stakeholders to learn more about the global burden of cervical cancer.

In the Spring 2016 academic semester, the four co-founders took the second semester of their biomedical engineering senior design course, again taught by their Engineering Advisor. In the second semester, they developed and sketched out their early ideas and then began to prototype tangible versions of their ideas. With these prototypes in hand, they began to gain feedback from US clinicians, eventually refining their prototype into a functional prototype of the ccScreen cervical scope by the end of the Spring 2016 semester. During this semester, the team developed the idea for the ccScreen app but did not yet build it out. Additionally, the team enrolled in an entrepreneurship class during the Spring 2016 academic semester, learning strategies of business model development and launching a startup.

The four co-founders graduated at the end of Spring 2016. During Summer 2016, the co-founders settled into their new locations and responsibilities, which included graduate school for some co-founders (Co-Founder A and Co-Founder D) and research for other co-founders (Co-Founder B and Co-Founder C). InVia Technologies, LLC was officially founded during Summer 2016.

In Fall 2016, the four co-founders continued to remotely develop ccScreen. Co-Founder A worked on developing the InVia business model. Team Member 1 joined the InVia team and began to work on developing the front-end of the ccScreen app. In December 2016, Co-Founder A, Co-Founder C, and the team's Prototyping and Development Advisor traveled to India to test their functional prototype with stakeholders in India. The prototype they tested was a refined version of the prototype developed during their senior design course.

The first half of 2017 was focused on learning from the India trip. The four co-founders discussed the necessary design changes that emerged from the December 2016 India trip. Each co-founder then focused on a unique aspect of developing the ccScreen system. Co-Founder A secured funding through grants and competitions for InVia. Co-Founder B developed the machine learning algorithm at the back-end of the ccScreen app. Co-Founder C learned how to use Android Studio and began to develop the ccScreen app. Co-Founder D iterated the physical design of the ccScreen cervical scope. Additionally, two new team members joined the InVia team. Team Member 2 joined the team with a focus on developing analytics for the app to monitor its usage in practice. Team Member 3 joined the team to support the physical design of the cervical scope. In Summer 2017, Visualize contacted InVia to begin collaborating on developing training for the ccScreen system.

The second half of 2017 and all of 2018 focused on the continued development of ccScreen. Co-Founder A continued to fundraise and develop the business model for ccScreen. Co-Founder B, Co-Founder C, and Co-Founder D continued to develop the app, the circuit design, and the physical design of the ccScreen system. As part of her work outside of InVia, Co-Founder C traveled to Cambodia and Thailand to learn about the state of sexual and reproductive health (including cervical cancer screening) in these two countries. Team Member 1 began to develop a survey to learn more about the broader need for the ccScreen system across India.

In Fall 2018, the team finalized the next iteration of ccScreen. Co-Founder B finalized the microcontroller, circuit design, and electronic design of the ccScreen cervical scope. Co-Founder B and Team Member 2 finalized the backend database of the ccScreen app. Co-Founder C finalized the interface of the ccScreen app. Co-Founder D coordinated with Prototype Manufacturing Company to 3D print functional medical grade prototypes. Simultaneously, the team's Biometric Device Collaborator had been independently developing the biometric authentication device.

In December 2018, I traveled with Co-Founder A and Co-Founder B to India. InVia's primary goals for this trip were to (1) gather usability feedback on the new version of the ccScreen app and cervical scope, and (2) set up plans to conduct future pilot studies and clinical trials with ccScreen in India. Additionally, InVia hoped to gain feedback on their emerging ideas for two new programs: the mobile health ecosystem and the biometric authentication device.

In Spring 2019, InVia worked to address the design changes made evident during the trip. I completed my data collection in April 2019 and therefore will not present the trajectory of the organization since then.

5.3 InVia's Process of Human-Centered Design for Accessibility

In this section, I discuss the HCD process that InVia employed to create ccScreen. I discuss how their HCD approach took them around the four design process phases presented in Beckman and Barry's Innovation Model [74] (Figure 2-9), and I explain the specifics of InVia's work in each phase.

Figure 5-4 below shows InVia's HCD process laid out on a timeline. Each number corresponds to a different phase of the design process, and the Innovation Model phase name is in ***bold italics***, starting in *Frame and Reframe* (Phase 1) and ending in *Frame and Reframe* (Phase 20). InVia's design activities are organized into "clusters" noted by the color coding in Figure 5-4. These clusters point out the high-level tasks that InVia carried out, and demonstrates that InVia often worked on several overlapping tasks at once, particularly in their later phases.

In the remainder of this section, I describe the various phases of InVia's process to design ccScreen and I explore how the InVia team considered accessibility during their design process. In Section 5.4, I discuss their HCD for accessibility approach, and I present an evaluation of the "human-centeredness" of their design approach plus the accessibility considerations present in their design approach.

Phase 1 - Project Initiation (*Frame and Reframe*)

The team of four co-founders began to work on ccScreen in Fall 2015 at their university in the US when they teamed up to work on their senior biomedical engineering design class taught by their Engineering Advisor. The class had an overall theme of global health, and therefore the team focused on global health issues as their initial project frame. All four team members were aligned on their global health focus. According to Co-Founder A:

"All of us [Co-Founder A, Co-Founder B, Co-Founder C, Co-Founder D] were either born in foreign countries or are the children of immigrants, and we all had extensive experience with either living there or going and visiting and seeing health care. Well, not only health care but [also] the lifestyle disparities."

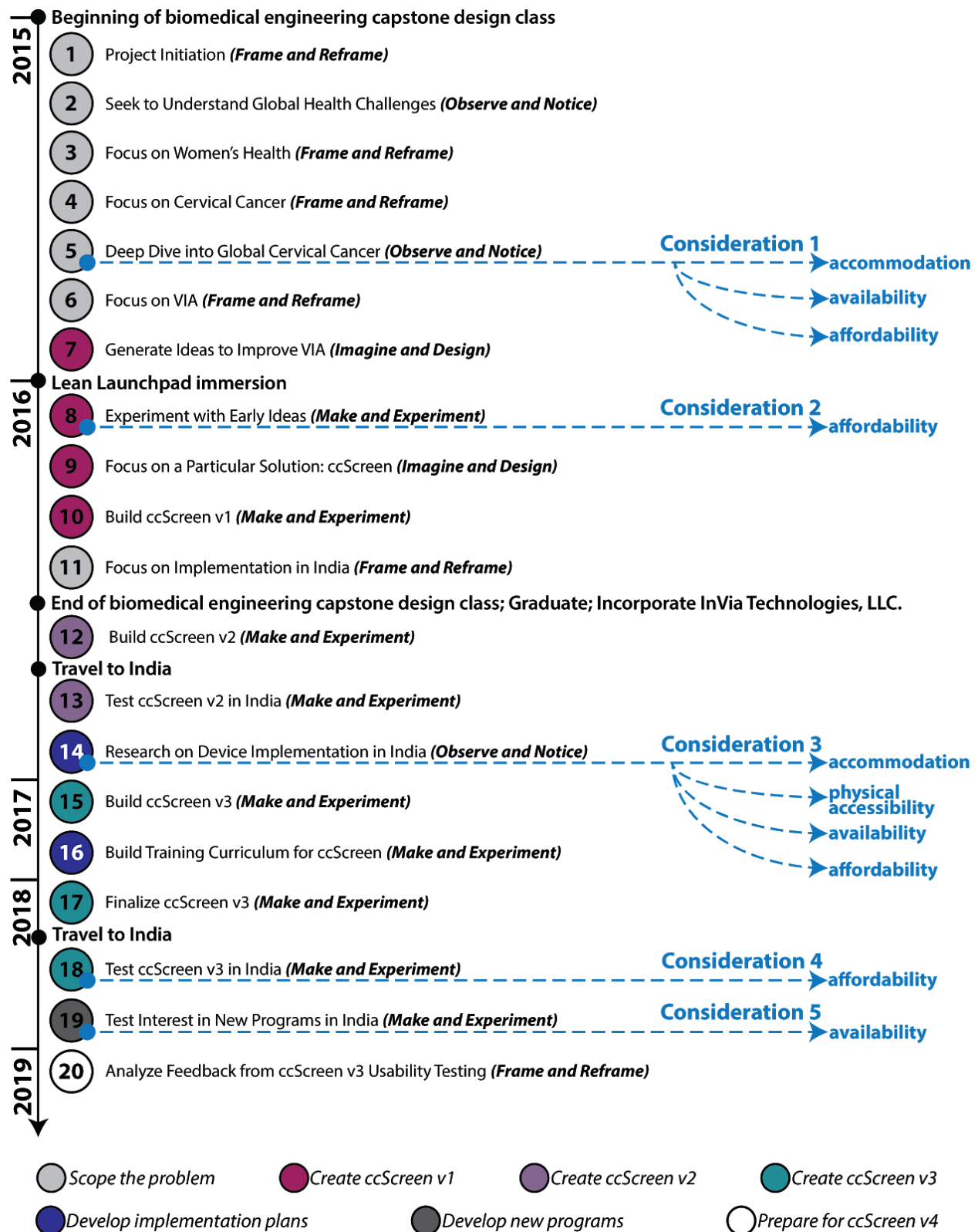


Figure 5-4. Timeline of InVia's design phases and considerations of accessibility.

Phase 2 - Seek to Understand Global Health Challenges (*Observe and Notice*)

In the first semester of their class, the team began doing broad research on global health. Their professor, their Engineering Advisor, had a pre-existing professional connection to Uganda and therefore set up remote interviews between students and clinicians in Uganda. From the interviews with Ugandan clinicians, Co-Founder C states there were several projects of interest that emerged:

"[One potential project was to create] a way to adapt medical devices that had different battery types, because [clinicians in Uganda] only had double A batteries or triple A batteries on hand. Those weren't compatible with a lot of devices that they had in the hospital, and so those devices were just not being used."

Additionally, the team conducted interviews with domestic clinicians who worked abroad. According to Co-Founder B, the team interviewed a broad range of stakeholders for their insight into global health challenges:

"In the design class we talked to gynecologists or health care workers or just general practitioners in lower resource settings. Sometimes [we would talk to] people who are professors of global health who go off and do those sorts of things... [We would] ask them, 'What are problems [you see in your work]?'"

In this phase of the design process, the team sought to identify "clinical deficits" that could effectively be addressed with technological solutions. Co-Founder A discusses that technology was a key consideration in how the team characterized clinical deficits:

"Our main thing was understanding where is the greatest need that can be addressed through technology in a way that is respectful to current standards, but also improves upon them. So we didn't want to just throw technology at a problem and say, Oh, it's fixed. We wanted to ... implement without it being intrusive."

Additionally, Co-Founder B acknowledges that the team's desire to create a technological solution for LMICs could have broader utility in high-income countries:

"Technologies that are developed in the context of global health... a large part of what they do is something that's done in developed countries or developed regions but cheaper or with fewer resources. I think a lot of the time those things end up doubling back to developed nations ... because they end up doing the same thing but cheaper and with less resources."

Phase 3 - Focus on Women's Health (*Frame and Reframe*)

From their initial research and their focus on applying technology in a way that actually addresses the clinical deficit, InVia narrowed their focus from global health to *women's* global health. Co-Founder A explains this decision:

“One thing that we settled on pretty early was this interest in women's health... First off health is such a marginalized subject area [in LMICs] compared especially to high-income countries... but women's health is even further marginalized in this context. So the thinking that went into this was ‘is there a way that we can help improve women's health in a way that is adaptable to current methods, but provides a noticeable improvement, whether it be in what we're looking for ultimately in accuracy, but also throughput [seeing more women]?’”

Phase 4 - Focus on Cervical Cancer (*Frame and Reframe*)

Once the team focused on women's health, they continued to narrow in on the types of clinical deficits they wanted to address. First, they chose to focus on deficits that offered clear opportunities for technological improvement. Specifically, they focused on women's global health issues that were not being sufficiently addressed by “first world technologies.” Co-Founder A explains how this process led the team to cervical cancer screening as a key problem to solve:

“We looked at solutions and need spaces where there were things that [other groups] tried and failed. And what we saw oftentimes was people trying to shoehorn ‘first world technologies’ into the wrong context... And, one of the things that came up as a result was cervical cancer screening.”

The team found that cervical cancer was a huge need, given the stark disparity in incidence and mortality between LMICs and high-income countries. The team thought that cervical cancer was a women's health challenge amenable to technology. Co-Founder B adds that Co-Founder A was a key driver in leading the team towards cervical cancer screening:

“We had a bunch of different ideas that we had to look into and think about in terms of feasibility and what we really wanted to do. Ultimately, [we] ended up deciding on cervical cancer. I think Co-Founder A really pushed for cervical cancer screening and I think it's partly because he was interested in point-of-care diagnostics. It seemed pretty interesting and feasible I think for everyone else in the group. So we all agreed on that.”

Phase 5 - Deep Dive into Global Cervical Cancer (*Observe and Notice*)

After the team decided to tackle cervical cancer, they dove deep into the global challenges of cervical cancer and cervical cancer screening. The team reached out to experts in cervical cancer, as Co-Founder C describes:

“[We] ended up talking to some people at PATH [a large global health non-profit] who were specialists in cervical cancer and developing interventions with regards to cervical cancer. The people at PATH were also connected to Jhpiego [another large global health non-profit, known for their work in cervical cancer screening]. So [Jhpiego] has that experience of coming up with the process of VIA when it was first being developed.”

Co-Founder B adds that the team reached out to a diverse range of stakeholders involved in the process of cervical cancer screening.

“A lot of the time we would talk to physicians, but we also spoke to a number of hospital administrators about the logistics of screening and how frequently people get screened. How easy is it for people to access that, where does that happen? We talked to NGOs [non-governmental organizations] and people at the World Health Organization to understand ‘screen-and-treat camps.’ We spoke to health care workers who are often the ones doing these tests.”

While doing this research, the team discovered that major issues in cervical cancer screening in LMICs are misdiagnosis and overtreatment. These problems are especially pernicious with the VIA procedure.

5.3.1 Consideration of Accessibility 1: Accommodation, Availability, and Affordability

During Design Phase 5, the team learned how cervical cancer screening was currently performed around the world. They learned about the VIA procedure and the ways VIA was carried out in different countries around the world.

These learnings led the team to frame their design challenge around three dimensions of access: *accommodation*, *availability*, and *affordability*. In the dimension of *accommodation*, the team was concerned with how their eventual solution would fit into existing cervical cancer screening clinical practices. This related to their consideration of *availability*: the team wanted to leverage their technical skill sets to create a technological solution that would standardize and therefore improve the quality of cervical cancer screening. The team envisioned that their challenge was not around replacing existing practices but amplifying the quality and therefore the impact of existing cervical cancer screening practices. Simultaneously, the team was conscious from the start about *affordability*. Given their focus on global cervical cancer issues, the team did not want to “over-engineer” the solution or create a solution so high-tech that it would be out of the price range of those who would need it most.

These accessibility considerations led the team to frame their design challenge in Design Phase 6 on the VIA screening method.

Phase 6 - Focus on VIA (*Frame and Reframe*)

The team specified their focus on improving the VIA cervical cancer screening procedure. The decision to focus on VIA was driven by expert recommendations for

cervical cancer screening in LMICs. Co-Founder C explains how the team decided to focus on VIA instead of another cervical cancer screening procedure:

“Our initial research showed that [VIA] is the technique that's been proposed by the World Health Organization to ... screen for most cervical cancer in low-income countries. We wanted to make sure that we were engineering within the typical cervical cancer screening pathway.”

The team also found a good fit between their technological skill sets and the challenges associated with VIA, as Co-Founder A describes:

“One thing I really fundamentally believe with technology ... is that it allows for standardization and automation. We wanted to see what was working and what was not working. And we saw VIA was both working and not working. It was working [for] someone who's trained well and consistently does it, [but] it doesn't work so well for someone who does [only] a few of them. It can be variable from person to person... so we focused on VIA because we could provide this level of automation and standardization simply through [our] device.”

The team remained extremely conscious of price. They tailored their focus towards developing a low-cost and effective technological solution that could actually solve the challenge of limited access to cervical cancer screening.

Co-Founder B discusses how their solution had to be based on a full understanding of VIA, including how the procedure could be used to quickly provide results and treatment:

“We always from the beginning felt like we knew [our solution would be] a screening thing, but we also had to understand the context ... how is the result then used afterwards? How is treatment [provided]?... if you couldn't get test results pretty quickly, then you might not ever see that [patient] again. You don't know if they're going to be in the area. A lot of times people would travel... [and you] don't have any contact information on them. So we definitely knew that ... the way we wanted to address this clinical deficit wasn't to replace VIA, but to supplement it and to work within its constraints and confines and workflow.”

Based on their understanding of VIA and their considerations of accessibility, the team framed their design challenge as standardizing the VIA procedure which would allow them to provide a high quality (*availability*) screening procedure at a low cost (*affordability*) that would not significantly alter current practices around cervical cancer screening (*accommodation*).

Phase 7 - Generate Ideas to Improve VIA (*Imagine and Design*)

At the end of the first semester of their design class, the team was armed with knowledge on global health, cervical cancer, and the issues prevalent in existing

cervical cancer screening methods. They leveraged these insights as they began to imagine what their solution might be.

They started with an open brainstorming session where team members would “shout out” ideas. Through this process, according to Co-Founder A, the team came up with “50 or a hundred ideas.” After this divergent process, Co-Founder B notes that the team cycled through converging and re-diverging:

“We had to come up with just dozens of ideas of how to address that clinical deficit and then think in depth about each one of them, like how they work, how feasible they are, why we would want to look in that direction or why we wouldn’t want to look in that direction. And then again, go through this iterative process of narrowing it down, adding more ideas as we were coming up with them, narrow it down until we get to one.”

Following this diverge-converge process, the team settled on a general idea of their solution: a device that would take images of the cervix to aid in diagnosing patients as VIA-positive or VIA-negative.

Phase 8 - Experiment with Early Ideas (*Make and Experiment*)

In Winter 2016 between the first and second semesters of their design class, the team engaged in a two-week intensive Lean Launchpad class. In this class, the team interviewed over 100 stakeholders to try to learn as much as possible about developing a technology to address challenges in cervical cancer screening. Co-Founder B describes the range of people the team interviewed in this class:

“It wasn’t just clinicians, but it was health care workers, hospital administrators, biotech companies, other startup co-founders or founders. So it was just anyone you could talk to that would have any value or pertinence to what you were trying to do.”

During these interviews, the team began to test some of their initial ideas for a device that would take images of a patient’s cervix to aid in the VIA procedure. The team continued this process of early experimentation throughout the second semester of their design class. At this point, the team sought feedback from stakeholders by showing them sketches or 3D models of their ideas. The team was developing working prototypes in the lab, but according to Co-Founder B:

“At that point, a lot of [the ideas we showed stakeholders] were more conceptual and the prototypes that we made were more stuff that we’d have for ourselves as we would make something, see how it [worked], remake it, make it a little better, and remake it.”

In this phase of the design process, the team gained feedback from stakeholders to keep the device simple.

According to Co-Founder C, one idea the team tested was to include an “acetic acid application system where it looked like a funnel of some sort that you could pour

acetic acid onto [the cervix]” along with the cervical imaging system. However, clinicians told the team that application of acetic acid is not a significant challenge in VIA, so the team dropped this idea.

According to Co-Founder A, another idea the team tested was to utilize fiber optic cables to go into the patient’s cervix and take images of the endocervical canal. The team gained feedback from stakeholders that this idea was too high tech, too expensive, and unnecessary to address the challenges of VIA. The team took a step back and focused on simplicity, as Co-Founder A describes:

“[We were] starting a little bit too, not too ambitious but too expensive ... too high tech. And then [we] realized that we can take steps backward and get to something that will be first off adaptable but also more importantly, practical to use. So we had to think about the user of this product. Because initially we were thinking clinicians, then we learned more and more that it’s [community] health care workers.”

5.3.2 Consideration of Accessibility 2: Affordability

As the team was testing some of their early ideas during Design Phase 8, Co-Founder B recalls that they gained feedback from interviewees to simplify their ideas and to remember not to make their solution too expensive:

“That was largely kind of the feedback that we had [received] of just we don’t want ... some sort of breakthrough technology because it’s [too] expensive.”

This reminder to consider *affordability* led the team to refine their ideas in Design Phase 9. In Design Phase 9, the team fleshed out the details for a more simple solution: ccScreen.

Phase 9 - Focus on a Particular Solution: ccScreen (*Imagine and Design*)

In the second semester of their design class, the team leveraged the feedback they gained on their initial ideas to develop more refined ideas for their solution.

In this phase, they conceptualized ccScreen: a device that pairs a camera with a mobile phone application that takes an image of the patient’s cervix during the VIA procedure and then generates a “map” showing where precancerous lesions are located on the patient’s cervix.

Phase 10 - Build ccScreen v1 (*Make and Experiment*)

With a refined vision of ccScreen, the team began to build and test the ccScreen concept (Figure 5-5). The team focused on developing the cervical scope and the lesion detection algorithm. The team built ccScreen v1 with an off-the-shelf borescope (an

optical device that connects a camera to a display through a flexible tube). ccScreen v1 was a proof-of-concept to show the team that their idea could feasibly be built.

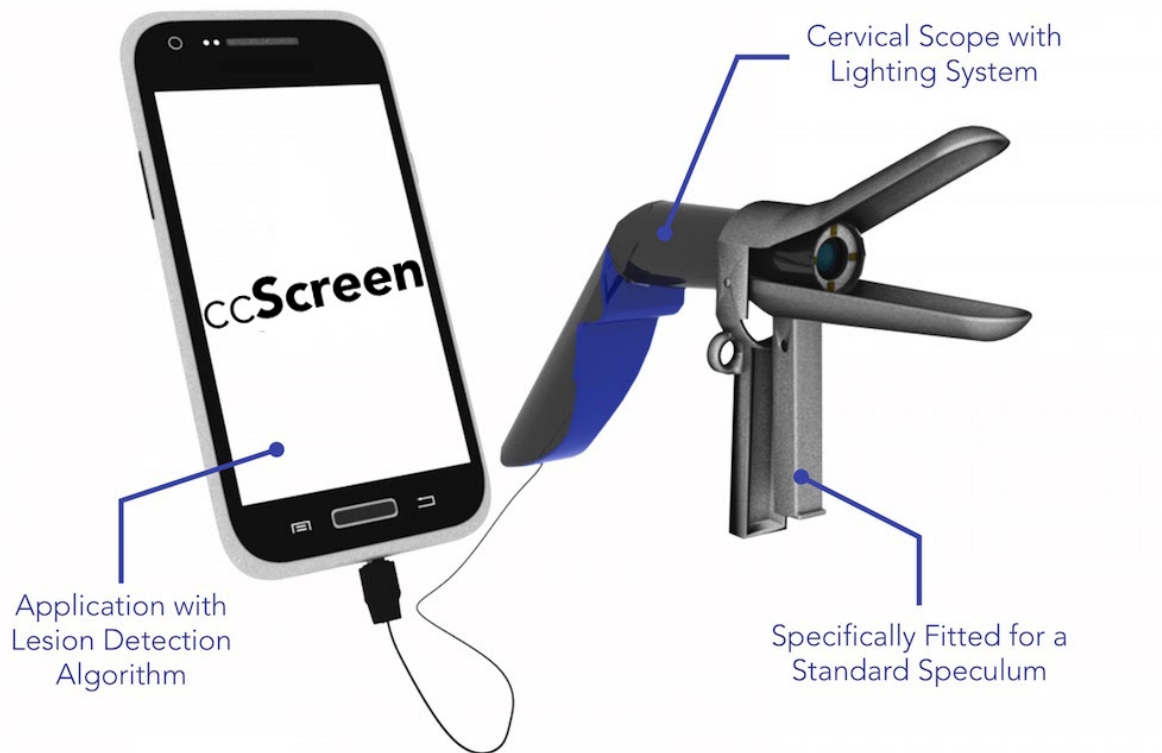


Figure 5-5. Schematic for ccScreen v1. Source: InVia.

Additionally, the team began to develop the lesion detection algorithm. Co-Founder B describes how the team leveraged an existing set of cervical images from Jhpiego (Figure 5-6) to test a machine learning algorithm:

"We took those [Jhpiego] images and tried basic machine learning. So the first thing we did was a ... regression ... to see if we could even categorize the images as VIA positive, VIA negative. And we [could categorize] better than guessing, but even with that we [realized] this isn't addressing the problem we want... it was the best we could do at the time. So after we learned that... we moved towards ... deep learning. How can we look at things as a segmentation problem [which would allow us to point out where pre-cancerous lesions are located]? But [as we] progressively moved forward on different things, [we] always [had] the constraint of an image set or a data set."

The team got as far as they could with the data set they had (the Jhpiego images). There were not enough images in the Jhpiego flashcard deck for the team to fully develop and test their algorithm. Therefore, the team chose to shift their focus away from algorithm development towards image collection. The team planned to develop the ccScreen device so it could be used in clinical settings to acquire cervical images which would allow the team to pick back up the algorithm development.

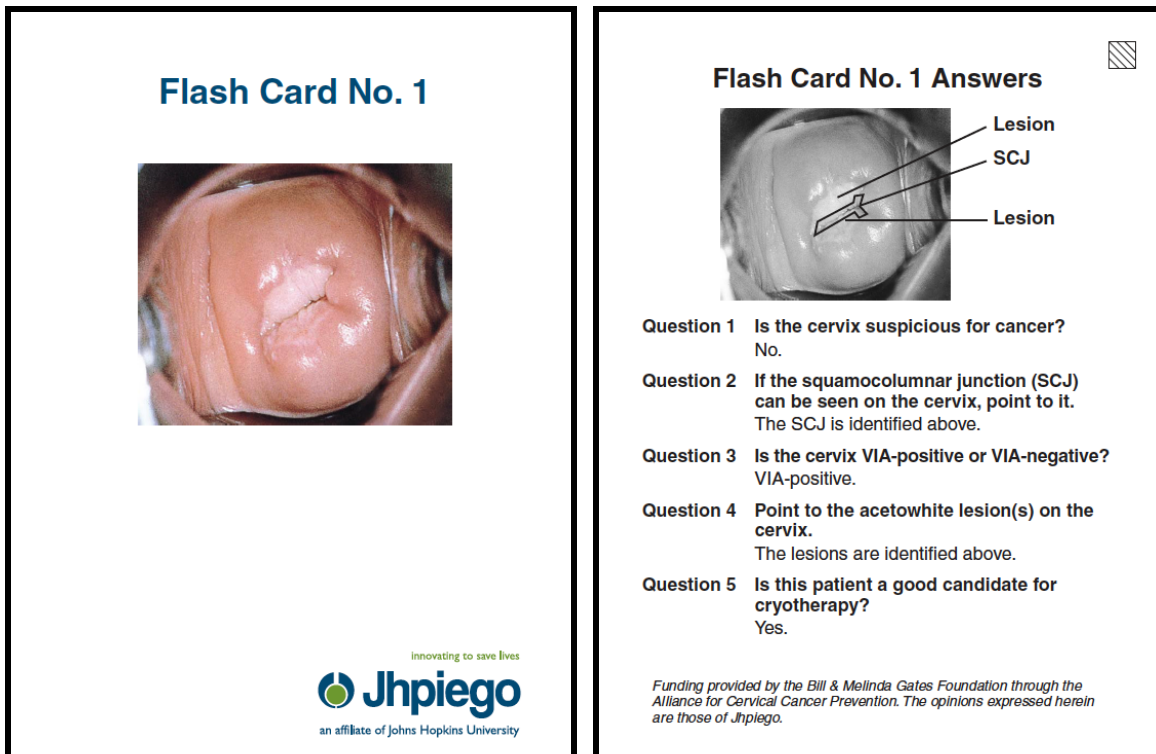


Figure 5-6. One of the 115 Jhpiego flashcards that show images of a patient's cervix after acetic acid has been applied during the VIA procedure. Source: [124]. *Reused with permission.*

Phase 11 - Focus on Implementation in India (*Frame and Reframe*)

Until Spring 2016, the team developed their ideas for a solution to improve VIA *without* a target implementation country in mind. However, in April 2016 nearing the end of the second semester of their senior design class, the team entered into a pitch competition to compete for funding for their idea. The competition forced the team to begin thinking about the market size for their solution, and it reframed their idea of the project from just a class assignment to an actual venture.

As the team began to think of ccScreen's implementation, they chose to focus on India for several reasons. First, India has a huge burden of cervical cancer incidence and mortality (see Section 5.1.1). Second, stakeholders from India who the team had earlier gained feedback from expressed significant interest in ccScreen. Third, Co-Founder A had a personal connection to India: his parents immigrated to the US from India, and he still had extended family members living in India. Co-Founder A remarked that the team wanted to be realistic about where they might penetrate the market and therefore wanted to focus on a country that a team member had connections to.

While the team is focusing on India for their initial implementation, they envision broader global implementation in the future. According to Co-Founder A:

"I think our whole team is motivated by the fact that we can help a lot of people [in India]. [I'm] not saying we can't help other people [elsewhere]. But if we can prove it here and [we are] able to scale it out here, then it can be applicable to other countries as well."

At the end of the Spring 2016 semester, the InVia team completed their senior design class and graduated from their university.

Phase 12 - Build ccScreen v2 (*Make and Experiment*)

The team finished their capstone class with the borescope prototype of ccScreen (ccScreen v1). In Fall 2016, the team picked back up their work on ccScreen and immediately focused on refining their proof-of-concept device. Specifically, they shortened the nose of the cervical scope (the end with the camera) so that it did not reach into the speculum but rather sat flush on the speculum. The goal of this design iteration was to make the cervical scope more able to be sanitized. Figure 5-7 below shows ccScreen v2.



Figure 5-7. ccScreen v2 schematic [left] and 3D printed prototype [right]. Source: InVia.

Phase 13 - Test ccScreen v2 in India (*Make and Experiment*)

In December 2016, Co-Founder A, Co-Founder C, and the team's Prototyping and Development Advisor traveled to India to gain feedback on ccScreen v2. At this point, the mobile application was not yet developed so the team could not test the full functionality of the system. However, stakeholders in India, including Medical Doctor A and India Institute for Cancer Prevention, provided the team with validation that their solution was on the right path. Specifically, stakeholders provided feedback on how they felt other cervical cancer screening devices had failed them in the past. Previously, a

number of other device developers had asked these stakeholders to test cervical cancer screening devices they had developed. The stakeholders felt that each device they tested from these other developers was either missing essential features or had major design flaws that impacted its clinical usability.

It was during this trip that the team learned how the system would be used by CHWs, clinicians, and health administrators. The ccScreen system would travel with CHWs into communities for cervical cancer screening procedures. Remote clinicians would provide a diagnosis based on the cervical images collected by CHWs. Health administrators would coordinate the screening procedure on the back-end, and would manage the privacy of the patient records being shared between CHWs and clinicians. The team's thoughts on usability have evolved with each trip, but this trip provided the team with their fundamental understanding of how the ccScreen system should work.

Phase 14 - Research on Device Implementation in India (*Observe and Notice*)

During the same trip to India in December 2016, Co-Founder A, Co-Founder C, and the Prototyping and Development Advisor conducted further research on how ccScreen might be implemented. They asked stakeholders about the desired workflow of the mobile application, the desired price and pricing strategy of ccScreen, and the process for testing ccScreen in clinical trials. According to Co-Founder C:

"[We were] trying to see what they thought of the subscription model that we were thinking of doing [where they would pay for each test individually], and trying to get a sense of the price point that would work best for them. [We also asked about] how we would work out clinical trials."

5.3.3 Consideration of Accessibility 3: Accommodation, Physical Accessibility, Availability, and Affordability

After the team graduated from their university in Spring 2016, they turned their focus further to the implementation of ccScreen. During a trip to India in December 2016, they simultaneously gained feedback on the ccScreen system itself (in terms of usability and functionality in Design Phase 13 and on the strategies to implement ccScreen in India in Design Phase 14).

From this research in India, the team considered four dimensions of accessibility: *accommodation*, *physical accessibility*, *availability*, and *affordability*. In the *accommodation* dimension, the team gained feedback from stakeholders in India to consider how ccScreen can bring cervical cancer screening closer to patients. The team discovered an opportunity for CHWs, who are less trained and more numerous than clinicians, to travel to communities across India and offer patients a local access point to

receive cervical cancer screening. Clearly, this opportunity also aligns with considerations of *physical accessibility*. The ccScreen system is small and mobile, therefore allowing CHWs to take it with them as they travel to communities.

The team also began to learn how important it would be for ccScreen to maintain patient privacy (which is related to the quality aspect of *availability*). The ccScreen system could be used by less-trained healthcare providers (i.e., CHWs instead of trained clinicians), but these less-trained healthcare providers could not be afforded full access to the patient's medical records. The ccScreen system would therefore need to account for this differential privacy and data access.

Finally, the team used their time in India to get feedback from stakeholders on the pricing strategy of ccScreen. The team gained positive feedback on the idea of ccScreen being paid for on a subscription basis, where the system would be purchased for a lower upfront cost and a small fee would be charged for each patient screened with the system. This idea enabled *affordability* considerations in a way that was appropriate for InVia's intended customers.

The team's consideration of *accommodation* and *physical accessibility* led the team to develop their app workflow in a way that allows for CHWs to use the ccScreen system to treat patients in several locations. They address these considerations in Design Phases 15, 16, and 17 as they built ccScreen v3 and developed a training curriculum for the ccScreen system. The consideration of privacy in the *availability* dimension remains an ongoing prompt for the team to address as they develop their mobile phone application. The feedback on their pricing strategy (*affordability*) remains an ongoing consideration as the team moves towards implementation.

Phase 15 - Build ccScreen v3 (*Make and Experiment*)

After the team returned from India, they spent the first half of 2017 beginning to implement changes to refine their cervical scope. They also developed the app, buoyed by the feedback and validation they received while in India.

During this phase, the new design iterations were inspired primarily by technical refinements rather than stakeholder-driven refinements. The prototype for which the team gained feedback in Design Phases 13 and 14 did not meet all of their engineering specifications but was rather shown as a way to elicit validation on the idea.

As the team was building the refined cervical scope and the mobile phone application, they tested their system on gynecological models that mimicked a patient's pelvis and cervix.

Phase 16 - Build Training Curriculum for ccScreen (*Make and Experiment*)

In Summer 2017, InVia and Visualize met and began to collaborate. Throughout Summer 2017 and into Fall 2017, the InVia team and the Visualize team worked

together to envision cervical cancer screening training for ccScreen users. Visualize and InVia were jointly interested in training CHWs how to screen for cervical cancer. InVia was additionally interested in training their users how to use the ccScreen system.

In this collaboration, my Visualize team and I worked with InVia to co-develop training protocols, plans, and wireframes of a training module to be included in the mobile phone application. We envisioned two types of tutorials included in the training:

1. Training CHWs how to perform VIA and how to use ccScreen to perform VIA
 - a. First, teach a CHW what VIA is, how it is performed, what materials it requires, and why it is preferable for use in LMICs.
 - b. Second, train a CHW how to perform VIA using the Visualize trainer so they can perform VIA without any assistance from the ccScreen system.
 - c. Third, train a CHW how to perform VIA with the ccScreen system. This training pairs the ccScreen system with the Visualize trainer so the CHW learns how to correctly use the ccScreen system to screen a patient for cervical cancer.
2. Explaining the functions and features of the ccScreen system
 - a. First, explain how the ccScreen cervical scope operates.
 - b. Second, explain how the ccScreen app works.

Following Fall 2017, we put these ideas on hold so the InVia team could focus on continuing to develop ccScreen in preparation for their next trip to India. These training protocols are intended to be tested before ccScreen undergoes clinical trials, as they will be necessary for CHWs to learn how to screen for cervical cancer using ccScreen.

Phase 17 - Finalize ccScreen v3 (*Make and Experiment*)

Most of 2018 was spent iterating and refining ccScreen v3 in preparation for InVia to travel to India in December 2018. During this time, Co-Founder B led the effort to develop the back-end of the mobile application, including the database of patient information and captured cervical images. Co-Founder B also led the development of the electrical system of the cervical scope, including the camera, lights, microcontroller, and battery. Co-Founder C led the effort to develop the front-end of the mobile application, including UX/UI considerations. Co-Founder D led the effort to develop the body of the ccScreen cervical scope and interfaced with Prototype Manufacturing Company to 3D print the cervical scope body in medical grade plastic.

Five cervical scopes were created, and the team had the intention of leaving cervical scopes with key stakeholders in India so these stakeholders could continue using and testing ccScreen after the InVia team left the country.

Figure 5-8 below shows an image of the ccScreen v3 cervical scope that was created in Fall 2018.

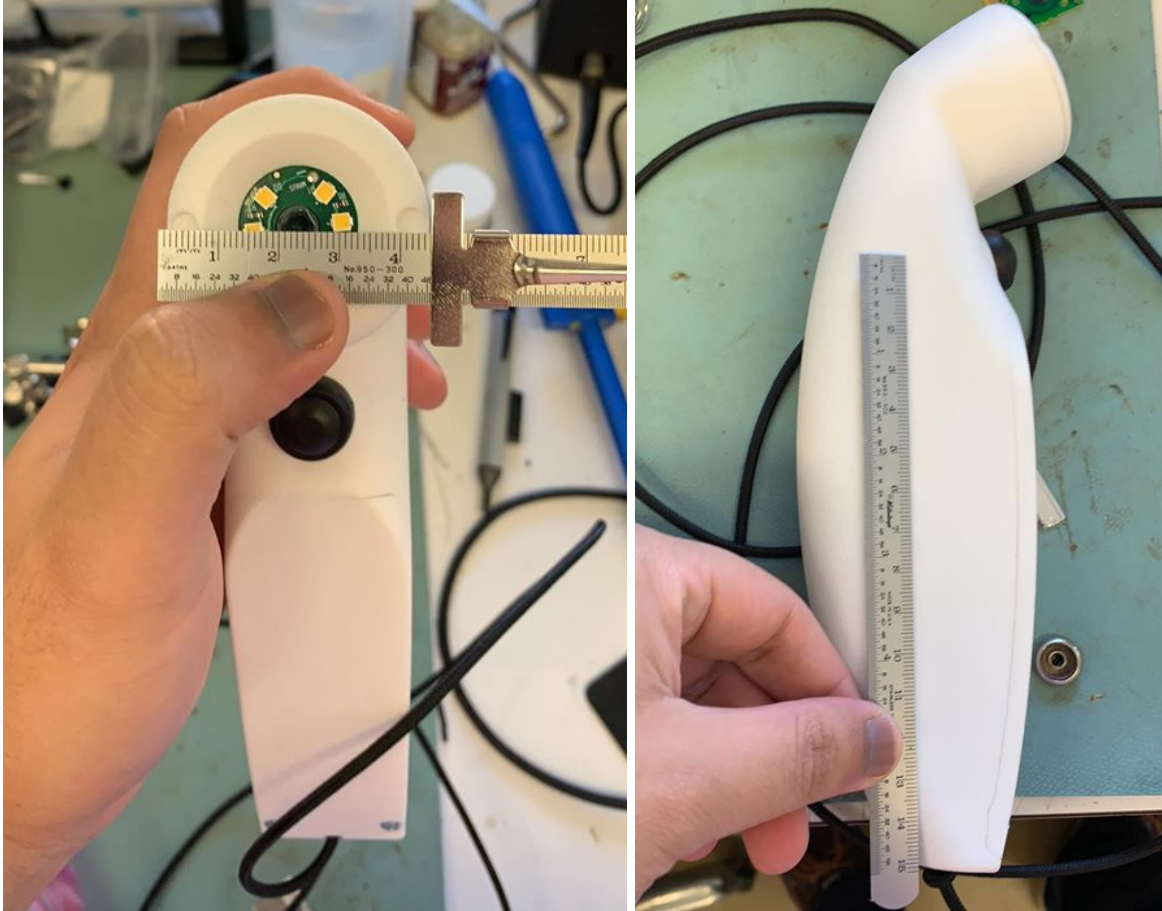


Figure 5-8. ccScreen v3 cervical scope, shown with approximate dimensions. The nose end of the device [left] measures 4.5 centimeters across. The camera in the middle of the nose is approximately 0.5 cm in diameter and is surrounded by lights. The handheld part of the device [right] is approximately 15 cm long from bottom to light switch, shown in black on the right side of the device. Source: InVia.

Phase 18 - Test ccScreen v3 in India (*Make and Experiment*)

In December 2018, Co-Founder A, Co-Founder B, and I traveled to India for two weeks to perform usability testing of ccScreen v3. We traveled to three cities in India and met with a range of stakeholders.

We met with Medical Doctor A in a northern state of India. Medical Doctor A, who the team met with previously in December 2016 (Phase 13), provided feedback on the look and feel of the cervical scope along with the functionality of the cervical scope and the mobile phone application. Medical Doctor A expressed a desire for the ccScreen app to use the Aadhaar ID — a unique identification number given to enrollees across India [125] — to identify patients. As of March 2019, 1.2 billion Indians were enrolled with Aadhaar [122]. Medical Doctor A suggested that this identification number would maintain patient privacy more than a photo of the patient.

We met with India Health Innovations Organization in a southern state of India. India Health Innovations Organization provided feedback on how CHWs would be able

to use ccScreen. They expressed a desire for InVia to create a less-expensive version of ccScreen that less-trained CHWs would be able to use in the community.

Finally, we met with India Institute for Cancer Prevention in an eastern state of India. The InVia team considers India Institute for Cancer Prevention to be their primary implementation partner. India Institute for Cancer Prevention coordinated three doctors within their network to use and test ccScreen. India Institute for Cancer Prevention had approval from their internal ethics board to allow their doctors to test ccScreen on patients seeking VIA. I observed the two doctors who tested ccScreen with patients and made notes of areas to improve the system in the future. The biggest issues that doctors encountered while using ccScreen were: (1) the ccScreen camera did not automatically focus, therefore making it difficult to capture a clear image of the patient's cervix, and (2) the lights surrounding the ccScreen camera were not bright enough to properly illuminate the cervix and therefore the photos that were taken were too dark to see any precancerous lesions.

Given the issues encountered by doctors in using ccScreen, InVia chose not to leave any of their ccScreen systems in India at the conclusion of the trip. Instead, they planned to iterate on these devices once back in the US.

5.3.4 Consideration of Accessibility 4: *Affordability*

During their trip to India in Design Phase 18, the team re-considered the specifics of *affordability*, and they asked stakeholders and future users of ccScreen to provide feedback on an appropriate price for the ccScreen system. InVia based these *affordability* considerations on price benchmarking of competitors in this space. To best meet the monetary constraints of the range of potential customers, InVia settled on two pricing options: a subscription model where customers pay 14,000 rupees (~\$184) upfront plus 20 to 30 rupees (~\$0.26 to \$0.39) per patient who is screened, or pay one flat fee of 70,000 rupees upfront (~\$918).

The team's consideration of *affordability* did not impact the subsequent design phases I observed, but it will play a key role when InVia rolls out ccScreen across India.

Phase 19 - Test Interest in New Programs in India (*Make and Experiment*)

During the same trip to India in December 2018, Co-Founder A, Co-Founder B, and I also sought feedback on the new program ideas that InVia is developing. The InVia team wanted to assess the interest in: (1) a mobile health ecosystem that would pair the ccScreen system with other mobile health systems in India and therefore create a more universal health data hub, and (2) a biometric authentication device that would limit

access to the ccScreen app and therefore provide greater security of the sensitive patient information collected on ccScreen.

The primary provider of feedback on these two ideas was India Health Innovations Organization in a southern state of India. Through their deep community-focused work, India Health Innovations Organization has a strong sense of what is needed to best serve the health needs of members of their network. They provided feedback in support of both new program ideas. They felt that a universal data hub would be useful in improving the general health of their community members, and they felt that a biometric authentication system would be necessary to protect the privacy of their members.

5.3.5 Consideration of Accessibility 5: Availability

Feedback on both the mobile health ecosystem and the biometric authentication device affirmed InVia's consideration of *availability*. The team learned that their proposed mobile health ecosystem would improve the quality of patient care by unifying currently disperse health data sources.

The team also learned that the biometric authentication device would provide much-needed privacy for the patients' health records. Specifically, India Health Innovations Organization noted that the use of the biometric authentication device in the ccScreen system would allow CHWs to have transient access to essential patient information but not full access to private patient health records. A health administrator would manage this access and use the biometric authentication device to temporarily grant access to the CHW. Co-Founder C explains what this process might look like:

"[We are talking through] potentially giving temporary access to the health care workers. So this would be controlled by some kind of supervisor, because we're not sure if we provide access to all patients under one organization, if that would compromise the patient information some way if there was like a leak of some data. And then also if that patient decided to go to a different organization to do their next screening, how that information would be provided to that other organization."

The team's consideration of *availability* did not directly impact the subsequent design phases that I observed, but it will play a key role as InVia further develops their new programs and works to implement ccScreen across India.

Phase 20 - Analyze Feedback from ccScreen v3 Usability Testing (Frame and Reframe)

After the team and I returned from India, we analyzed the feedback we received on ccScreen v3. The feedback was categorized as either changes to be made to the

ccScreen cervical scope or changes to be made to the ccScreen app. A summary of this feedback is provided below:

Cervical scope feedback

- Increase the brightness of the lights surrounding the ccScreen camera
- Add a scroll wheel so a user can adjust the brightness of the lights
- Add functionality for the camera to be able to zoom and autofocus
- Maintain the light weight of the cervical scope
- Decrease the width of the cervical scope to better fit into clinicians' hands
- Make the battery pack smaller and move it inside the cervical scope

Mobile phone application feedback

- Add Hindi and Bengali translations to the mobile phone application screens
- Improve functionality of the patient look-up to be more user-friendly
- Remove the photo of the patient's face and add in the Aadhaar ID to make the information more private

Since Spring 2019, InVia has continued to refine ccScreen and continues to pursue implementation across India.

5.4 Discussion and Evaluation of InVia's Process of Human-Centered Design for Accessibility

In Section 5.3, I provide a narrative timeline of how InVia designed ccScreen and how they considered accessibility throughout their design process. In this section, I discuss these HCD practices and considerations of accessibility.

5.4.1 Discussion of InVia's Process of Human-Centered Design for Accessibility

Figure 5-9 below shows InVia's design process overlaid with their considerations of accessibility. One overarching pattern is clear in Figure 5-9: InVia's considerations of accessibility follow their research activities, either in the *Observe and Notice* phase or the *Make and Experiment* phase. The team always considered access due to feedback they received from stakeholders. In all cases, the team's considerations of accessibility happen on the "concrete" research-oriented side of the design process (*Observe and Notice, Make and Experiment*); the team learns about accessibility through concrete interactions with stakeholders rather than by developing an "abstract" sense of accessibility through the *Frame and Reframe* or *Imagine and Design* phases.

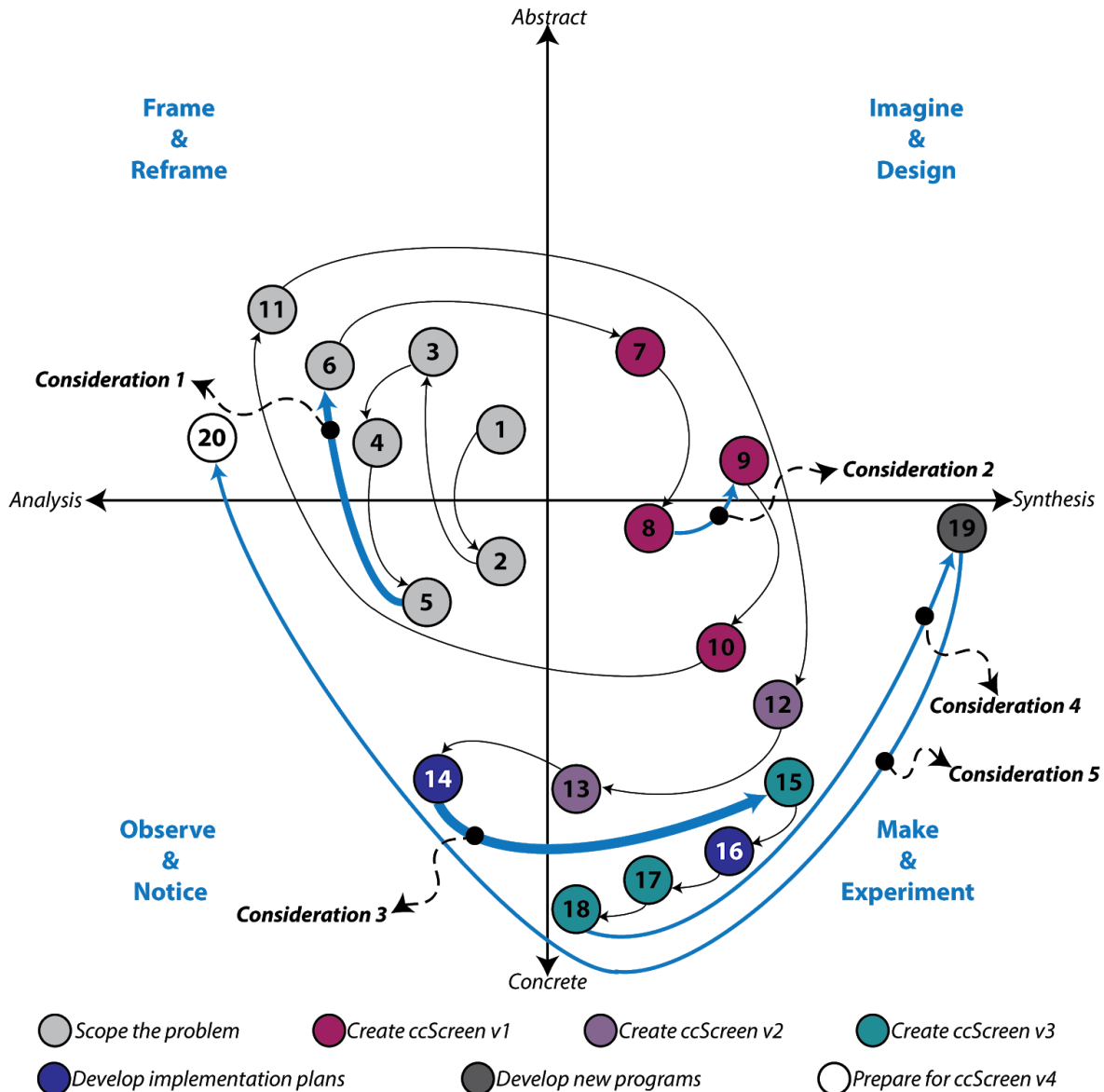


Figure 5-9. InVia's design process plus their considerations of accessibility. Each blue arrow corresponds to a consideration of accessibility, as I describe in Section 5.3. The thicker the blue arrow, the more dimensions of accessibility considered.

Not all aspects of accessibility are considered equally. First, and most notably, *affordability* was considered most heavily by the InVia team, showing up in Considerations 1 through 4. InVia's original focus on the problem was grounded in their desire to create a technological solution to improve a low-income context. As the team dove deep into cervical cancer (Design Phase 5), they began to explicitly consider how to create an affordable device that could actually be purchased and used in LMICs. The team continued to revisit the notion of *affordability* as they experimented with their early ideas (Design Phase 8), conducted research on the device's implementation in India

(Design Phase 14), and gained feedback on ccScreen v3 (Design Phase 18). *Affordability* has been InVia's most important accessibility driver.

Second, *accommodation* and *availability* appear earlier in the process and are among the first aspects of access the team considers. As I discuss in Section 5.4, InVia's goal within *accommodation* is to ensure that ccScreen fits within existing clinical practices. InVia does not consider *accommodation* after Design Phase 14. It is likely that InVia will reconsider *accommodation* when they implement ccScreen and are able to evaluate the successes and failures of the system. Within the *availability* dimension of access, InVia's goal is to improve both the quality and the accuracy of cervical cancer screening. First, InVia was concerned with developing a system that would standardize and therefore improve the VIA method (Design Phase 5). Then, InVia was concerned with ensuring a patient's privacy during the screening procedure (Design Phases 14 and 19). InVia has not yet been able to evaluate the success of ccScreen in standardizing VIA and has therefore not further considered the quality aspect of *availability*. InVia will likely assess and reconsider the meaning of quality as they implement ccScreen.

Third, *physical accessibility* is explicitly engaged with only after Design Phase 14 when the team conducted in-person research on device implementation in India. This is surprising, as one of the key strengths of the ccScreen system is its mobility: clinicians and CHWs can take the device with them as they travel between different tiers of health facilities. It is possible that the InVia team implicitly considered mobility in their original ideation but did not express this consideration fully until they articulated how the device would be used by clinicians and CHWs. Going forward, the team may continue to consider *physical accessibility* explicitly, leading to further refinements in the mobility of the ccScreen system.

Fourth, *acceptability* is absent from InVia's considerations of accessibility. This is not altogether surprising, given InVia's focus on creating a device for clinicians and for CHWs but not for patients. When a patient's health options are limited, they cannot exercise agency or preference over the tools their healthcare providers use. However, it is possible that patients will not return for repeat cervical cancer screening appointments if they are not satisfied with the procedures they underwent [126]. Therefore, InVia should consider how the patient's *acceptability* of ccScreen will impact the system's overall goal of screening more women in India.

5.4.2 Evaluation of InVia's Human-Centered Design Process

To evaluate the "human-centeredness" of InVia's design process in creating ccScreen, I apply the International Organization for Standardization (ISO) 9241-210 framework. As I present in Section 2.3.2.b, ISO 9241-210 puts forth six criteria of HCD [85]:

1. Adoption of multidisciplinary skills and perspectives
2. Explicit understanding of stakeholders, tasks and environments
3. Stakeholder-centred evaluation driven/refined design
4. Consideration of the whole stakeholder experience
5. Involvement of stakeholders throughout design and development
6. Iterative process

InVia's design process in creating ccScreen meets all six of the ISO HCD criteria in some way. In this section, I critically evaluate how InVia's design process adheres to and diverges from each characteristic. I also provide recommendations for the InVia team to improve the human-centeredness of their design process going forward.

1. Adoption of multidisciplinary skills and perspectives

InVia's team of four co-founders are all biomedical engineering graduates with a range of focuses within the field. Co-Founder A and Co-Founder B focus on bioimaging, Co-Founder C focuses on cell and tissue engineering, and Co-Founder D focuses on biomechanics. After graduating from their undergraduate education, the co-founders pursued different paths: Co-Founder A started a PhD program in bioengineering, Co-Founder B conducted medical research and went on to medical school, Co-Founder C conducted medical research in a lab setting and in a global setting before going on to a PhD program in bioengineering, and Co-Founder D went on to medical school. There is some variety of skills and interests within the context of biomedical engineering, design, and entrepreneurship.

The team does recognize the importance of multidisciplinary skills and perspectives. According to Co-Founder B:

"I think pretty much anything that I do or most people do requires an interdisciplinary and multidisciplinary understanding, and most times require a collection or a team of people that are able to work together. I think a really beneficial thing with being a biomedical engineer [and also] a physician and a researcher is that even if I don't understand something in depth, I have at least enough knowledge to be able to converse in that kind of conversation. [I can] understand but then also relay information and have intelligent inputs on all aspects. I can't be the one drafting up a patent, or I could maybe do a first draft, but I definitely want to have that looked over by someone who does that as a job. So having the ability to at least understand what other people are saying and to be an intermediary between different aspects of this process of implementation is really important, such that you can have inputs in how things are going, but then also you can understand your role and how that works in a relation to others."

While they recognize the importance of multidisciplinary knowledge and perspectives, and they do have some varying interests within biomedical engineering, the InVia team

members do not currently include a broad range of skills outside of biomedical engineering. As the team moves closer to implementing ccScreen, they aim to hire a team in India to manage the manufacturing and supply chain of ccScreen. This is an opportunity for InVia to significantly expand their within-team perspectives.

As the organization grows larger and takes on a broader range of projects, the team will need to broaden their multidisciplinary skills further. For example, the team will need members dedicated to identifying problems to solve (e.g., researchers, or those with lived experience in the problem), to solving problems (i.e., engineering), and to delivering solutions (e.g., sales).

2. Explicit understanding of stakeholders, tasks, and environments

A major strength of InVia's design process is their diligence in understanding the context of cervical cancer screening in India. Their design process began with an open-ended search for "clinical deficits" that they could solve with a technological solution. This exercise in problem framing was guided by domestic and global clinicians who provided insight into global health needs.

Upon narrowing their focus to cervical cancer screening, InVia front-loaded their design process with months of interviews to learn as much as possible about the problems associated with cervical cancer screening globally. They chose India as an implementation site due to the concentrated interest they saw in India and due to their pre-existing connections to India (primarily through Co-Founder A). These personal connections to India allowed the team to quickly dig into understanding the Indian cervical cancer screening environment.

As they were developing the ccScreen system, they explicitly focused on designing ccScreen to fit into existing clinical workflows. InVia has been clear from the start that their goal is to leverage technology as an amplifier and not a replacement to existing clinical practices. Co-Founder B explains this further:

"So we definitely knew that ... the way we wanted to address this clinical deficit wasn't to replace VIA, but to supplement it and to work within its constraints and confines and workflow."

The team was not able to observe the Indian clinical context firsthand while developing early iterations of ccScreen (v1). However, their usability testing of ccScreen v2 and v3 in India allowed the team to observe how clinicians in India perform VIA and how ccScreen fits into this process.

3. Stakeholder-centered evaluation driven/refined design

InVia plans semi-regular trips to India so they can test new versions of ccScreen. Often, their design changes are driven by stakeholder feedback of the ccScreen system,

although technical refinements also drive their iterations. Each version of ccScreen attempts to account for stakeholder feedback.

The cycles between building and evaluation are relatively long, driven in large part by InVia living in the US instead of in India. The team is able to travel to India about once per year, which means that most of the year is focused on refining the ccScreen system into a functional state so it can be tested by clinicians in India.

InVia has not yet implemented ccScreen and the team is still developing the details of the system. They collect stakeholder evaluations of ccScreen through interviews and observations of clinicians using the ccScreen system. Going forward, particularly as ccScreen is implemented, InVia will need to broaden this evaluation to include metrics of ccScreen's clinical success. The team has some ideas around the types of clinical metrics and usability statistics they might measure. However, there is an opportunity going forward for InVia to consider how stakeholders would evaluate the system, beyond clinical or usability statistics. What do stakeholders believe constitutes "success"? InVia can wrap the perspective of stakeholders into their evaluation plan. This would help round out their evaluation of ccScreen by focusing on what is actually considered important by stakeholders and not just what is easy to evaluate or what is perceived to be important by InVia.

4. Consideration of the whole stakeholder experience

InVia focuses on the experience of three groups of stakeholders in the VIA process: CHWs who perform VIA, clinicians who review the screening results and make a diagnosis, and health administrators who coordinate screening and granting system access. Co-Founder A describes how InVia seeks to understand the broad range of stakeholder experiences with ccScreen:

"Another thing that we took into consideration was that it isn't just the clinicians who were buying in. It's the health care workers and the admin and the public health officials. This [highlights a] need to appeal to multiple people. If we just [focused on] the clinicians, it would have completely thrown off admin. I'm talking about people who do purchasing decisions and whatnot. [Without the buy-in of admin] then it [ccScreen] will never be put in the hands of clinicians. So I think it was an important move for us... getting the viewpoints of multiple stakeholders but also not spending too much time just getting opinion, opinion, opinion without doing something."

The ccScreen system accounts for the different ways these actors may experience the ccScreen system (see Figure 5-2), and InVia is focused on developing their system to meet the needs of CHWs, clinicians, and health administrators.

However, InVia does not currently focus on the experience of patients, even though patients are the ones who are getting screened and the end-goal of ccScreen is to prevent patients from dying of cervical cancer. InVia's goal with ccScreen right now is

to improve the CHW's and clinician's ability to perform cervical cancer screening. Going forward, there is an opportunity for InVia to leverage ccScreen to overcome key barriers in the *patient's* ability to access cervical cancer screening.

5. Involvement of stakeholders throughout design and development

InVia involves stakeholders through regular trips to India when they perform interviews and observations of ccScreen being used. Therefore, InVia involves stakeholders continuously through the *testing* of ccScreen. However, InVia does not currently involve stakeholders in the *design* of ccScreen. Some stakeholders provide new ideas for ccScreen of their own accord (e.g., India Health Innovations Organization suggested that InVia develop a less-expensive cervical scope that would sit on a mobile phone instead of requiring an external device as it currently does) but this is not a regular part of InVia's design process. In this way, InVia's design process is not participatory.

Going forward, InVia can consider involving stakeholders earlier in the design process which could improve their designs and shorten the length of an iterative cycle.

6. Iterative process

InVia bases their design process around an iterative cycle. They develop their ideas based on stakeholder feedback, they build out new versions of ccScreen, and they travel to India to test these new versions with stakeholders. The team acknowledges the importance of iteration, as Co-Founder A notes:

"Whatever we have as a first idea is probably not going to be perfect and [in our experience] it wasn't. What we have right now may not be perfect either and we'll just iterate on that."

It is worth noting the InVia never pivoted from their original idea. ccScreen v1 is very similar to the current version, ccScreen v3. Any changes to the system have primarily been focused on making the system work correctly and have not been focused on changing how the system works.

5.4.3 Evaluation of InVia's Considerations of Accessibility

Through their ccScreen program, InVia primarily prioritizes three dimensions of access: *availability*, *accommodation*, and *affordability*. InVia did not focus much on two dimensions of access: *physical accessibility* and *acceptability*.

At a meta-level, InVia views the ccScreen system as enabling access for other inventors to learn from their example. ccScreen is an example of applying mobile health, machine learning, and technical innovation towards a clinical deficit. Illustrating this point, Co-Founder B states:

"I think it [ccScreen] also has a lot of application for ... its ability to prove and support this idea of mobile health and address a lot of problems ... that are beyond just cervical cancer. For example, the role that technology should have in treating, the role that AI [artificial intelligence] can have in treating, the role that mobile technology can have in treating. But then also those things should be implemented ... in a way that is safe, efficacious, and beneficial to the patients and especially more vulnerable populations."

Focus on Availability

According to Penchansky and Thomas [22], *availability* refers to "the relationship between the location of supply and the location of clients, taking account of client transportation resources and travel time, distance and cost." Within the *availability* dimension of access, InVia's chief aim through the ccScreen system is to improve *quality* and *accuracy* of existing cervical cancer screening procedures. InVia specifically chose to build their system to support the VIA procedure because of VIA's ability to share results quickly. According to Co-Founder B: *"it's a test that you get the results of very quickly, such that you can... screen and treat in the same visit."* ccScreen thus enables the *availability* of VIA in India and improves the quality of VIA: based on initial testing, InVia believes that ccScreen improves the diagnostic sensitivity of VIA.

InVia is also concerned with the role that ccScreen plays in sharing patient information between the CHW, clinician, health administrator, and patient. This challenge is particularly important in India where much health work is done on mobile devices. According to Co-Founder C:

"Figuring out exactly the best way to both make that patient information accessible to the healthcare workers that are seeing that patient, while making sure that none of that information has a possibility of getting out is a huge issue that we're struggling with."

Focus on Accommodation

According to Penchansky and Thomas [22], *accommodation* refers to "the relationship between the manner in which the supply resources are organized to accept clients (including appointment systems, hours of operation, walk-in facilities, telephone services) and the clients' ability to accommodate to these factors and the clients' perception of their appropriateness." Within the *accommodation* dimension of accessibility, InVia is concerned with making the ccScreen system fit into existing clinical practices. The ccScreen cervical scope was built to fit onto standard specula, therefore integrating into the existing VIA workflow. Additionally, the ccScreen system seeks to accommodate folks who are unlikely to follow up with a medical appointment, including patients who are *"traveling from further away or [are] transient people or don't have any contact information"* (according to Co-Founder B). The ccScreen system provides the patient with better health care *accommodation* by enabling high-quality

VIA. The patient is better able to find access points within the healthcare system by only focusing on one appointment as opposed to multiple appointments and follow-ups.

Focus on Affordability

According to Penchansky and Thomas [22], *affordability* refers to “*the relationship of prices of services and providers’ insurance or deposit requirements to the clients’ income, ability to pay, and existing health insurance.*” Within the *affordability* dimension of accessibility, InVia is primarily concerned with making the ccScreen system affordable to health administrators. Public hospitals in India provide free services for patients so InVia is only concerned with the willingness of health administrators to pay, not the willingness of patients to pay. InVia envisions two pricing strategy options: (1) a subscription-based pricing scheme, where healthcare administrators pay 14,000 rupees (~\$184) upfront plus 20 to 30 rupees (~\$0.26 to ~\$0.39) per patient who is screened, or (2) healthcare administrators pay one flat fee of 70,000 rupees upfront (~\$918).

This dimension of accessibility directly relates to InVia’s business model: there are a number of competitors in the space of cervical imaging, and InVia seeks to position ccScreen as lower priced and higher quality than these competitors. Affordability was also a chief consideration in the early idea generation and testing for ccScreen; the team initially developed an idea to create a higher-tech colposcope, but decided against this idea because their initial market research showed them that colposcopes would be too expensive for their target market.

Limited Focus on Physical Accessibility and Acceptability

According to Penchansky and Thomas [22], *physical accessibility* refers to “*the relationship between the location of supply and the location of clients, taking account of client transportation resources and travel time, distance and cost*” and *acceptability* refers to “*the relationship of clients’ attitudes about personal and practice characteristics of providers to the actual characteristics of existing providers, as well as to provider attitudes about acceptable personal characteristics of clients.*” These two dimensions of accessibility were of less concern for InVia and were only considered to a minor degree in the ccScreen system. The ccScreen system enables the *physical accessibility* of cervical cancer screening because the cervical scope is small and easy for the CHW to bring from place to place. The ccScreen system seeks to be *acceptable* to healthcare providers by fitting into their existing practices, but it does not address social *acceptability* of cervical cancer screening in India among patients and potential patients.

Proposed Framework to Evaluate Accessibility

InVia has not yet implemented the ccScreen system in a clinical setting for real-world testing. Therefore, I cannot evaluate the success of the ccScreen system in actually

improving access to cervical cancer screening in India. However, inspired by Penchansky and Thomas [22], [29] (see Table 2-1), I propose a set of questions to assess a patient's satisfaction with their access to cervical cancer screening through ccScreen. These questions can be asked of patients after ccScreen is implemented, therefore allowing the InVia team to evaluate whether or not ccScreen improves access to cervical cancer screening. The **bolded** sections in the Table 5-2 below demonstrate the additions and alterations I made to Penchansky and Thomas' original framework.

Table 5-2. Adapted from Penchansky and Thomas' framework to evaluate a patient's satisfaction with access to health care [22]. These questions have been edited to address a patient's satisfaction with their access to cervical cancer screening through the ccScreen system. These questions are to be assessed through a patient survey where patients respond on a five-point Likert scale, ranging from "very satisfied" (1) to "very dissatisfied" (5)

Dimension of Accessibility	Question to Evaluate Patient Satisfaction
Availability	All things considered, how much confidence do you have in being able to get good cervical cancer screening for you and your family when you need it?
	How satisfied are you with your ability to find one good provider of cervical cancer screening ?
	How satisfied are you with your knowledge of where to get screened for cervical cancer ?
	How satisfied are you with the amount of privacy you are given during a cervical cancer screening procedure?
Physical Accessibility	How satisfied are you with how convenient your cervical cancer screening provider is to your home?
	How difficult is it for you to get to your cervical cancer screening provider's location ?
Accommodation	How satisfied are you with how long you have to wait to get a cervical cancer screening appointment?
	How satisfied are you with how convenient your cervical cancer screening provider's hours are?
	How satisfied are you with how long you have to wait in the waiting room?
	How satisfied are you with how easy it is to get in touch with your cervical cancer screening provider ?
	How satisfied are you with the level of education and explanation specific to cervical cancer your cervical cancer screening provider gave you?

(continued)	Question to Evaluate Patient Satisfaction
Affordability	How satisfied are you with your health insurance's coverage of cervical cancer screening ?
	How satisfied are you with the cervical cancer screening provider's prices ?
	How satisfied are you with how soon you need to pay the bill for your cervical cancer screening services ?
Acceptability	How satisfied are you with the appearance of the cervical cancer screening provider's locations ?
	How satisfied are you with the neighborhoods your cervical cancer screening provider's locations are in?
	How satisfied are you with the other patients you usually see at the cervical cancer screening provider's locations ?
	How satisfied are you with the general health education and guidance offered by your cervical cancer screening provider?

Note that none of the patient satisfaction questions are specific to the ccScreen system because the patient does not directly interface with the ccScreen system. The direct “users” of ccScreen are the CHWs, clinicians, and health administrators. While the ultimate goal of ccScreen is to improve a patient's access to cervical cancer screening, this access is mediated through the users of ccScreen.

To appropriately measure and evaluate the changes in cervical cancer screening access afforded by ccScreen, the questions in Table 5-2 should be considered for use in a between-subjects experimental design where control and experimental groups of patients are designated and surveyed. Such an experimental design would allow InVia to isolate the changes in cervical cancer screening access due to the ccScreen system. For example, a control group might be a group of patients who are screened for cervical cancer by a provider who does not use the ccScreen system, and an experimental group might be a group of patients who are screened for cervical cancer by a provider who does use the ccScreen system. Both the control and experimental groups would then be surveyed twice: once before they encounter their cervical cancer screening provider and once after they encounter their cervical cancer screening provider.

5.5 Summary of the Case Study of InVia Technologies

In this chapter, I have presented InVia as a case study of an organization leveraging HCD to improve access to cervical cancer screening. First, I provided background context on the state of health in India. Then, I documented the history of InVia with a specific focus on their development of ccScreen.

I presented a journey through InVia's design process, starting in their biomedical engineering design class in Fall 2015 and continuing through my data collection which concluded in April 2019. InVia continues to operate today although I did not collect any data after April 2019. I then discussed the intersection of InVia's design process and their considerations of accessibility. I analyzed the design phases where InVia began to consider and reconsider various dimensions of accessibility and I discussed how the team brought these considerations forward into their design journey. From this analysis, I discussed how InVia's accessibility considerations were always borne from concrete research conducted, either in the *Observe and Notice* phase or the *Make and Experiment* phase. In all cases, the team considered accessibility due to their learnings from concrete research activities and they carried these considerations forward as they framed their design challenge, generated ideas, and iterated on their design.

Next, I used the ISO 9241-210 criteria to evaluate the "human-centeredness" of InVia's design process [85]. I found that InVia generally adhered to the criteria of HCD, although there is room for improvement in their HCD processes going forward. Particularly, the team can improve the multidisciplinary of their team, the team can better integrate stakeholders in developing an evaluation plan for ccScreen, the team can better account for the experience of patient's in the ccScreen ecosystem (rather than just CHWs, clinicians, and administrators), and the team can involve stakeholders throughout the design of ccScreen and not just during the evaluation of ccScreen.

Finally, I explored how InVia considered accessibility as they were developing ccScreen, and I found that the team primarily focused on *availability*, *accommodation*, and *affordability* of ccScreen. I then presented a framework the team might consider adopting when they eventually evaluate the ccScreen system. This framework, inspired by Penchansky and Thomas [22], [29], provides a set of survey questions InVia can ask of patients to assess their satisfaction with the cervical cancer screening accessibility provided by ccScreen.

Chapter 6

A Case Study of Mujeres Móviles

In this chapter, I present a case study of an organization designing a new service to improve accessibility to cervical cancer screening in Nicaragua: Mujeres Móviles. To set the stage for this organization's work, I first provide an overview of the historical and demographic and health care context of Nicaragua (Section 6.1) including the burden of disease and the healthcare system in Nicaragua. I then provide a descriptive overview of Mujeres Móviles (Section 6.2) including the programs Mujeres Móviles has created, the personnel involved in Mujeres Móviles, and the historical timeline of Mujeres Móviles. After presenting this descriptive context, I then present an analysis of how Mujeres Móviles applied human-centered design (HCD) and considered accessibility as they created their mobile cervical cancer clinic program to improve access to cervical cancer screening (Section 6.3). Then, I discuss and evaluate Mujeres Móviles' HCD process and Mujeres Móviles' ways of considering accessibility (Section 6.4).

Mujeres Móviles is the second of two case studies I present in this dissertation of organizations who are applying HCD to improve access to cervical cancer screening. Mujeres Móviles is a service-providing non-profit organization founded in Nicaragua. I consider Mujeres Móviles to be an exemplar of best practices in HCD for service design. In Chapter 7, I compare the case study of Mujeres Móviles that I present in this chapter to the case study of InVia Technologies I present in Chapter 5. By comparing these two exemplary cases, I develop a set of frameworks to describe the process and the characteristics of HCD for accessibility in Chapter 7.

6.1 Nicaraguan Context

In order to understand why Mujeres Móviles developed their programming to address cervical cancer screening access, it is important to first understand the historical and demographic context that the Mujeres Móviles team considered while crafting their solution. The team created their cervical cancer screening program as a direct response to the lack of preventive health services in Nicaragua, which is influenced by the

broader political context and health system in the country. These contextual factors continue to play a role in how the Mujeres Móviles organization develops and implements their services.

Nicaragua is the geographically-largest country in Central America, with a population of 6.5 million people [127], [128]. Nicaragua is one of the poorest countries in the Western hemisphere, with a gross domestic product of \$13.118 billion [127], [129]. The majority of Nicaraguans live in urban areas, and therefore the rural population of Nicaraguans is dispersed across a wide geographic area [127], [130].

Nicaragua was colonized by the Spanish until becoming a fully independent nation in 1838 [127]. Following independence, Nicaragua's history is characterized by internal power struggles and by United States (US) intervention. Between 1909 and 1933, the US intervened in Nicaragua, first to depose the presidency of José Santos Zelaya and then to install the US's preferred Nicaraguan leaders. Augusto César Sandino led a successful guerilla campaign against the US before being assassinated on the orders of General Anastasio Somoza García of the Nicaraguan National Guard (trained by the US military). General Somoza became president in 1937 and his family ran a dictatorship in Nicaragua until 1979. In opposition to Somoza's dictatorship, the Sandinista National Liberation Front (*Frente Sandinista de Liberación Nacional*, a.k.a. FSLN) — named for Sandino — was founded in 1961. In 1978 and 1979, the FSLN united with other groups opposing the Somoza dictatorship to oust the Somozas. The Sandinista revolution was interpreted by the US as a move towards communism, and the US suspended economic aid to Nicaragua. The Sandinistas worked to weaken their political opponents and consolidate their power in the country. The US continued to intervene in Nicaragua by training counterinsurgents (the Contras) to oppose the Sandinistas, by embargoing trade, and by mining Nicaraguan harbors. Daniel Ortega was elected president of Nicaragua in 1984, and eventually the Contras and the Sandinista government came to a peace agreement in 1987. In the 1990 elections, the US-backed National Opposition Union (*Unión Nacional Opositor*, a.k.a. UNO) beat the FSLN. The FSLN eventually regained power when Daniel Ortega was elected in 2006. In 2011, the Nicaraguan Supreme Court lifted an existing ban on the president being able to seek re-election, and Ortega was elected to another term. President Ortega was elected for his third consecutive and current presidential term in 2016.

In April 2018, a small group of protesters spoke out against the Ortega government's proposed changes to the country's social benefits [113]. The government cracked down on the protesters, sparking a broad outcry from tens of thousands of Nicaraguan protesters. Ortega eventually scrapped his proposed plans, although many Nicaraguans continued to call for his resignation, citing decades of authoritarianism [131]. As of this writing, the protests are ongoing, negatively impacting the ability of Nicaraguans to receive governmental services or to go about their normal lives.

6.1.1 Context of Health in Nicaragua

Figure 6-1 below shows the general burden of disease in Nicaragua. The majority of disease and disability in Nicaragua is due to non-communicable diseases. Communicable, maternal, neonatal, and nutritional diseases are responsible for less death and disability in Nicaragua than in India (see Figure 5-1) and than in the world as a whole (see Figure 2-1).

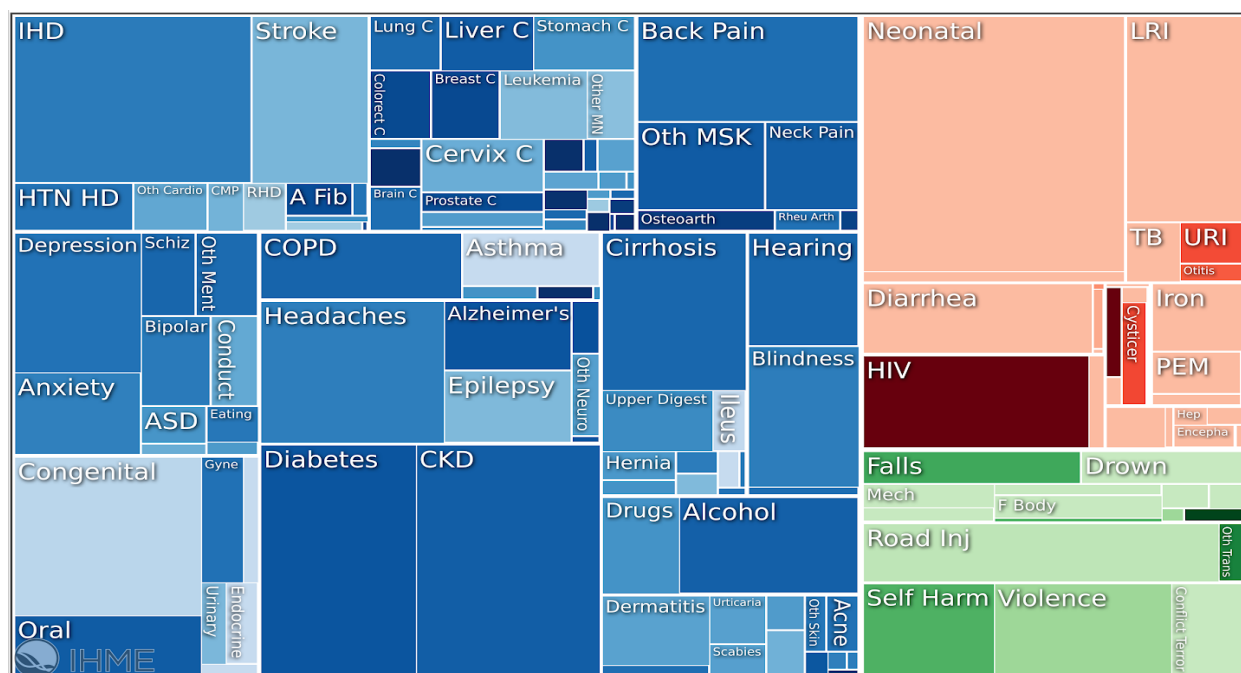


Figure 6-1. Burden of death and disability in Nicaragua, measured in disability-adjusted life years (DALYs), 2017. The majority of death and disability in Nicaragua is due to non-communicable diseases (blue), and a smaller portion of death and disability is due to communicable, maternal, neonatal, and nutritional diseases (red), and injuries (green). Larger boxes indicate a larger proportion of DALYs. Darker colors indicate a more positive percent annual change (1990 to 2017). Source: [132]. Reused per Creative Commons BY-NC-ND 4.0 license.

The health system in Nicaragua is based around the Ministry of Health (*Ministerio de Salud*, a.k.a. MINSA). MINSA acts as both a regulatory body and a direct provider of health services. MINSA operates at three levels: the central level, the “departmental” level (analogous to the state level), and the municipal level [130].

At the central level, MINSA conducts public health activities (e.g., disease surveillance) and provides health services through national hospitals [130]. Most national hospitals require referral from departmental hospitals. At the departmental level, MINSA oversees seventeen Local Comprehensive Health Care Systems (*Sistemas Locales de Atención Integral de Salud*, a.k.a. SILAIS) [130]. Every department and autonomous region in Nicaragua has its own SILAIS which oversees health care in that area. Departmental SILAIS provide health services directly through

departmental hospitals, which require referral from municipal health facilities. At the municipal level, each department's SILAIS oversees health centers, health posts, and community clinics [130]. Health centers provide all primary health care services while health posts provide some primary health care services plus health promotion activities. The community clinics are a unique strength of the Nicaraguan health system: MINSA trains a large network of volunteers in the country to offer health promotion and disease prevention activities at the community level [130].

A number of challenges afflict the health system in Nicaragua. First, much of Nicaragua is sparsely populated, so it is difficult to provide physically accessible health care to such a dispersed population. All of the national hospitals are located in the capital city of Managua and as of 2011, only three of the thirty-two public hospitals in Nicaragua were located on the Caribbean side of the country, despite this region comprising over half of the total area of Nicaragua [130]. Second, the health facility infrastructure requires major upgrades to improve the consistency of electricity, water, and waste management. Third, there is a need for more trained healthcare providers in Nicaragua, particularly in rural parts of the country. Fourth, Nicaragua has not invested heavily in their health system. As of 2011, Nicaragua's per capita health care expenditure was the lowest in Central America [130].

Nicaraguans can access health services through MINSA for free. However, given concerns about the quality of the public health facilities, some Nicaraguans opt for private health facilities [133]. To cover these expenses, health insurance is available for Nicaraguans who are employed in the formal sector. As of 2007, only 13.5% of the population was covered by health insurance [134]. In January 2007, the government attempted to create a health insurance program for those employed in the informal sector, but after one year the majority of people left this program and only 10% of people in the nation remained enrolled [135].

In summary, Nicaragua has middling healthcare access and quality. As I discuss in Section 2.1.1, the Healthcare Access and Quality (HAQ) index, which ranges from zero to 100, approximates healthcare access and quality by measuring the mortality rates of health conditions that are amenable to care [21]. I consider the HAQ index to be a cumulative measure of all five of Penchansky and Thomas' dimensions of health care accessibility. Nicaragua's HAQ index is 64. The authors who constructed the HAQ index divide the world into quartiles based on each country's Socio-Demographic Index (SDI), a composite metric of a country's income, education, and fertility [120]. Out of 38 countries in the third SDI quartile (i.e., lower middle SDI countries), Nicaragua ranks third in terms of HAQ. This means that when comparing Nicaragua to other countries with similar socio-demographic contexts, Nicaragua's healthcare quality and access is quite good. For comparison, India's (third SDI quartile) HAQ index is 45. This is likely due to the provision of free health services for all Nicaraguans. However, an HAQ of 64

out of 100 is still low compared to much of the world. For comparison, the US's (first SDI quartile) HAQ index is 81.

Cervical cancer is a major problem in Nicaragua. Behind breast cancer, cervical cancer is the second most common cancer among women. Cervical cancer is the deadliest cancer among women in Nicaragua [121]. In 2018, 21.2 per 100,000³ women in Nicaragua were diagnosed with cervical cancer and 13.3 per 100,000 women in Nicaragua died of cervical cancer. Translated to raw numbers, in 2018 677 women in Nicaragua were diagnosed with cervical cancer and 409 women in Nicaragua died of cervical cancer.

6.2 Description of Mujeres Móviles

Mujeres Móviles is a non-profit organization based in Nicaragua focused on improving the holistic health of women and girls in Nicaragua. The first project the organization developed focused on improving access to cervical cancer screening for women in Nicaragua by delivering cervical cancer screening and education to women in rural areas of Nicaragua. The organization has also developed a number of other programs focused on other aspects of women's health, including a sexual health education program for adolescents, an after-school club for low-income girls, and a training program for recent graduates of Nicaraguan nursing and medical schools.

6.2.1 Overview of Mujeres Móviles' Programs

The overall vision of Mujeres Móviles is to improve the health and well-being of women and girls across Nicaragua. To meet this vision, Mujeres Móviles currently offers four unique programs: (1) the mobile cervical cancer clinic, (2) adolescent sexual health education, (3) the Girls Club, and (4) the Leadership Institute.

In their first program, the primary focus of this chapter, Mujeres Móviles created the mobile cervical cancer clinic that travels into rural areas of Nicaragua to provide cervical cancer education, screening and treatment. The vision of the mobile cervical cancer clinic is to combine proactive outreach and sexual health education with cervical cancer screening and treatment procedures to bring health to women in the communities Mujeres Móviles serves. A key feature of the mobile cervical cancer clinic is that they are primarily run by women: all of the current clinical staff members are women. Currently, Mujeres Móviles has two mobile cervical cancer clinics: one in

³ The incidence rate of 21.2 per 100,000 women and the mortality rate of 13.3 per 100,000 women are both age-standardized rates.

Central Nicaragua and one in Northwestern Nicaragua. Each mobile cervical cancer clinic team travels to communities around their respective region and screens women in at least two communities each week. At each screening event, the teams aim to screen around 50 women for cervical cancer. The other days of the week, the teams organize the data they collected at each screening event, send off any Pap smears they have collected to a bioanalysis laboratory, prepare their supplies for the next screening event, and reach out to new communities to organize future screening events. Some weeks, the teams travel back to communities where they have previously screened in order to hold treatment (i.e., cryotherapy) clinics. At the beginning of every year, the team meets with the local SILAIS to map out every town in their region and every community in each town. From this mapping, the mobile cervical cancer clinic teams decide where they would like to go to perform their screening and SILAIS provides their permission for the team to do so. The mobile cervical cancer clinic teams aim to visit a community once every two years and therefore they do not travel back to perform screening in the same community more than once in a two year period.

In their second program, Mujeres Móviles developed a curriculum to teach adolescents about sexual health. The vision of the adolescent sexual health education program is to help adolescent girls better understand their own bodies. The program covers four topics: the menstrual cycle, teenage pregnancy, sexually-transmitted infections, and family planning. The program was inspired by the high rates of adolescent pregnancy in Nicaragua: around 25% of women in Nicaragua between the ages of 15 and 19 have been pregnant at least once [136]. Currently, the mobile cervical cancer clinic team in Northwestern Nicaragua is pilot testing an adolescent sexual health education program at schools in their region. The full Mujeres Móviles team plans to learn from the Northwestern Nicaragua team's experiences piloting the curriculum before rolling it into the operations of the other mobile cervical cancer clinic team in Central Nicaragua.

In their third program, Mujeres Móviles created an after-school club for school-age girls in an urban area of Western Nicaragua. The vision of the Girls Club program is to provide a safe, enriching, and supportive environment so that girls can avoid unwanted early pregnancy and prepare for rewarding careers. The program was initiated when a donor gave her house and property to Mujeres Móviles. The Mujeres Móviles co-founders then brought on the Girls Club Leader to develop ideas around what to do with this space. The Girls Club Leader, who has a background in education and speaks fluent English, decided to create an after-school program for low-income girls who attended school near the house. The purpose of the program is to provide sexual health education, to teach English, and to create a safe and supportive community.

In their fourth program, Mujeres Móviles created a leadership training program for nurses who work in the mobile cervical cancer clinics. The vision of this Leadership Institute program is to help develop Mujeres Móviles' leaders of the future through skills-based training, personal coaching, and leadership development. The full Leadership Institute training lasts for the first two years a nurse works with one of the mobile cervical cancer clinic teams. After the nurse graduates from university with a clinical degree, she applies for a job with Mujeres Móviles. When the nurse is hired by one of the mobile cervical cancer clinic teams, she spends one week observing how the current team operates. Then, she begins to work with the team under the supervision of the mobile cervical cancer clinic team leader. If the nurse is interested in becoming a team leader in the future, she can choose to engage in the Leadership Institute training sessions. Every three months after that, the nurse is offered additional training on topics including how to educate a patient, how to perform visual inspection with acetic acid (VIA), how to perform Pap smear, how to communicate results to a patient, how to treat precancerous lesions with cryotherapy, how to plan a screening or treatment event, and how to be a team leader. As the nurse is learning, she works with the rest of the mobile cervical cancer clinic team to provide assistance under supervision. At the conclusion of the two year program, the nurse is able to be a team leader of her own mobile cervical cancer clinic team. Currently, the Mujeres Móviles only has two mobile cervical cancer clinic teams but hopes to increase their capacity to take on more teams and to place their trained leaders into new mobile cervical cancer clinic teams. The Leadership Institute program feeds into the mobile cervical cancer clinic program by training nurses how to effectively screen and treat cervical cancer.

In this chapter, I focus specifically on Mujeres Móviles' first program: the mobile cervical cancer clinic. This program is most directly related to the improvement of access to cervical cancer screening, which is the subject of this dissertation. Therefore, this program is the most comparable to the work of InVia (Chapter 5). In Section 6.2.1.a below, I provide further details on the mobile cervical cancer clinic in practice.

6.2.1.a Mobile Cervical Cancer Clinic

There are five main categories of activities that the mobile cervical cancer clinic teams engage with: (1) planning the screening and treatment events, (2) educating patients, (3) screening patients, (4) communicating results to patients, and (5) treating patients. I describe each of these activities in further detail below.

Planning the Screening and Treatment Events

At the beginning of every calendar year, the Mujeres Móviles mobile cervical cancer clinic teams meet with their local SILAIS to map out every town in their region and every

community in each town. Based on the location and number of people in each community, the mobile cervical cancer clinic teams plan where they will visit that year. The local SILAIS provides permission for the team to visit those communities.

After the team sets their annual vision of which communities to visit, they travel to each community two weeks before their planned screening event. During this initial visit, the teams get to know the community and deliver invitations to the screening events. To deliver invitations, the teams find the health posts in each community and ask the health post to contact community leaders on their behalf. The mobile cervical cancer clinic teams then ask community leaders to contact others in the community and deliver invitations for the screening event. Depending on whether or not the community has adequate phone service, these conversations happen either by phone or in person.

Educating Patients

At the screening events, one or two nurses in the mobile cervical cancer clinic team provide all patients with pre-screening education. While the patients are waiting to get screened, the nurses spend about 20 minutes discussing topics related to cervical cancer with the patients, including an overview of the burden of cervical cancer, the symptoms of cervical cancer, the risk factors for cervical cancer, the ways to prevent cervical cancer (including screening), and the ways to treat precancerous lesions. The goal of this pre-screening education is to ensure the patients are informed of their risks for cervical cancer and to tell them why Mujeres Móviles is in the community to conduct the screening. Additionally, Mujeres Móviles leverages the pre-screening education as an opportunity to teach patients about menstruation and breast cancer (Figure 6-2).



Figure 6-2. A nurse on the Central Nicaragua team demonstrates women's reproductive anatomy.

Although not directly related to cervical cancer, Mujeres Móviles found that their patient population typically lacked knowledge on women's health topics, including breast cancer and menstruation. Therefore, Mujeres Móviles uses the educational talks as an opportunity to provide more holistic women's health education. Throughout the pre-screening education, the nurses engage the patients to check for their understanding of the topics presented.

On a weekly basis, the mobile cervical cancer clinic teams discuss the topics they cover in their pre-screening education and they decide if any changes are needed.

Screening Patients

At each screening event, the teams aim to screen around 50 women. When the teams first arrive at the screening location, which is often a school or a health post, they unload their truck of supplies and set up a private screening area with a gynecological table and screening supplies (e.g., specula, cotton swabs, acetic acid for VIA, glass slides for Pap smear, gloves, and headlamps) (Figure 6-3).



Figure 6-3. The mobile cervical cancer clinic teams bring all the required cervical cancer screening supplies, including a gynecological table [right], cotton swabs, vinegar, and gloves.

Then, the mobile cervical cancer clinic operators ask the patients to come to him so that he can create a screening order. The Central Nicaragua team and the Northwestern Nicaragua team do this slightly different from each other: in Northwestern Nicaragua, the operator gives each woman a number whereas in Central Nicaragua, the operator takes down each woman's name.

The nurses in the mobile cervical cancer clinic team then call patients either by number or by name. Typically, two nurses conduct patient intake. They ask the patients intake questions, including personal demographic information (e.g., age and education) and reproductive health information (e.g., number of children and number of cervical cancer screenings previously received). Based on this information, the nurse then makes a determination of which type of screening the patient should receive. This determination is based on the established guidelines of Mujeres Móviles that have been set in accordance with MINSA's regulations. If the patient is between 30 and 49 years old; has no history of cervical biopsy, cryotherapy or hysterectomy; and has no gynecological concerns, then she receives VIA. If the patient is younger than 30 or older than 49 years old; has a history of cervical biopsy, cryotherapy or hysterectomy; or has any gynecological concerns, then she receives a Pap smear. I outline these considerations in Figure 6-4 below.

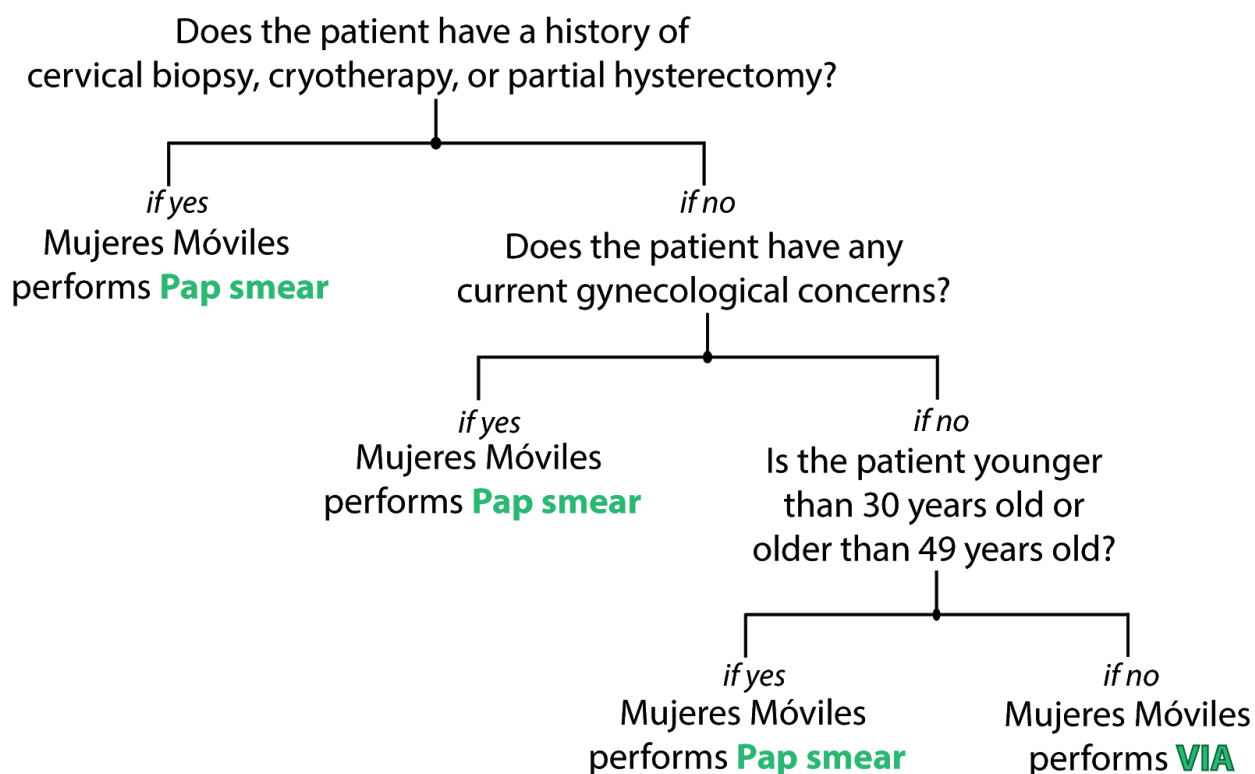


Figure 6-4. Mujeres Móviles' cervical cancer screening guidelines.

After the patient's intake is complete, the nurses then instruct the patient to wait until they are ready to screen the patient. Typically, two nurses conduct screening. When the nurses are ready, they call each patient by name. Based on the determination made during intake, the nurses either perform VIA or the Pap smear. Overall, Mujeres Móviles performs Pap smear on half of the patients and performs VIA on the other half of the patients. If the nurses perform VIA, they are able to diagnose the patient as precancerous or not directly after the screening. If the patient does have any precancerous lesions, the nurses tell her when the Mujeres Móviles mobile cervical cancer clinic will be back to perform cryotherapy. If the nurses perform the Pap smear, they collect the patient's cervical cells on a glass slide and then wrap the slide in a piece of paper, stapling it to the patient's intake sheet. This is then sent off to the lab after the screening event. While performing the screening, if the nurses see that the patient has a serious gynecologic condition (e.g., the patient already has advanced cervical cancer), then they refer the patient to a health center or departmental hospital. Approximately 5% of Mujeres Móviles' patients need a referral for more specialized care.

When the team has finished screening all patients at the event, they re-pack all of their supplies into the truck and they collect all the trash from the screenings. Because many of the health posts do not have an adequate waste management system, they burn all of the medical waste onsite.

Communicating Results to Patients

After the screening events, Mujeres Móviles sends the collected Pap smear samples to a contracted cytologist working in a bioanalysis laboratory in Nicaragua. Once they receive the results back from the lab, the teams write a simple explanation of the results and the necessary follow-up steps (e.g., medication needed, procedures needed, future check-up with Mujeres Móviles needed). They then seal the results and the explanation into an envelope with the patient's name. If the patient is found to be precancerous, then the teams add her to the "watch list" where they will continue to monitor and reach out to the patient proactively for further testing and/or treatment.

To deliver the envelopes to the patients, Mujeres Móviles has two options. First, if the community is close to the city center where the Mujeres Móviles mobile cervical cancer clinic teams work or if Mujeres Móviles is already planning to come near the community, then the teams will go to the health post and personally deliver the set of envelopes to the patients. If any envelopes are undelivered at the end of the day, Mujeres Móviles will leave the envelopes with the health post so they can distribute the envelopes to patients. Second, if the community is far from the city center where the Mujeres Móviles mobile cervical cancer clinic teams work, then the teams will coordinate with local bus drivers or with MINSA nurses who travel to the community to deliver the results to the community's health post who then deliver results to patients.

Treating Patients

During the initial screening events, the mobile cervical cancer clinic teams inform the patients when cryotherapy will be held. The cryotherapy events are scheduled at least 15 days after the screening event, which leaves enough time for the Pap smear results to come in. Typically, the Mujeres Móviles teams schedule a cryotherapy event to be held in a town's health center and then instructs all precancerous patients from the communities surrounding that town to come to receive treatment.

During the treatment events, the Mujeres Móviles teams bring their typical screening supplies (e.g., specula, cotton swabs, acetic acid for VIA, glass slides for Pap smear, gloves, and headlamps) plus cryotherapy supplies (e.g., tank of compressed carbon dioxide and cryotherapy probes of varying sizes) (Figure 6-5). Regardless of whether the patient initially received VIA or Pap smear, a Mujeres Móviles nurse performs VIA so that she can see the precancerous lesions. Then, she performs cryotherapy to freeze off the lesions.



Figure 6-5. The mobile cervical cancer clinic teams bring a tank of compressed carbon dioxide (shown in orange) to perform cryotherapy. The teams set up cryotherapy in the same manner as they set up screening, and bring a gynecological table, cotton swabs, vinegar, and gloves.

The journey map in Figure 6-6 shows all of these interactions.

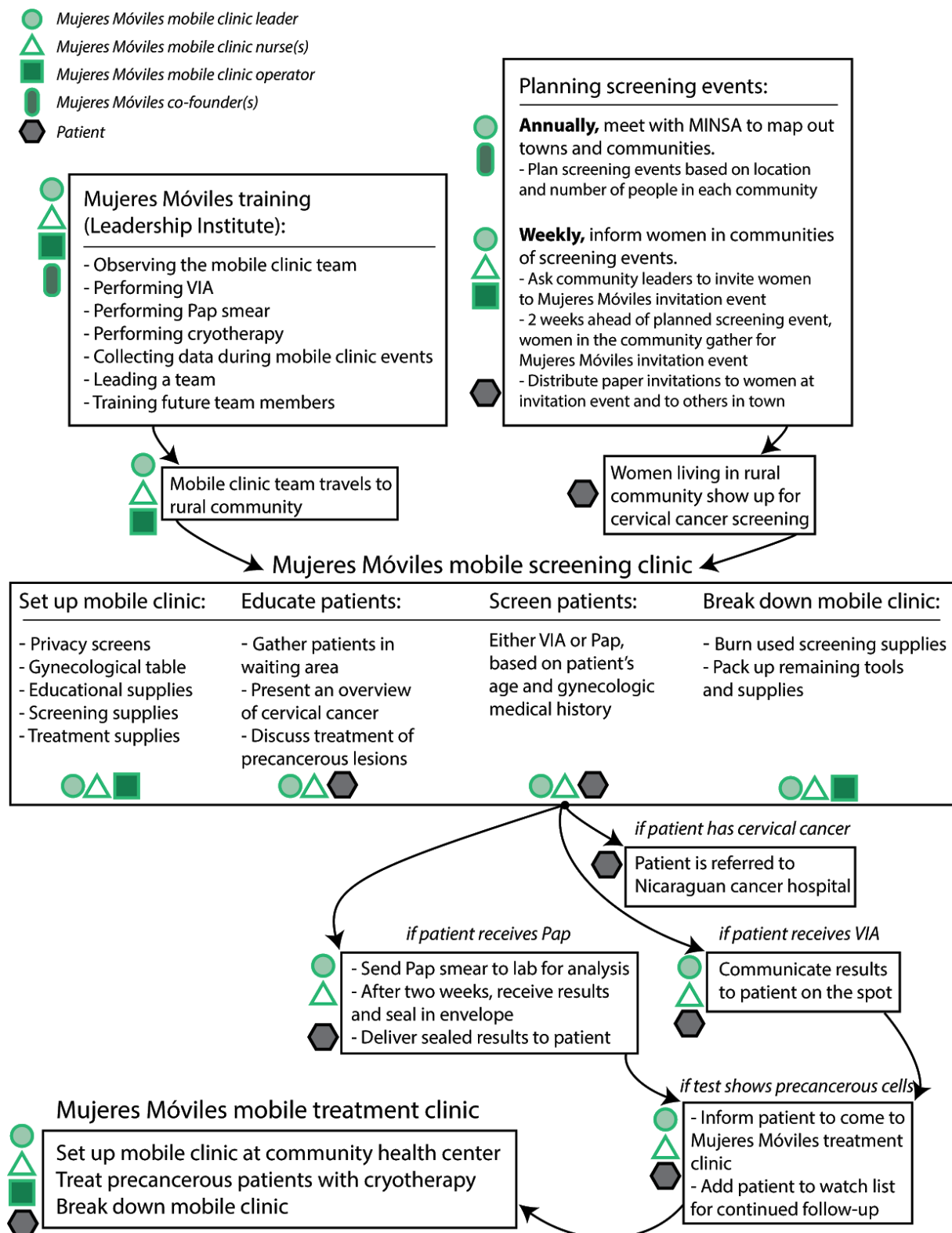


Figure 6-6. The journey map of Mujeres Móviles mobile cervical cancer clinics.

A Typical Week for the Mujeres Móviles Mobile Cervical Cancer Clinic Teams

In any given week, all of these activities overlap. Here, I outline a typical week of one of the Mujeres Móviles mobile cervical cancer clinic teams. On Monday, the team compiles patient data (i.e., demographics, VIA results) from the previous week's screening events. They also receive results of the Pap smears they collected from their screening events two weeks ago,⁴ and they inform precancerous patients when the team will be back in the community to perform cryotherapy. Some Mondays, the team might actually travel out to the communities to perform cryotherapy if it was scheduled previously. On Tuesday and Wednesday, the team travels to communities in the region to host cervical cancer screening events. After the events, the mobile cervical cancer clinic team sends the collected Pap smear slides to the bioanalysis lab for testing. On Thursday, the team organizes for the following week, and reaches out to communities to schedule screening events for weeks further in the future. On Friday, the team continues to compile their data collected from patients and also discusses topics in pre-screening education to see if they should revise their educational talks in any way. Some Thursdays and Fridays, the team might travel to the communities to perform cryotherapy.

Figure 6-7 below shows the Mujeres Móviles truck parked at a local school where the team set up a mobile cervical cancer screening clinic.



Figure 6-7. A Mujeres Móviles truck parked at a school during a mobile screening event.

As a reminder, the vision of the mobile cervical cancer clinic is to combine proactive outreach and sexual health education with cervical cancer screening and treatment procedures to bring health to women in the communities Mujeres Móviles serves. To

⁴ There is at least a two-week turnaround between when the Pap smears are collected and when the results are received from the lab.

understand how the mobile cervical cancer clinic program seeks to enact this vision, I have created a theory of change, where the goals of the mobile cervical cancer clinics are categorized as *inputs*, *outputs*, *outcomes*, and *impacts*. Figure 6-8 below shows the theory of change for Mujeres Móviles' mobile cervical cancer clinic program.

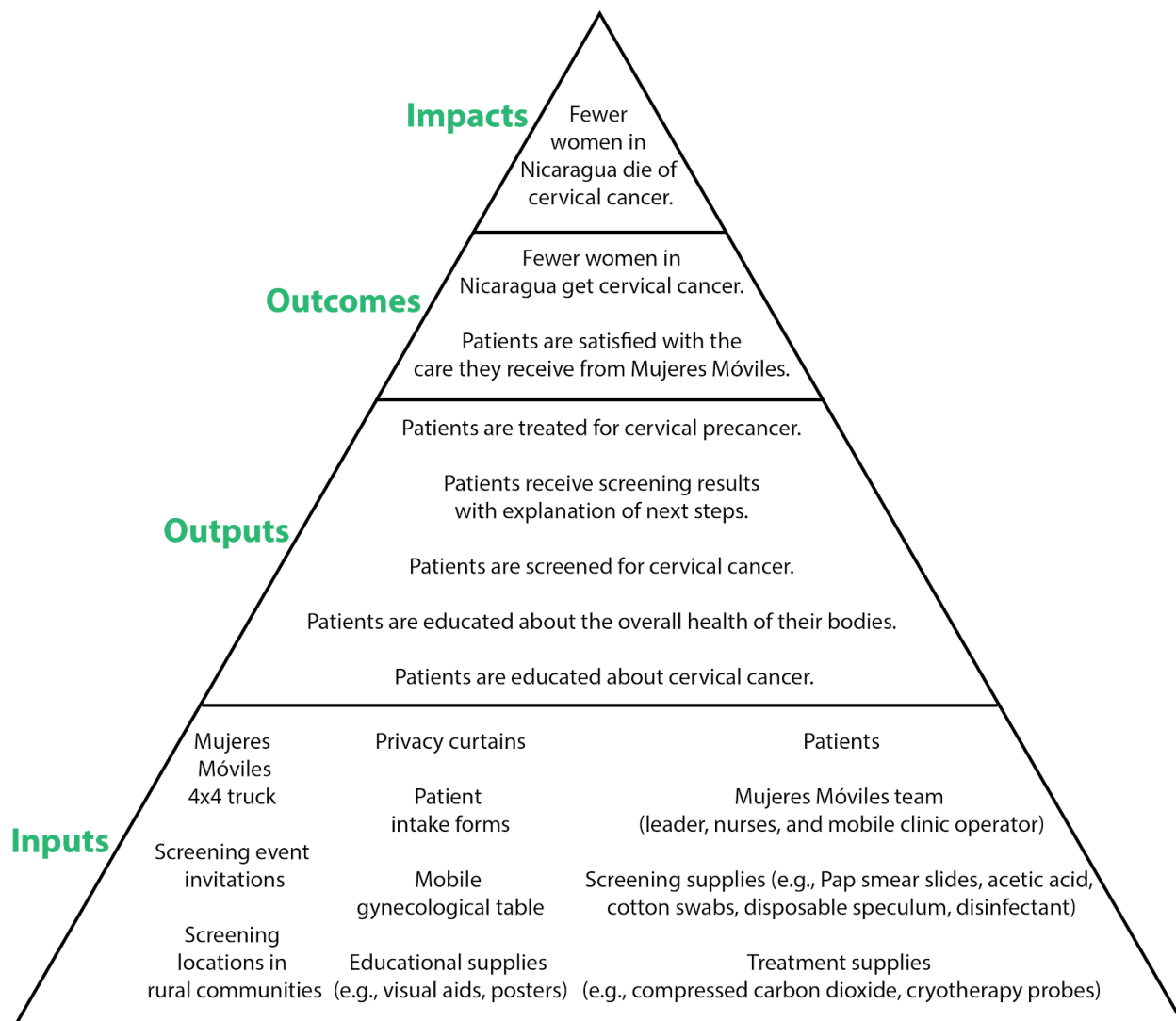


Figure 6-8. Theory of change demonstrating how Mujeres Móviles intends for the mobile cervical cancer clinics to create impact.

6.2.2 Personnel of Mujeres Móviles

The Mujeres Móviles team is composed of three co-founders, two mobile cervical cancer clinic teams, one Girls Club team, a financial controller, five board members, and a range of collaborating organizations.

Co-Founder X is the Executive Director of Mujeres Móviles. She leads the clinical aspects of Mujeres Móviles, and is trained in Pap smear, VIA, and cryotherapy.

Co-Founder X was born and raised in Nicaragua, and has a degree in bioanalysis from a Nicaraguan university. Before she graduated high school, Co-Founder X's mother died of cervical cancer, therefore inspiring Co-Founder X's college trajectory and eventual founding of Mujeres Móviles. Co-Founder Y is the Chief Operating Officer of Mujeres Móviles. He supports the administrative operations of Mujeres Móviles and is spearheading new collaboration opportunities for Mujeres Móviles in Nicaragua. Co-Founder Y was born and raised in the US and moved to Nicaragua in 2013. Co-Founder Z is the Chair of the Mujeres Móviles Board. She works with Co-Founder Y to foster new collaboration opportunities and she communicates with Mujeres Móviles board members on these new opportunities and on existing activities at Mujeres Móviles. Before joining Mujeres Móviles, Co-Founder Z held a distinguished career in the US in marketing and health care. Today, Co-Founder Z continues to live in the US and she coordinates Mujeres Móviles operations with Co-Founders X and Y remotely.

Mujeres Móviles is composed of two mobile cervical cancer clinic teams. Mujeres Móviles first implemented their mobile cervical cancer clinic in a city in Central Nicaragua, and a mobile cervical cancer clinic team remains there today. The second mobile cervical cancer clinic is located in a city in Northwestern Nicaragua. The Central team is led by the Central Clinic Leader while the Northwestern team is led by the Northwestern Clinic Leader. Both of these clinical leaders coordinate their team's screening events with the local SILAIS and with community leaders. The Central Clinic Leader and the Northwestern Clinic Leader also participate as full team members at the screening events, providing educational talks to women who seek to receive cervical cancer screening, conducting VIA and Pap smear, and conducting cryotherapy and referrals. Two nurses round out each clinical team, Central Nurse 1 and Central Nurse 2 in Central Nicaragua and Northwestern Nurse 1 and Northwestern Nurse 2 in Northwestern Nicaragua. These nurses have similar jobs at the screening events: to provide educational talks to women who seek to receive cervical cancer screening, to conduct VIA and Pap smear, and to conduct cryotherapy and referrals. Finally, the mobile team operators, Central Clinic Operator in Central Nicaragua and Northwestern Clinic Operator in Northwestern Nicaragua, drive the rest of their teams to and from the rural communities, help set up and break down the mobile cervical cancer clinic each day, coordinate the order in which patients at the events will be screened, and take photos at the screening events. The Central Clinic Leader, Northwestern Clinic Leader, Central Nurse 1, Central Nurse 2, Northwestern Nurse 1, and Northwestern Nurse 2 are all women and all hold clinical degrees (either nursing or bioanalysis) from a Nicaraguan university. The Central Clinic Operator and Northwestern Clinic Operator are men and both hold business degrees from a Nicaraguan university.

Mujeres Móviles includes two additional team members. First, the Girls Club Leader runs the Girls Club. She developed the Girls Club from the ground up, with

support from the Mujeres Móviles co-founders. The Girls Club Leader has a background working for non-profit and educational organizations in Nicaragua, and she received her degree in journalism and communications from a Nicaraguan university. The Girls Club Leader speaks fluent English and worked as my translator during my trip to Nicaragua in June 2019. Second, the Financial Controller manages the accounting and finances of Mujeres Móviles, and helps procure supplies needed for the teams.

Five board members advise the Mujeres Móviles team on a range of subjects, including cervical cancer screening, research, outreach, and non-profit management. Several organizations collaborate with Mujeres Móviles, including Team Gynecological Table, Board Member 1's university research group, American High School, and a host of US health training organizations.

Table 6-1 shows the range of personnel involved with Mujeres Móviles.

Table 6-1. Personnel involved with Mujeres Móviles, including co-founders, team members, board members, and collaborators.

Role	Name	Description of Work with Mujeres Móviles
Co-founder	Co-Founder X	Executive Director. Leads the clinical teams
	Co-Founder Y	Chief Operating Officer. Supports administrative operations and seeks out collaboration opportunities
	Co-Founder Z	Chair of the Board. Communes with the board and seeks out new collaboration opportunities
Mobile cervical cancer clinic team members	Central Clinic Leader	Leads mobile cervical cancer clinic team in central Nicaragua. Collaborates with SILAIS and community leaders. Performs cervical cancer education, screening, and treatment
	Central Nurse 1	Performs cervical cancer education, screening, and treatment in central Nicaragua
	Central Nurse 2	Performs cervical cancer education, screening, and treatment in central Nicaragua
	Central Clinic Operator	Drives the central Nicaragua team to events. Helps manage operations at events
	Northwestern Clinic Leader	Leads mobile cervical cancer clinic team in northwest Nicaragua. Collaborates with SILAIS and community leaders. Performs cervical cancer education, screening, and treatment
	Northwestern Nurse 1	Performs cervical cancer education, screening, and treatment in northwest Nicaragua
	Northwestern Nurse 2	Performs cervical cancer education, screening, and treatment in northwest Nicaragua
	Northwestern Clinic Operator	Drives the northwestern Nicaragua team to events. Helps manage operations at events

(continued)	Name	Description of Work with Mujeres Móviles
Other team members	Girls Club Leader	Leads after-school girls club in western Nicaragua
	Financial Controller	Manages accounting and supply procurement
Board members	Board Member 1	Advises Mujeres Móviles on research and data collection strategies
	Board Member 2	Advises Mujeres Móviles on clinical strategies
	Board Member 3	Advises Mujeres Móviles on educational strategies
	Board Member 4	Advises Mujeres Móviles on communications strategies
	Board Member 5	Advises Mujeres Móviles on non-profit management
Collaborating organization	Team Gynecological Table	Collaborates with Mujeres Móviles to create a mobile gynecological table for use in screening events
	Board Member 1's University Research Team	Collaborates with Mujeres Móviles to conduct research on patient stress following cervical cancer screening results
	American High School	Collaborates with Girls Club to develop professional development and sexual health lessons
	Assorted US health training organizations	Provide human and financial resources to support Mujeres Móviles mobile cervical cancer clinics

6.2.3 Historical Timeline of Mujeres Móviles

In 2013, Co-Founder X, a student in bioanalysis at a Nicaraguan university at the time, began to host sexual health classes for adolescents in the city where Co-Founder Y worked. Co-Founder X and Co-Founder Y began to work together in rural communities with MINSA to deliver vaccinations door-to-door. As they were doing this work, Co-Founder X shared with Co-Founder Y the story of her mother's battle with cervical cancer. Co-Founder X and Co-Founder Y became inspired: could they bring quality cervical cancer health care to women living in rural areas of Nicaragua? One of their first ideas to meet this vision was to mobilize the cervical cancer screening procedure by putting all the necessary supplies in a suitcase.

In 2014, Co-Founder X began her residency at a large cancer hospital in Nicaragua as part of her degree in bioanalysis. Co-Founder Z was pursuing a master's degree at a US university and reached out to Co-Founder Y at the recommendation of her program's dean. Co-Founder Y had finished his master's degree from the same US university several years prior, so Co-Founder Y and Co-Founder Z bonded over their shared educational experience and their shared interest in global social

entrepreneurship. Co-Founder Z became inspired by Co-Founder X's story and by the idea of mobile cervical cancer screening, and therefore began to conduct background research on the topic. Through her research, Co-Founder Z discovered the VIA screening procedure. She also identified a doctor, who eventually became Board Member 2, in Nicaragua who offered training in VIA. This doctor then trained Co-Founder X, who was already trained in Pap smear through her university classes, to perform the VIA procedure. Additionally, Co-Founder X learned how to perform cryotherapy, a method to freeze off and therefore treat precancerous cervical cells.

In August 2014, Co-Founders X, Y, and Z wanted to pilot test the feasibility of their idea to bring cervical cancer screening to rural communities. They identified a remote community on the Pacific coast of Nicaragua and began to ask women in the community what they would want from a cervical cancer screening event. The women in the community highlighted their need for education on cervical cancer, a rapid turnaround of results (two weeks would be appropriate), and a set of medication and treatment options following the results of the cervical cancer screening examination. Then, Co-Founders X, Y, and Z came back to the community and Co-Founder X performed the Pap smear for women in the community. A week later, the co-founders returned once again with the results from the Pap smears. They hosted a small party to celebrate the success of the pilot test with the women in the community. They delivered results to the women who were able to attend and they went door-to-door to find the other women who could not join the party but were screened the previous week. While delivering results, Co-Founders X, Y, and Z facilitated feedback from the women to learn what the women liked and did not like about the pilot test.

In 2015, Co-Founder X graduated with her degree in bioanalysis. Co-Founder Z took the lead in officially founding Mujeres Móviles as a non-profit organization. In July 2015, the Mujeres Móviles team brought on the Northwestern Clinic Leader,⁵ who was a friend of Co-Founder X from school. The team began to use Co-Founder Y's truck to travel to rural communities in Central Nicaragua to perform cervical cancer screening, with permission from the local SILAIS office to conduct screenings in this region.

In 2016, the team continued to travel to rural communities around Central Nicaragua. They also expanded their operations into Northwestern Nicaragua.

In 2017, Mujeres Móviles officially partnered with the national MINSA office to conduct cervical cancer screening. In Summer 2017, Mujeres Móviles officially launched their operations in Northwestern Nicaragua and created a team exclusively based in Northwestern Nicaragua. The Northwestern Clinic Leader became the leader of this new team. As they began to screen in rural communities in Northwestern Nicaragua,

⁵ The Northwestern Clinic Leader was initially brought on to work with the mobile cervical cancer clinic in Central Nicaragua, and later became the leader of the new mobile cervical cancer clinic team in Northwestern Nicaragua.

they saw that women at the screening events did not know much about their menstrual cycle. Several women thought their menstrual cycle was a monthly sickness that kept making them tired. Co-Founder Y developed the idea for a tracking bracelet when he remembered seeing tracking bracelets used in natural family planning. Inspired by this idea, the Mujeres Móviles decided to create menstrual cycle tracking bracelets (“power bracelets”) to teach women in Northwestern Nicaragua about their menstrual cycle. In November 2017, as they began to see the success of the power bracelet in teaching women at screening events about menstruation, the Mujeres Móviles began to share the bracelets with adolescents in Northwestern Nicaragua who were unable to come to screening events because they were in school. The Mujeres Móviles team began to teach adolescent sexual health in schools in rural Nicaraguan communities.

Around the same time in Fall 2017, Mujeres Móviles launched their leadership training program. Board Member 3 noticed that many people in Nicaragua, including the women who Mujeres Móviles were hiring, were not familiar or trained in leadership. Therefore, the goal of the Leadership Institute is to develop the leadership skills of women who worked with Mujeres Móviles.

In 2018, a sociology professor, now Board Member 1, at a US university became interested in studying a patient’s stress after receiving a precancerous diagnosis in a cervical cancer screening examination. Mujeres Móviles had been compiling a database of all the women they had screened, and they had previously developed a “watch list” of women who received a pre-cervical cancer diagnosis. Mujeres Móviles began to work with Board Member 1, and they collaboratively developed plans to formalize and improve the ways Mujeres Móviles collects patient data. Also in 2018, a donor in Western Nicaragua donated her house and property to Mujeres Móviles. The Mujeres Móviles hired the Girls Club Leader to develop a plan for how Mujeres Móviles could use this property. The Girls Club Leader created the Girls Club, an after-school club for adolescent girls in urban Western Nicaragua. The Girls Club aimed to teach girls about sexual health, in addition to general skills like leadership and professional development.

In 2019, Mujeres Móviles piloted two new innovations. First, the team in Central Nicaragua piloted an adolescent sexual health curriculum. This curriculum built upon Mujeres Móviles previous efforts to teach adolescents about menstruation through the power bracelet. The team in Central Nicaragua was granted permission from the Ministry of Education in Nicaragua (*Ministerio de Educación*, a.k.a. MINED) to host sexual education talks for adolescents. Second, the team in Northwestern Nicaragua piloted a new electronic data collection procedure. This innovation was inspired by the collaboration with Board Member 1, as Mujeres Móviles needed a more efficient way to capture and analyze information from the women they screen for cervical cancer. Mujeres Móviles chose to develop these two pilot programs in separate locations so that

each team would have the opportunity to fully develop and test the program. Mujeres Móviles' intention is to wrap both of these innovations into their standard operations.

I traveled to Nicaragua in June 2019 to observe the Mujeres Móviles team in action. I observed and interviewed the teams in Central Nicaragua and in Northwestern Nicaragua. I wrapped up my data collection at the end of June 2019.

6.3 Mujeres Móviles' Process of Human-Centered Design for Accessibility

In this section, I discuss the HCD process that Mujeres Móviles employed to create the mobile cervical cancer clinic. I discuss how their HCD approach took them around the four design process phases presented in Beckman and Barry's Innovation Model [74] (Figure 2-9), and I explain the specifics of Mujeres Móviles' work in each phase.

Figure 6-9 below shows Mujeres Móviles' HCD process laid out on a timeline. Each number corresponds to a different phase of the design process, and the Innovation Model phase name is in ***bold italics***, starting in *Frame and Reframe* (Phase 1) and ending in *Make and Experiment* (Phase 17). Mujeres Móviles' design activities are organized into "clusters" noted by the color coding in Figure 6-9. These clusters point out the high-level tasks that Mujeres Móviles carried out, and demonstrate that Mujeres Móviles often worked on several overlapping tasks at once, particularly in their later phases.

In the remainder of this section, I describe the various phases of Mujeres Móviles' process to design the mobile cervical cancer clinics and I explore how the Mujeres Móviles team considered accessibility during their design process. In Section 6.4, I discuss their HCD for accessibility approach, and I present an evaluation of the "human-centeredness" of their design approach plus the accessibility considerations present in their design approach.

Phase 1 - Personal Motivation to Address Cervical Cancer (***Frame and Reframe***)

The initial spark for Mujeres Móviles began in 2008, when Co-Founder X's mother in Nicaragua died of cervical cancer. This traumatic event inspired Co-Founder X to dedicate her college education to addressing cervical cancer mortality in Nicaragua. She learned that many women like her mother living in rural Nicaragua were not able to access the resources necessary to prevent cervical cancer. Co-Founder X knew that something needed to be done to change this reality for women in rural Nicaragua.

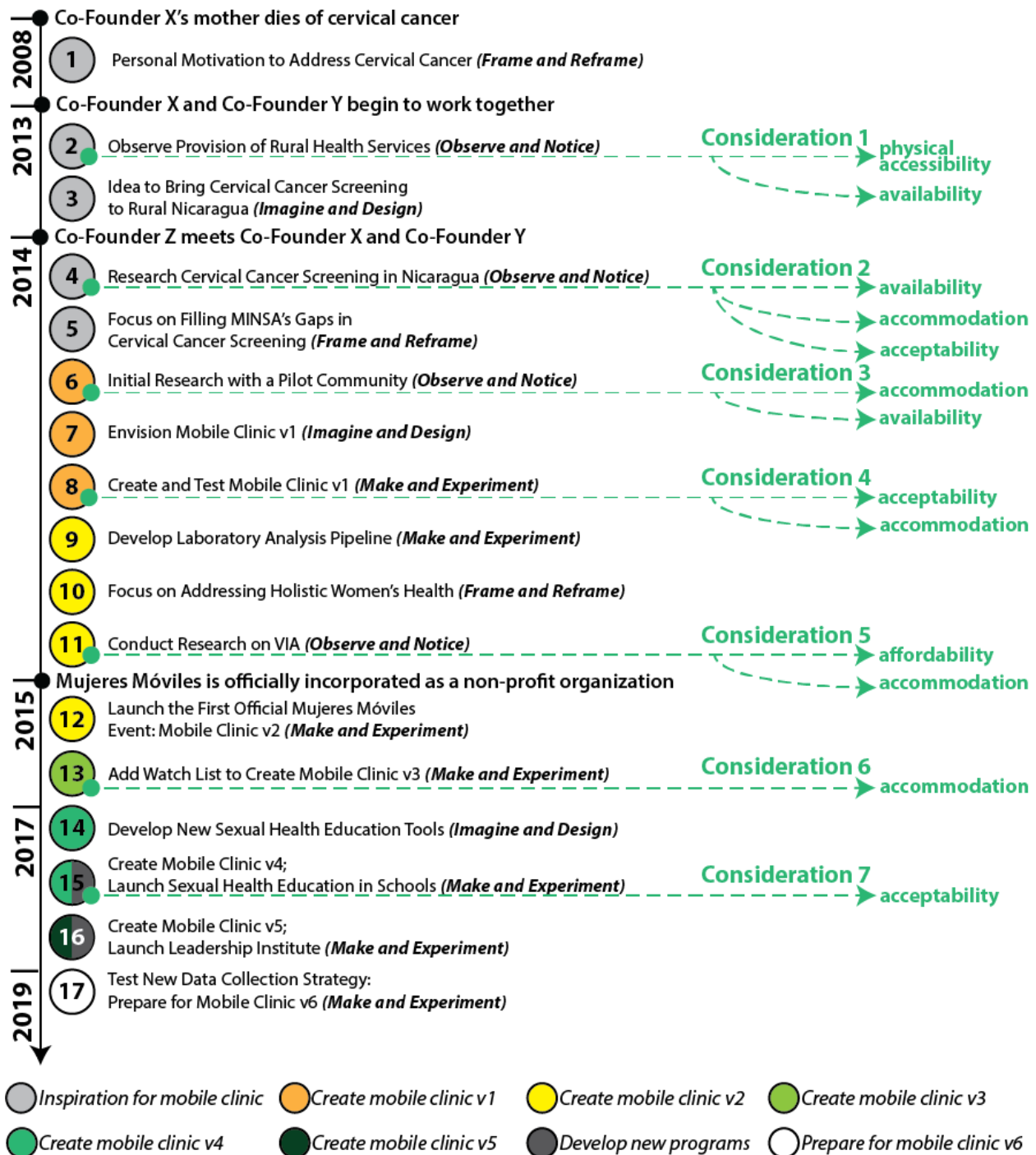


Figure 6-9. Timeline of Mujeres Móviles' design phases and considerations of accessibility.

Phase 2 - Observe How MINSA Provides Health Services in Rural Nicaragua (*Observe and Notice*)

In 2013, several years after the initial spark, Co-Founder X and Co-Founder Y began to work together in rural Nicaragua to transport MINSA doctors to deliver vaccinations in

rural Nicaragua. At the time, Co-Founder X was finishing her clinical residency in the last year of her bioanalysis degree.

As the two co-founders were working with MINSA, they observed how the Nicaraguan health system currently provides services to people living in rural areas, beyond the reach of many public health posts.

6.3.1 Consideration of Accessibility 1: *Physical Accessibility and Availability*

After Co-Founder X and Co-Founder Y observed MINSA delivering vaccinations to children in rural communities of Nicaragua (Design Phase 2), they began to consider the utility of mobile health services that can travel to hard-to-reach communities. They observed the challenges of *physical accessibility* to health services facing many who live in rural communities. They realized the benefits of being able to travel to a community to deliver health services near to where people live.

By considering *physical accessibility*, Co-Founder X and Co-Founder Y also began to consider the lack of *availability* of health services available in rural Nicaragua. In order to make health services available to people living in rural Nicaragua, they would need to make health services *physically accessible*. This consideration informed the rest of Mujeres Móviles' process to create their mobile cervical cancer clinic.

Phase 3 - Initial Idea to Bring Cervical Cancer Screening to Rural Nicaragua (*Imagine and Design*)

As Co-Founder X and Co-Founder Y were working with MINSA to bring doctors to rural Nicaragua to deliver vaccinations, they began to envision a mobile cervical cancer clinic. According to Co-Founder Y:

"We had the vision of Mujeres Móviles when we were watching [MINSA] do the vaccination process for children in the community, going house to house in rural communities with their little coolers and their vaccinations and injecting children house to house. They got names and lists. It was quite interesting to see that."

Their first idea to bring cervical cancer screening to rural Nicaragua was inspired by the question: *"what if we could fit everything we need for screening in a suitcase?"*

Phase 4 - Background Research on Cervical Cancer Screening in Nicaragua (*Observe and Notice*)

In 2014, Co-Founder X and Co-Founder Y met Co-Founder Z. At the time, Co-Founder Z was in the middle of her master's program in the US, and she was encouraged to

reach out to Co-Founder Y by her program's dean. The three co-founders connected around their shared interest in community development and women's empowerment, and they began to discuss how Co-Founder Z could help Co-Founder X and Y conduct research on cervical cancer screening.

The three co-founders then dove deep into exploring cervical cancer screening. Co-Founder Z conducted a literature review on best practices for cervical cancer screening in low-resource settings and on how to translate these best practices into locally relevant processes. Co-Founder X conducted first-hand observations of the existing issues in the process of delivering cervical cancer screening to rural Nicaragua. According to Co-Founder X:

"I worked in a hospital in Managua... It's the same place where my mom was in treatment. So when I was working there, I had the opportunity to speak and learn so much about women that were coming into that hospital from very rural locations of Nicaragua. [In my schooling,] I also focused on cytology and the Pap exam. So I learned about all the different processes of the Ministry of Health as well as the challenges with those processes."

According to Co-Founder Z: *"we probably put eight months to almost a year of research into the design of our process, and we continue to develop it as we stand today."*

Mujeres Móviles saw several specific gaps in MINSA's cervical cancer screening procedures. First, MINSA takes too long to deliver results to patients. MINSA struggled to communicate results directly to patients and instead delivered results to health centers and health posts. These health facilities were not always able to get in touch with patients to deliver results. Second, Pap smears collected by MINSA suffer from quality issues and are therefore often inconclusive. Third, the various pieces of the MINSA health system (i.e., health posts, health centers, hospitals, laboratories) are disconnected and therefore MINSA struggles to track patient data and patient results throughout the system. Fourth, MINSA focuses on episodic health treatment instead of regular preventive health services. Preventive health care is limited across Nicaragua, particularly in rural Nicaragua.

Additionally, the Mujeres Móviles team realized that there are issues brought on by patriarchal cultural norms in Nicaragua. Co-Founder X notes that "machismo" culture negatively impacts the health of women throughout their life.

"Our [culture of] machismo [negatively impacts] how well [women] are treated. That's very important as well. Something that we saw and have seen, and another reason for [creating] our organization, is ... how our women have been mistreated by men."

Co-Founder Y adds that machismo culture may cause women not to show up to get regular cervical cancer screening examinations.

6.3.2 Consideration of Accessibility 2: Availability, Accommodation, and Acceptability

In Design Phase 4, both Co-Founder X and Co-Founder Z carried out research on how MINSA conducts cervical cancer screening in Nicaragua. The co-founders noticed three main issues in accessibility: low quality of care (*availability*), limited communication and follow-up with patients (*accommodation*), and patriarchal cultural norms devaluing women's health (*acceptability*).

After observing these accessibility issues, the Mujeres Móviles team began to frame their solution to fill in the gaps of MINSA's process (Design Phase 5). This framing allowed Mujeres Móviles to establish themselves as a unique service provider focusing on delivering high-quality (*availability*), proactive (*accommodation*), and holistic (*acceptability*) care. Mujeres Móviles focused on bringing women the level of cervical cancer care that MINSA could not provide.

Phase 5 - Focus on Filling In Gaps in the MINSA's Cervical Cancer Screening (Frame and Reframe)

Based on the research conducted in Phase 4, Mujeres Móviles envisioned their mobile cervical cancer clinic as filling in the gaps left by MINSA. As Co-Founder X expresses:

"Since I understood how the current system was working... I knew that I could focus on the errors or the challenges or the under-resourced parts of the system so that Mujeres Móviles would be able to bring about resources to these women in rural [communities]."

Mujeres Móviles created the mobile cervical cancer clinic to fill in the gaps they observed in MINSA's cervical cancer screening procedures. Mujeres Móviles committed to delivering conclusive Pap smear results to patients within two weeks by putting in significant effort to keep in touch with patients by phone, through community leaders, and through community health posts. The team committed to tracking patient data to ensure the best possible care.

Mujeres Móviles' vision became delivering high-quality preventive cervical cancer screening to women beyond the reach of traditional health services in Nicaragua.

Phase 6 - Conduct Initial Research with a Pilot Community (Observe and Notice)

In Summer 2014, the Mujeres Móviles team conducted research with a rural community in Western Nicaragua. According to Co-Founder X, the team needed to conduct a pilot study to understand the viability of the mobile cervical cancer clinics. Women in rural Nicaragua had the option to travel to a community health center to receive a Pap smear, and Mujeres Móviles wanted to understand if that system was well-received by patients.

“The pilot really enabled us to get out there into the communities and form our theories around why women wanted to go into those community health centers, and get their Pap. [We] started talking to the women to see if this was a viable project and [to understand] what the impacts could be.”

From the research, the team found that community health centers were not meeting women’s expectations for cervical cancer screening. The rural community where the team carried out their research did not have a local community health center. The team applied this research to inform their vision of a mobile cervical cancer screening clinic. The community members shared several key pieces they would want in a mobile cervical cancer screening clinic:

- Education on cervical cancer
- Two-week turnaround on results
- Provision of medication and/or treatment

6.3.3 Consideration of Accessibility 3: Accommodation and Availability

As they were beginning to develop their pilot mobile cervical cancer clinic (v1), Mujeres Móviles conducted research with a community in rural Western Nicaragua (Design Phase 6). The women in the community agreed on three main offerings: cervical cancer education (*accommodation*), rapid turnaround of results (*accommodation*), and referrals for medication and treatment (*availability*). First, women in the community stressed the importance of Mujeres Móviles providing education on cervical cancer and on the screening procedure patients would receive, so that patients could be more informed of the need to undergo cervical cancer screening and could be more comfortable with receiving an examination. Second, women in the community shared their desire for results from the cervical cancer screening to be shared rapidly. This stands in direct contrast to women’s experiences with MINSA, and they wanted Mujeres Móviles to better *accommodate* their needs for receiving results of their examination. Third, women in the community agreed that Mujeres Móviles should make medication and treatment *available* for patients who need it.

The accessibility considerations in Design Phase 6 directly informed the creation of the envisioned and piloted mobile cervical cancer clinic v1 in Design Phases 7 and 8.

Phase 7 - Envision Mobile Cervical Cancer Clinic v1 (*Imagine and Design*)

Based on their initial background research and their research with the community in Western Nicaragua, Mujeres Móviles began to envision the format of their mobile cervical cancer screening clinic.

The pilot mobile cervical cancer clinic would include a brief educational talk on cervical cancer. The patients would be screened with Pap smear, and Mujeres Móviles would guarantee their results within two weeks. If the patient were to have any gynecological conditions that required further care, Mujeres Móviles would work with MINSA to provide medication and treatment options. Finally, Mujeres Móviles would provide cryotherapy treatment for patients with precancerous cells.

Phase 8 - Create and Test Mobile Cervical Cancer Clinic v1 (*Make and Experiment*)

In August 2014, Mujeres Móviles piloted the first version of their mobile cervical cancer clinic. Because their pilot community in Western Nicaragua did not have a local health center, Mujeres Móviles set up their mobile cervical cancer clinic at a local public school, which became a trend as the organization grew in size and scope.

In the pilot, Mujeres Móviles screened all 26 women who lived in the small community. According to Co-Founder Y: *“we considered it a success because the women were happy with the services and the attention that they received.”* The team collected feedback from the women right before they received their examination and then again when Mujeres Móviles returned to the community with the Pap smear results. The women were asked to provide feedback on what they did and did not like about Mujeres Móviles’ process.

From the pilot, Mujeres Móviles gained feedback on the need for informative pre-screening education and the importance of treating patients with respect. They found that pre-screening education was needed to inform the patients about: (1) what to expect from the Pap smear they would receive, and (2) basic human and reproductive health, including fertility and menstruation. As Co-Founder Z recalls:

“The women we were talking to didn’t understand what their menstrual period was all about. Menstrual bleeding to them was a disease, not part of their fertility.”

To treat patients with due respect, Mujeres Móviles learned of the need to: (1) pay attention to the questions and needs of patients, and (2) perform the exam gently. Co-Founder Y notes that the patients were not used to receiving sufficient attention from healthcare providers, and it was important for Mujeres Móviles to *“treat them as patients, like clients, like women. They deserve attention and it’s not something that they were normally receiving.”* Related, Mujeres Móviles learned how important it was for women to be treated gently while they received the Pap smear. Co-Founder X relates the need to perform the Pap smear gently with Mujeres Móviles decision to exclusively employ women to administer the Pap smear: *“we’ll use women in our project, so women treating other women the way that they want to be treated as well.”*

6.3.4 Consideration of Accessibility 4: *Acceptability* and *Accommodation*

In Design Phase 8, the Mujeres Móviles team piloted the first version of their mobile cervical cancer clinic with a community in rural western Nicaragua. The team began to consider two additional aspects of accessibility as a result of the pilot: the need to provide sexual health education to patients (*acceptability*) and the need to treat women respectfully and gently during the examination (*accommodation*). First, the Mujeres Móviles team learned that women who participated in the pilot study did not fully understand their menstrual cycle and often confused menstruation with a disease. Second, the team learned that patients were surprised at the level of attention and comfort they were afforded during the pilot, and they noted that they were not used to receiving such care from MINSA. Mujeres Móviles would need to provide sexual health education to improve the *acceptability* of women's reproductive health in the minds of patients, and they would need to continue treating patients with comfort and respect (*accommodation*).

Both of these considerations were addressed in mobile cervical cancer clinic v2, developed in Design Phases 9 through 11.

Phase 9 - Develop a Pipeline for Laboratory Analysis (*Make and Experiment*)

After Mujeres Móviles finished their pilot test, they began to refine their envisioned mobile cervical cancer clinic program. In order to maintain quality throughout their screening process, the team wanted to be able to control how the Pap smear samples would be analyzed. Specifically, Co-Founder X did not want to put Mujeres Móviles' samples through the same process as MINSA and instead wanted to pay cytologists to analyze Mujeres Móviles' samples independently. Co-Founder Z explains this process in more detail:

"We actually pay them separately and they become an outside contractor. We have two [cytologists] right now who are devoted and love the work, which is a good thing, but it allows us to know the quality and be able to hold [them] accountable to time frames."

These cytologists are then able to share their feedback with Mujeres Móviles on how the samples are collected. Cytologists currently do not have such a feedback loop with MINSA. One of the cytologists shared with Mujeres Móviles that MINSA was not collecting samples in a way to ensure conclusive results. According to Co-Founder X:

"There was some feedback [that our cytologist shared] regarding the community that we worked in the very first time. [Our cytologist] had just received a package of samples from that community's health center, as well as our [samples] from our events. And [our cytologist] immediately realized that the number of results that were positive from our

group absolutely dwarfed what was coming in from the Ministry of Health [despite the Ministry of Health collecting more samples]. So something clearly was off in terms of how they [at the Ministry of Health] were taking the exam."

Co-Founder Z notes that Pap smear samples have to be collected in a very specific way in order to be properly tested in Nicaragua. Even clinicians from the US who have come to Nicaragua to help with testing have not been able to consistently collect samples able to be properly analyzed.

"We had groups come down from the United States who are professional doctors and nurses to assist in training and it turns out they use a technology and a technique that ... may work in the US, but it doesn't work in Nicaragua, and they ended up with some bad results as well. We have older equipment, older processes, and a very specific way of collecting a sample that would be effective in the testing. And unless you follow those rules... the opportunity to have false results is just so high... You really have to learn to do this well and that's the training that we take our team through, but the Ministry of Health can't necessarily afford to do that... It's just not part of the process."

A key differentiator of Mujeres Móviles is their commitment to accountability and quality. Co-Founder Y notes the importance of women being able to receive conclusive and accurate results:

"Can you imagine you're a woman that walks two hours to a community health center, you get this [Pap smear] done and then [the healthcare provider] can't even do it properly and you don't know if it was good or bad? It's just inconclusive. They'll probably never come back."

Phase 10 - Focus on Addressing Holistic Women's Health (*Frame and Reframe*)

One of the key learnings from Mujeres Móviles' pilot study was the need to include holistic women's health education. Co-Founder Z expresses:

"What do we need to do to allow women to better understand and be educated about not just cervical cancer what is, but what is sexual health, what's their fertility, how does it all relate together? So that they are not just in a position of being screened for a disease that they have no frame of reference or understanding about and it stays mystical, and it stays 'as God's intention,' [but it's] something that they can learn about ... to be able to take control and care for their own bodies."

A key detriment to women's health, as the team learned in Phase 5, is the machismo culture in Nicaragua. Patriarchal, machismo attitudes contribute to women's inability to take care of their own well-being. Through their women-centered model of care, the team envisions Mujeres Móviles as a counterpoint to the dominant machismo narrative in Nicaragua.

Phase 11 - Conduct Research on VIA (*Observe and Notice*)

In late 2014, the Mujeres Móviles team learned about the VIA screening method. They learned about VIA through their literature review and found that it could be very impactful in low-resource communities because it does not depend on the cytology lab. The team wanted to see how they could include VIA in their operations, according to Co-Founder Z:

“[VIA was] something that we started looking at and Co-Founder X started doing more investigation around to see if there was something that we could actually do and do successfully in an environment like she was seeing in rural Nicaragua.”

In her investigation, Co-Founder X discovered that there were a few opportunities to learn VIA in Nicaragua. Specifically, according to Co-Founder X:

“I was able to find a program at that same hospital where I did my residency to participate in training around colposcopy... as well as visualization. So I enrolled in that program and received training from doctors that specialize in that.”

Co-Founder X was trained in VIA in November 2014.

6.3.5 Consideration of Accessibility 5: *Affordability and Accommodation*

In Design Phase 11, the Mujeres Móviles team conducted literature and clinical research on the VIA cervical cancer screening method. Co-Founder Z originally discovered the method through her search through best practices of cervical cancer screening in other low-resource settings. They began to consider the benefits of VIA, specifically its *affordability* and its ability to improve the *accommodation* of cervical cancer screening.

Although the patients of Mujeres Móviles do not pay for the cervical cancer screening they receive, *affordability* is still a concern for Mujeres Móviles who subsidizes the price of screening for patients. Because VIA only requires vinegar and cotton swabs, it is less expensive for Mujeres Móviles to provide than the Pap smear, which requires a cervical spatula, a cervical brush, glass slides, and a cytology lab.

Additionally, VIA improves the *accommodation* of cervical cancer screening by providing patients with immediate results. Patients are not required to receive their results separately outside of the mobile cervical cancer clinic and can therefore be educated about any necessary treatment options on the spot.

The Mujeres Móviles team integrated VIA into mobile cervical cancer clinic v2, launched in Design Phase 12, in an effort to improve the *affordability* and *accommodation* of their clinic.

Phase 12 - Launch the First Official Mujeres Móviles Event: Mobile Cervical Cancer Clinic v2 (*Make and Experiment*)

In January 2015, Mujeres Móviles launched mobile cervical cancer clinic v2, which they consider to be their first “official” event. They launched in Central Nicaragua and they began to operate out of Co-Founder Y’s personal truck.

Mobile cervical cancer clinic v2 included the changes made following the piloted mobile cervical cancer clinic v1. Mujeres Móviles included their tightly controlled Pap smear analysis process in mobile cervical cancer clinic v2, along with their new capacity to perform VIA. Additionally, they carried forward their reframed vision of Mujeres Móviles as focusing on holistic women’s health and not just cervical health. Starting with mobile cervical cancer clinic v2, the team established a continuous improvement process to continue refining the mobile cervical cancer clinics even after the official launch. Mujeres Móviles consistently collects feedback from patients during each screening event. According to Co-Founder Z, this is challenging because asking for candid feedback is outside of the cultural norm:

“Basic questions like, how are you feeling aren’t even things that are ever asked of these women... They’re expected to be a mother, daughter, provider, wife, whatever. They’re not ever expected to be the person who is getting care... It’s really an interesting dynamic ... so what I see happen is a lot of listening on our end and observing, [rather] than it is explicitly asking a lot of times.”

However, Co-Founder X notes that women are more vocal about providing feedback when they perceive that things go wrong in the screening event.

“There was one patient that was unhappy with the response time. So [the mobile cervical cancer clinic team] contacted me [so we could] something about that. [In this case,] I think [the patient] was confused about something, so that’s why she called upset about [the perceived slow response time], ‘Oh, I thought it was this date.’ So I had to clarify that, but still ... the patient still gave her opinion.”

In practice, the mobile cervical cancer clinics incorporate a continuous improvement process by empowering the mobile cervical cancer clinic teams to refine their practices as appropriate. For example, both of the mobile cervical cancer clinic teams used to conduct patient intake by giving all patients a number when they arrived and then calling the number when it is time for the patient to speak with a nurse. However, the Central clinic team noticed that this system did not work well for patients at their clinics. According to the Central Clinic Operator:

“For some reason the women didn’t understand their numbers. I was calling out Number 5, Number 4, and they were not understanding. Either because they didn’t know how to read and they didn’t know the number they had in hand, or because they lost the paper. We decided to start working by creating lists and we write the full name of the woman that is coming. So [instead of calling their number,] I start calling their name... We find that it’s way better to work with names.”

Phase 13 - Add the Watch List to the Mobile Cervical Cancer Clinic: Mobile Cervical Cancer Clinic v3 (Make and Experiment)

After launching mobile cervical cancer clinic v2, the Mujeres Móviles team continued to refine their mobile cervical cancer clinic program by “*evolution versus revolution*” (according to Co-Founder Z). At the advice of Board Member 2, a medical doctor in Nicaragua, the team included a “watch list” to more proactively monitor women who are screened by Mujeres Móviles. According to Co-Founder Z:

“He [Board Member 2] was very much a proponent of the watch list that we have ... we really monitor women throughout their lives ... because this disease is very [slow] growing and you don’t want to remove lesions unless it’s the right signs... Unlike the Ministry of Health, which just makes themselves available, we actually do proactively monitor women on an ongoing basis, which is a big commitment of Mujeres Móviles.”

The watch list categorizes patients based on their test results. Women with negative test results are in their own category. Women with positive test results are divided into multiple categories, according to Co-Founder X: “[one category includes] women that might just need another exam in six months, [another category might include] a woman that is an emergency situation [who] maybe needs a hysterectomy.” These categories then help Mujeres Móviles follow up with patients proactively to best ensure their health.

The watch list helps Mujeres Móviles overcome one of the biggest challenges in the Pap smear: the inability to screen and treat in the same visit. According to Co-Founder Z:

“It takes a lot of work to make sure we’re getting back to the people constantly, but we have overcome or really tried to deal with that particular barrier to the [Pap smear] process by making sure we keep connected to the women ... with the data and throughout their life cycle.”

6.3.6 Consideration of Accessibility 6: Accommodation

In Design Phase 13, Board Member 2 suggested that Mujeres Móviles create a “watch list” of precancerous patients as a way to better *accommodate* women. The watch list allows the team to provide more preventive health care and to more easily follow-up

with patients who are precancerous. At Board Member 2's suggestion, the team integrated the watch list into mobile cervical cancer clinic v3 in Design Phase 13.

Phase 14 - Develop New Tools to Provide Sexual Health Education During Mobile Cervical Cancer Clinics (*Imagine and Design*)

Based on the earlier research Mujeres Móviles had done in Design Phase 10, the team began to imagine new tools to help provide more holistic sexual health education during the mobile cervical cancer clinics. In 2017, Co-Founder Y had the idea to create low-cost beaded bracelets to demonstrate the menstrual cycle. Co-Founder Y had initially seen these bracelets used for natural family planning and he had the idea to use them as an educational tool to teach women at the mobile cervical cancer clinics about their menstrual cycle. Mujeres Móviles calls this the “power bracelet” (Figure 6-10).



Figure 6-10. The power bracelet is a tool to help teach women at Mujeres Móviles mobile cervical cancer clinics about their menstrual cycle.

As Figure 6-10 shows, the power bracelet includes five light pink beads representing the number of days in a typical menstrual period, eleven white beads representing neutral days, eleven blue beads representing days of ovulation, and one bright fuschia bead representing the day of peak fertility. The metal charm is meant to be clipped onto a different bead each day to help a woman keep track of her menstrual cycle.

Phase 15 - Add Sexual Health Education Tools to Mobile Cervical Cancer Clinic: Mobile Cervical Cancer Clinic v4. Launch Sexual Health Education in Schools (*Make and Experiment*)

In 2017, Mujeres Móviles added the power bracelet to their mobile cervical cancer clinics. The power bracelet was launched by the mobile cervical cancer clinic team in Northwestern Nicaragua.

At first, the Northwestern mobile cervical cancer clinic team tried to have women at the events make the bracelets, but found this to be too logistically complicated and too messy. Therefore the team pivoted and began to make bracelets on their own to then give to women at their events. I observed the mobile cervical cancer clinic team use the bracelet as both an explanatory prop and as a prize: while the nurses were sharing menstrual health information with the women waiting at the mobile cervical cancer clinic, they gave away power bracelets to women who spoke up to answer questions the team posed to check for understanding.

In addition to being used at the mobile cervical cancer clinics, the power bracelet spun out into its own formal programs within Mujeres Móviles. The power bracelet program was used as part of a new program to go beyond the mobile cervical cancer clinics to teach adolescents in rural schools about sexual and reproductive health. This new program is currently being piloted by the Central mobile cervical cancer clinic team.

6.3.7 Consideration of Accessibility 7: *Acceptability*

In Design Phase 15, the Mujeres Móviles team extended their work to provide sexual health education. First, they added the “power bracelet” as an educational tool to teach women at the mobile cervical cancer clinics about their menstrual cycle. Then, they broadened their educational module to be taught in local schools to adolescents. The team noted that education on sexual and reproductive health was needed beyond the limited interaction that Mujeres Móviles had with patients. They decided to create a sexual health educational curriculum to improve the *acceptability* of reproductive health among adolescents in schools.

This consideration of accessibility led to Mujeres Móviles creating a new program focused specifically on women’s health education. This program is currently being piloted in rural communities of Central Nicaragua.

Phase 16 - Add Training to Mobile Cervical Cancer Clinic: Mobile Cervical Cancer Clinic v5. Launch Leadership Institute (*Make and Experiment*)

In 2017, Mujeres Móviles also began to build out more training for nurses working in the mobile cervical cancer clinics. At the advice of Board Member 3, who has a background

in education, the team launched a Leadership Institute to train young medical graduates how to perform cervical cancer screening in the field. The Mujeres Móviles team previously thought to rely on interns to work for only a few years, anticipating that they might get burnt out quickly from the intense schedule before moving on to their next job. The Leadership Institute poses an alternative to that model, focusing on building the skills of women who work with Mujeres Móviles.

The Leadership Institute is now its own program within Mujeres Móviles. The Leadership Institute expanded in scope to go beyond just training nurses to perform cervical cancer screening but to also equip them with the professional development skills needed to become a future leader.

Phase 17 - Test a New Data Collection Strategy to Add to Mobile Cervical Cancer Clinic: Prepare for Mobile Cervical Cancer Clinic v6 (*Make and Experiment*)

In 2018, Board Member 1 reached out to Mujeres Móviles about working together to study a patient's stress response to receiving a precancerous diagnosis. Mujeres Móviles began to collaborate with Board Member 1 and leveraged the collaboration as a way to improve their own data collection techniques and strategies. Mujeres Móviles already collects comprehensive data from the patient, including demographics, gynecological history, sexual history, and history of rape or abuse. They collect all this information on paper during the mobile cervical cancer clinics and then transcribe the written information into an electronic database after the clinics. Therefore, the team sought to streamline the collection of data by using a touch screen tablet equipped with an existing electronic data collection tool.

In 2019, the mobile cervical cancer clinic team in Northwestern Nicaragua launched a pilot test with this new tablet-based electronic data collection. The Mujeres Móviles team intends to wrap the electronic data collection into their formal operations after evaluating the successes and the areas of improvement from the pilot. The electronic data collection will be added to the mobile cervical cancer clinic program to create mobile cervical cancer clinic v6.

6.4 Discussion and Evaluation of Mujeres Móviles' Process of Human-Centered Design for Accessibility

In Section 6.3, I provide a narrative timeline of how Mujeres Móviles designed the mobile cervical cancer clinic and how they considered accessibility throughout their design process. In this section, I discuss these HCD practices and considerations of accessibility.

6.4.1 Discussion of Mujeres Móviles' Process of Human-Centered Design for Accessibility

Figure 6-11 below shows Mujeres Móviles' design process overlaid with their considerations of accessibility.

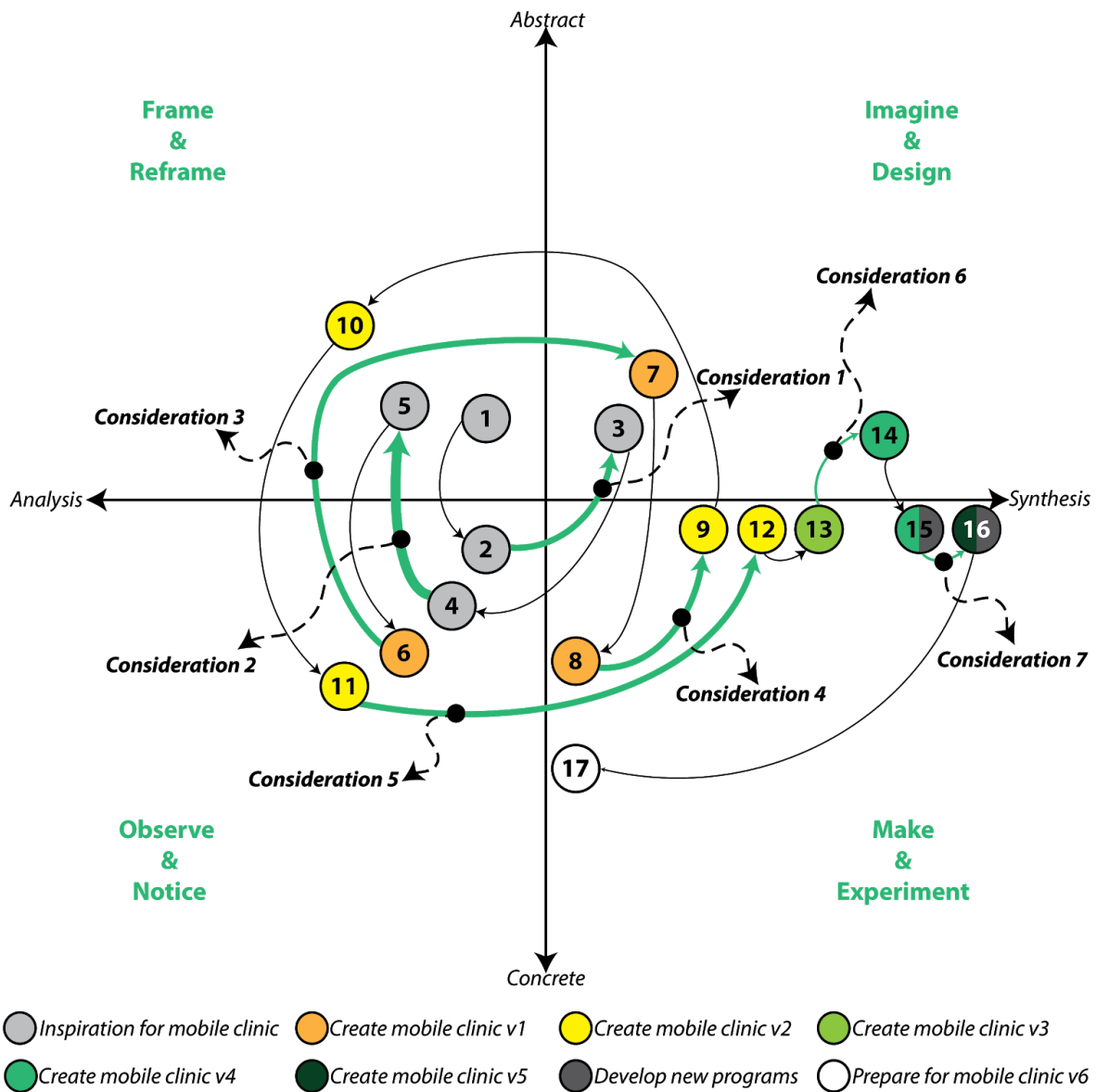


Figure 6-11. Mujeres Móviles' design process plus their considerations of accessibility. Each green arrow corresponds to a consideration of accessibility, as I describe in Section 6.3. The thicker the green arrow, the more dimensions of accessibility considered.

Similar to InVia (Figure 5-9), Mujeres Móviles' considerations of accessibility followed their research activities, either in the *Observe and Notice* phase or in the *Make and*

Experiment phase. These accessibility considerations, informed by either background research (*Observe and Notice*) or by research gained by testing prototypes of the mobile cervical cancer clinic (*Make and Experiment*), informed how Mujeres Móviles continued to frame the problem and develop new ideas. Several points of discussion emerge from analyzing the intersection of Mujeres Móviles considerations of accessibility with their HCD process.

First, Mujeres Móviles considered *accommodation* most often in their design process, with *accommodation* showing up in Considerations 2 through 6. They continued to discover new facets of *accommodation*, including the need for strong and proactive communication with patients (Consideration 2 in Design Phase 4 and Consideration 6 in Design Phase 13), the need to provide education to patients about cervical cancer (Consideration 3 in Design Phase 6), the need for a quick turnaround of examination results (Consideration 3 in Design Phase 6 and Consideration 5 in Design Phase 11), and the need to treat women with respect and gentleness during the examination (Consideration 4 in Design Phase 8). These dimensions of *accommodation* directly relate to the patient's experience during the mobile cervical cancer clinic, and therefore it makes sense that Mujeres Móviles would continue to revisit notions of *accommodation* as they continue to learn more from patients with every interaction.

Second, Mujeres Móviles' considerations of *acceptability* demonstrate their increasing focus on broadening the scope of their services towards holistic women's health. Within *acceptability*, Mujeres Móviles is concerned with providing socially *acceptable* education about sexual and reproductive health that challenges the status quo of women's health being undervalued in Nicaragua. Mujeres Móviles therefore walks a fine line of ensuring social *acceptability* while also challenging social norms.

Third, Mujeres Móviles only considered *physical accessibility* once in their design process at the very beginning. However, this consideration was incredibly impactful and indeed set the course for Mujeres Móviles to develop their mobile cervical cancer clinic program going forward. The fact that they did not reconsider *physical accessibility* again suggests that the team does not feel like they need to improve the *physical accessibility* of their mobile cervical cancer clinic. This is likely related to logistics: although *physical accessibility* would surely be improved if the clinic went door-to-door (as the MINSA vaccination team in Design Phase 2 did), it is not feasible for the mobile cervical cancer clinic teams to do so because they would need to set up a clean screening environment at each location.

Finally, Mujeres Móviles only considered *affordability* one time. This makes sense because *affordability* is not a key concern for the patient: the patient does not have to pay for any services provided by Mujeres Móviles. However, *affordability* does have an effect on Mujeres Móviles business model, as they cover the cost of materials and of bioanalysis for the Pap smear samples. My analysis focused on the design of the

mobile cervical cancer clinic itself and not on the organization's business model, and it is likely that a deeper look at the design of Mujeres Móviles business model would illuminate further considerations of affordability.

6.4.2 Evaluation of Mujeres Móviles' Human-Centered Design Process

To evaluate the “human-centeredness” of Mujeres Móviles' design process in creating their mobile cervical cancer clinic, I apply the International Organization for Standardization (ISO) 9241-210 framework. As I present in Section 2.3.2.b, ISO 9241-210 puts forth six criteria of HCD [85]:

1. Adoption of multidisciplinary skills and perspectives
2. Explicit understanding of stakeholders, tasks and environments
3. Stakeholder-centered evaluation driven/refined design
4. Consideration of the whole stakeholder experience
5. Involvement of stakeholders throughout design and development
6. Iterative process

Mujeres Móviles' process in creating the mobile cervical cancer clinic meets all six of the ISO HCD characteristics in some way. In this section, I critically evaluate how Mujeres Móviles' design process adheres to fits with and diverges from each characteristic. I also provide recommendations for the Mujeres Móviles team to improve the human-centeredness of their design process going forward.

1. Adoption of multidisciplinary skills and perspectives

The core team of Mujeres Móviles' co-founders is quite multidisciplinary, with a clinical background (Co-Founder X), community development background (Co-Founder Y), and marketing background (Co-Founder Z). These skills are well represented in the mission of Mujeres Móviles, which includes the provision of health services and the focus on holistic health and empowerment. Mujeres Móviles benefits from a diverse board of advisors who support Mujeres Móviles on their clinical, educational, and research missions.

Considering their goals, Mujeres Móviles has adopted an impressive number of multidisciplinary perspectives. If Mujeres Móviles were to become more invested in policy development, a position they could take given their increasing work in all parts of the Nicaraguan health system, they would benefit from the additional perspective of someone with a background in government or health policy development.

2. Explicit understanding of stakeholders, tasks and environments

Mujeres Móviles' understanding of their stakeholders, tasks, and environments is perhaps their biggest strength. Co-Founder X was born and raised in Nicaragua, and Co-Founder Y has lived in Nicaragua full time since 2013. These co-founders therefore interact every day with the environment they work within: Nicaragua's culture, health system, and government. Additionally, Co-Founder X has firsthand experience dealing with the failings of the Nicaraguan health system at providing adequate cervical cancer screening and treatment.

Mujeres Móviles was inspired by observing the limitations of MINSA. Then, the co-founders spent at least 8 months conducting research and incubating on the topic of cervical cancer screening. During this time, Co-Founder X gained additional firsthand knowledge of how MINSA actually operates and how Mujeres Móviles could improve upon these operations. Therefore, Mujeres Móviles benefits from the co-founders' deep knowledge of the subject area (cervical cancer screening), the processes (providing screening and treatment), the context (rural Nicaragua), and the people (patients to be screened and MINSA healthcare providers to partner with).

3. Stakeholder-centered evaluation driven/refined design

Mujeres Móviles has adopted a process of continuous improvement that allows the team to flexibly refine their operations based on feedback they receive from stakeholders, including patients. However, Co-Founder Z notes that this feedback can be difficult to come by, as critique goes against patriarchal Nicaraguan norms:

"Within the culture itself, asking people's opinions isn't necessarily ... you have to almost listen for it more than ask, because people don't want to disappoint you. They're not used to being asked 'what do you think?' That's just not a norm."

The Mujeres Móviles team might consider adding more structure to the process of regularly receiving feedback from patients who interact with the Mujeres Móviles mobile cervical cancer clinic. This could be a significant design challenge for the team, requiring deeper research into what modes of feedback are most appropriate for patients to provide. The provision of feedback is not only influenced by cultural norms, but is also influenced by creating appropriate times during the mobile cervical cancer clinics for patients to provide feedback. Co-Founder Y notes that the team does not believe a survey would be successful, and that they must observe patients' interactions with the mobile cervical cancer clinics closely in order to understand areas of improvement:

"Well, and it's so important to understand... we couldn't go in and say we're going to do a survey. We would get all positive [responses]... it wouldn't work. So how [the nurses gain feedback] is just following up on what's going on, what has happened in the past."

[They ask] the reason that [patients are] there at the event, they're able to pick up a lot of information from that."

Therefore, a patient-centered evaluation might include an outside evaluator coming to observe the mobile cervical cancer clinics in action rather than conducting a survey or an interview with patients. Additionally, Mujeres Móviles can consider involving patient feedback more directly in the design of the mobile cervical cancer clinics. The best example of patients driving and refining the mobile cervical cancer clinic design was from the pilot community in 2014. Women in the pilot community were asked for their design input before the mobile cervical cancer clinic was tested, and then they were asked for their feedback after the mobile cervical cancer clinic was piloted. This model worked quite well for the patients and for Mujeres Móviles, although it required three separate trips to visit the rural community. Since then, Mujeres Móviles has not made significant changes to their mobile cervical cancer clinics, instead focusing on serial small iterations. If the team were to make a larger and more sudden change to their offerings, they should consider developing another in-depth pilot study based on the successful model from 2014.

4. Consideration of the whole stakeholder experience

Similar to Mujeres Móviles strong understanding of stakeholders, tasks, and environments, a key strength of Mujeres Móviles is their consideration of the whole stakeholder experience. Each iteration of the mobile cervical cancer clinic takes on more of the stakeholder experience, including the framing of holistic women's health in Design Phase 10 (which led to the inclusion of broader sexual health education during mobile cervical cancer clinics) to the addition of the watch list in Design Phase 13 (which allowed Mujeres Móviles to continuously follow-up with high-risk patients).

The Mujeres Móviles sees their organization as an end-to-end service provider, starting with the provision of preventive cervical cancer screening and continuing through cervical cancer treatment, if needed. Additionally, Mujeres Móviles advocates for patients with advanced cervical cancer who must navigate the Nicaraguan health system to receive appropriate care.

Each new iteration of Mujeres Móviles takes on some additional aspect of the Nicaraguan health system as a whole, including high-quality cytology and the provision of VIA in mobile cervical cancer clinic v2, the watch list in mobile cervical cancer clinic v3, sexual health education in v4, and training for nurses in v5. Therefore, it appears that as Mujeres Móviles continues to grow, they will continue addressing bigger and bigger issues within the Nicaraguan health system. Going forward, the team may discover that in order to address the whole stakeholder experience, they must take on

addressing the whole Nicaraguan health system and the culture of patriarchy in Nicaragua in general.

5. Involvement of stakeholders throughout design and development

Mujeres Móviles has fostered collaborative partnerships with a broad range of stakeholders, including MINSA and SILAIS administrators, MINSA healthcare providers, patients, cytologists, advisors, and collaborating organizations.

MINSA and SILAIS administrators provide Mujeres Móviles permission to carry out their mobile cervical cancer clinics across two regions of Nicaragua. If Mujeres Móviles expands into other regions, MINSA and SILAIS will need to provide their permission. MINSA healthcare providers, on the other hand, provide Mujeres Móviles with direct support by helping Mujeres Móviles locate rural community leaders, by distributing results to patients, and by providing medications to women who Mujeres Móviles screens.

Patients who are screened and treated at the mobile cervical cancer clinics have been involved in the design and development of Mujeres Móviles. The pilot community was involved early, as I describe in *Stakeholder-centered evaluation driven/refined design* above. Patients at the mobile cervical cancer clinics today continue to be prompted for their feedback, although it is not clear how honest the patients feel they can be in providing critiques.

Mujeres Móviles works with cytologists to analyze their collected Pap smear samples, and these cytologists provide Mujeres Móviles feedback on how to best collect samples.

Finally, advisors and external collaborating organizations are quite involved in the continued development of Mujeres Móviles. There are multiple examples of a Mujeres Móviles donor or board member inspiring Mujeres Móviles to create a new program of practice. A donor in western Nicaragua donated her house to Mujeres Móviles, which inspired the team to create the Girls Club on the property. A sociology professor, who became Board Member 1, sought to collaborate on a research project with Mujeres Móviles, which inspired the team to improve their data collection strategies. Board Member 2, a medical doctor in Nicaragua, suggested the team keep track of their patients so they can follow-up proactively, which led to the team creating the watch list. Board Member 3, with her background in education, inspired the Mujeres Móviles team to further develop their training for nurses which led to the creation of the Leadership Institute.

Clearly, a range of stakeholders are involved in inspiring new practices and programs and in providing feedback on Mujeres Móviles practices and programs. These moments of involvement happen ad hoc, and Mujeres Móviles is consistently open to new ideas and to feedback on their current operations. If Mujeres Móviles were to

structure their continuous development process further, as suggested in *3. Stakeholder-centered evaluation driven/refined design*, they should consider how to structure specific moments of inspiration and of feedback from stakeholders.

6. Iterative process

Mujeres Móviles has employed a process of small and frequent iterations. The team is frequently refining their practices and adding new programs. Continuous small iteration is a running theme throughout Mujeres Móviles design process.

The Mujeres Móviles mobile cervical cancer clinic has not significantly changed since the pilot. The team has added services, but they still travel in a rugged truck to rural communities to set up mobile screening and treatment clinics.

There is no evidence of structured idea generation activities. The ideation the team conducted (Design Phases 3, 7, and 14) were generally spontaneous and not structured. The ideas that were developed in these phases were generally direct responses to research that had been previously conducted, and it is not clear if any members of the team sat down to think through multiple different options for what their offerings might look like. More work is needed to understand if there would be a significant benefit to Mujeres Móviles ideating more at various points, and if this would improve the iterative process already employed by the organization.

6.4.3 Evaluation of Mujeres Móviles' Considerations of Accessibility

Mujeres Móviles was created with a specific focus on improving access to cervical cancer screening for women in rural Nicaragua. To meet this overarching vision, the team addresses all five dimensions of access, as I describe below.

Focus on *Physical Accessibility*

Mujeres Móviles demonstrates a commitment to *physical accessibility*, “the relationship between the location of supply and the location of clients, taking account of client transportation resources and travel time, distance and cost” [22]. This dimension of health care accessibility is at the core of Mujeres Móviles' vision: to bring cervical cancer screening services to women in rural Nicaragua.

The initial idea for Mujeres Móviles was to try and conduct cervical cancer screening where everything needed could fit inside a suitcase. This idea was sparked when Co-Founder X and Co-Founder Y saw the lack of resources within MINSA to be able to go to rural Nicaraguan communities. In practice, Mujeres Móviles requires more than a suitcase: the organization fits their mobile cervical cancer clinic into an all-terrain

truck. According to Co-Founder Y: *“We’ve designed our mobile clinic to be small and quick, and able to access the most rural areas, so it really is just a 4x4... We can fit everything in the back of one of those trucks.”*

Today, the Mujeres Móviles mobile cervical cancer clinic teams often travel several hours through mountainous terrain to reach rural communities. Once they reach rural communities, they take less than 20 minutes to set up their mobile cervical cancer clinic in local schools and churches. These local institutions are often within walking distance for women in the community.

Focus on Accommodation

Mujeres Móviles demonstrates a commitment to health care *accommodation*, *“the relationship between the manner in which the supply resources are organized to accept clients (including appointment systems, hours of operation, walk-in facilities, telephone services) and the clients’ ability to accommodate to these factors and the clients’ perception of their appropriateness”* [22]. Specifically, any education, messaging, or other efforts to help the patient better engage with the particular services offered by Mujeres Móviles is included in *accommodation*.

Mujeres Móviles views their mobile cervical cancer clinics as a holistic health service that goes beyond just cervical cancer screening and treatment but also includes listening, teaching, and counseling. To best accommodate their patients, Mujeres Móviles focuses on building trust with patients, delivering health services through an all-women team, navigating the Nicaraguan health system for women, providing education throughout the screening procedure, flexibly accommodating as many patients as possible, and recognizing the need for psychosocial counseling.

Mujeres Móviles relies on their reputation of providing high-quality services as a way of building trust with the women they screen. As the Northwestern Clinic Operator puts it:

“I think that what brings the women is the trust that we’ve built with them, because sometimes they don’t feel that when they are doing ... or taking the health center. But when we come, they feel it’s different.”

By continuing to provide high-quality services, Mujeres Móviles continues to build their reputation as a trustworthy healthcare provider.

To counter a patriarchal culture and to provide comfort for women who get screened, the Mujeres Móviles clinical teams are all women. Co-Founder X highlights the importance of Mujeres Móviles women screening women patients:

“[We] perform the exam in such a way that [is] gentle and very careful. We use women in our project, so women [treat] other women the way that they want to be treated as well.”

The Clinic Operators in the Northwestern and Central clinics are both men, and they recognize that their presence might make the women getting screened uncomfortable. As the Central Clinic Operator explains:

“I do my best to make them feel comfortable because... sometimes it happens that they think I am going to be the one taking the pap spears so they feel kind of weird so I let them know that what I'm doing there.”

Mujeres Móviles helps to accommodate patients in the broader Nicaraguan health system by helping them navigate the health system as needed. The team views Mujeres Móviles as an end-to-end service, as Co-Founder Z explains:

“We [ensure] that the results that they get are communicated, and that there's actually action taken based on those results. If a woman has precancerous lesions that need to be removed, they get [them] removed. If a woman has early stage cancer, she gets treatment. So we take the... we really look at it as an end to end process from the standpoint of when we get a woman in front of us, all the way through to whatever eventual treatment she may or may not need.”

Mujeres Móviles helps patients get on the waiting list and move up on the waiting list at cancer treatment centers in Nicaragua. Mujeres Móviles also refers patients to other NGOs and organizations that can help the patient receive care, as needed.

During the screening events, Mujeres Móviles accommodates patients by providing education before, during, and after the patients are screened. Before patients are screened, one of the Mujeres Móviles nurses will explain the objectives of the event to the women and then explain how screening will be conducted. The nurse will then ask the patients if they have any questions about the procedure, making sure they understand what procedure they will receive and why. As Co-Founder Y explains: *“there's no woman that ever gets an examination with us without being thoroughly educated as to why it's happening.”* While the patient is getting screened, the nurse performing the screening asks if the patient is comfortable or has any questions. After the patient is screened, the Mujeres Móviles nurse either explains the results on the spot if the patient received VIA or the nurse sends the collected Pap smear sample to the lab for analysis. When the lab results come back two weeks later, the Mujeres Móviles team then writes a note explaining the results as simply as possible, including next steps and ways to contact Mujeres Móviles. Additionally, in communities with a high illiterate population, Mujeres Móviles includes a yellow sheet, which they tell patients during screening means that patients should call Mujeres Móviles to hear their results over the phone. These materials are sealed in an envelope to be handed out to the patients.

Currently, the Mujeres Móviles team offers a listening ear to women who come to get screened. However, many of the women who come for screening are dealing with

psychosocial trauma due to sexual abuse, domestic violence, or other gender-based violence. Central Nurse 1 explains how Mujeres Móviles currently does not offer enough mental health support for women who come seeking cervical cancer screening and how they can broaden their mental health support to help women manage their cervical cancer screening results:

“I realized that what we’re doing [takes] care of the physical part, and that’s pretty good, but we also need to take the psychological aspect because it’s very important. And there are so many women that sometimes they just need somebody to talk to, and to give them advice and to give them a couple of words of comfort or help them understand what’s going on with them. And I feel like that’s something important that we need to also try to combine in what we do... I think that we should start by focusing the counselor aspect into cervical cancer [screening] because we have people who probably have [been] found with cervical cancer, and getting that news is very shocking for them. Or even little things that are not even cervical cancer, just something abnormal that they have on their Pap results. But providing that information, and if they had a chance to talk with someone, like a counselor, they would feel probably more comfortable and be like, ‘Oh I’m being understood and heard by how I feel by getting these results.’”

Focus on Acceptability

Mujeres Móviles demonstrates a commitment to health care *acceptability*, “the relationship of clients’ attitudes about personal and practice characteristics of providers to the actual characteristics of existing providers, as well as to provider attitudes about acceptable personal characteristics of clients” [22]. As compared to *accommodation*, *acceptability* includes broader health education that seeks to educate clients of the importance of health services or to convince them to use health services, including sexual health services and cervical cancer screening.

Within the context of their mobile health clinics, Mujeres Móviles addresses *acceptability* in two main ways: developing an effective messaging strategy to invite women to the screening events, and providing general sexual health education during the screening events. Additionally, Mujeres Móviles offers sexual health education in their Girls Club and adolescent education programs, but I do not discuss these programs in detail.

Several of the staff members at Mujeres Móviles note that the hardest part of their job is in convincing people that cervical cancer screening is necessary. They find that some women are afraid to come to the health posts for fear of what other community members will think. Therefore, Mujeres Móviles works with other local organizations and with the local SILAIS to develop an effective messaging strategy to convince women to come and get screened. Additionally, members of Mujeres Móviles are periodically featured in the local media where they leverage their platform to raise awareness of cervical cancer screening.

When women do come to the screening events, Mujeres Móviles provides general women's health education, including education on menopause, menstrual health, and breast cancer, in addition to specific cervical cancer screening education. The goal of this general education is to provide women with more agency to understand and care for their own bodies, as CFZ notes:

"Really we engineered it as much as possible to eliminate the barriers to being able to provide a quality screening process, as well as what do we need to do to allow women to better understand and be educated about what not just cervical cancer is, but what is sexual health, what's their fertility, how does it all relate together? So that they are not just in a position of being screened for a disease that they have no frame of reference or understanding about and it stays mystical, and it stays as God's intention, versus something that they can learn about what they need to do to be able to take control and care for their own bodies."

During the general sexual health education, Mujeres Móviles tries to foster an open and educational environment where women can ask any health-related questions they may have. As Northwestern Nurse 2 notes, this can go beyond questions directly related to women's health:

"So I provide talks about sexual education and other topics like menstrual cycles and everything that is related with women's health. And also it depends on what other questions the women have because sometimes they are very curious and they have more questions. So we have to also go deep into what they want to know."

Focus on Availability

Mujeres Móviles demonstrates a commitment to health care *availability*, *"the relationship of the volume and type of existing services (and resources) to the clients' volume and types of needs"* [22]. health care quality, privacy, timely provision of results, timely provision of treatment, and continuous monitoring are included in *availability*.

Mujeres Móviles aims to provide cervical cancer screening to women at the quality expected of private hospitals but for the free price expected at public hospitals. Co-Founder X notes that this focus on the quality of health care is a key differentiator of Mujeres Móviles:

"Something that was very different about the project from the very beginning was this vision to not just to bring them this exam that was so necessary, like what the health sector of their local government health services was doing, but also ensure that they were getting a quality results in a reasonable amount of time, as well as treatment if necessary, in a reasonable amount of time as well. And all these services would be free, but quality. Not just quality from a medical standpoint, but also quality in terms of how women were treated."

In 2018, the SILAIS in Northwestern Nicaragua realized that Mujeres Móviles detected three out of four cases of advanced cervical cancer in Northwestern Nicaragua. Co-Founder Z notes that:

“They [SILAIS] realize that there is something that we’re doing that’s higher quality than they are doing currently... So there is a recognition that, from just a quality standpoint, that Mujeres Móviles has something that really does [show] ... well, my vernacular coming out of corporate is a ‘competitive advantage’ of what we do.”

Mujeres Móviles assures patient privacy throughout the screening process. During the screening events, the Mujeres Móviles nurses ask patients intake questions as privately as possible, sitting away from other women and speaking in soft voices. The screening procedure is then conducted behind a privacy curtain, either brought by the Mujeres Móviles team or featured in the screening location already. After the screening events, Mujeres Móviles maintains patient privacy by sealing patient results in envelopes that are hand-delivered to the women. At the public clinics, patient results are not sealed.

After screening, Mujeres Móviles aims to provide results to patients in a timely fashion. In the public health system, women often have to wait months to receive their Pap smear results and sometimes they never end up receiving their results. At Mujeres Móviles, women receive their VIA results instantly or they receive their Pap results within two weeks. The public health system does not yet offer VIA, and Co-Founder Y notes that Mujeres Móviles would *“prefer to use visualization more... it certainly is a low resource option, and quite frankly, if you’re trained properly, the results are better.”*

Once the patients’ results are provided, Mujeres Móviles connects patients with treatment options. They either refer patients for follow-up with doctors in the public health system or they provide cryotherapy treatment for women in the community, depending on the eligibility of the patient. If Mujeres Móviles did not offer cryotherapy to patients, then patients would need to travel to the capital city to receive treatment, a journey that few women are likely to make.

Finally, Mujeres Móviles ensures quality by proactively monitoring women on an ongoing basis. Mujeres Móviles maintains a “watch list” of women who have had abnormal test results, and they regularly check in on these patients more often than they do patients who have not had any abnormal test results. In this way, Mujeres Móviles stays connected with women who are most at risk of developing cervical cancer so that Mujeres Móviles can help proactively deal with the disease.

Focus on Affordability

Mujeres Móviles demonstrates a commitment to health care *affordability*, “the relationship of prices of services and providers’ insurance or deposit requirements to the

clients' income, ability to pay, and existing health insurance" [22]. Mujeres Móviles express their commitment to *affordability* for two groups of stakeholders: for women receiving cervical cancer screening services and for donors who provide funding to Mujeres Móviles.

Mujeres Móviles does not charge women any fee to receive cervical cancer screening. The organization notes that screenings provided by other nonprofits in Nicaragua cost between \$5 and \$50, which dramatically decreases women's ability to receive a screening. Other health services offered through the public health system in Nicaragua are free for patients and Mujeres Móviles aims to keep their services at public health costs (free).

Mujeres Móviles spends less than \$10 per patient on average to deliver cervical cancer screening. The organization advertises this cost-to-serve target to potential donors on their website to incentivize potential donations.

Proposed Framework to Evaluate Accessibility

To evaluate the success of the mobile cervical cancer clinic program in improving access to cervical cancer screening in Nicaragua, I propose a set of questions to assess a patient's satisfaction with their access to cervical cancer screening through the Mujeres Móviles mobile cervical cancer clinics. The **bolded** sections in Table 6-2 below demonstrate the additions and alterations I made to Penchansky and Thomas' original framework [22], [29] (see Table 2-1).

Table 6-2. Adapted from Penchansky and Thomas' framework to evaluate a patient's satisfaction with access to health care [22]. These questions have been edited to address a patient's satisfaction with their access to cervical cancer screening through the Mujeres Móviles mobile cervical cancer clinics. These questions are to be assessed through a patient survey where patients respond on a five-point Likert scale, ranging from "very satisfied" (1) to "very dissatisfied" (5)

Dimension of Accessibility	Question to Evaluate Patient Satisfaction
Availability	All things considered, how much confidence do you have in being able to get good cervical cancer screening when you need it?
	How satisfied are you with your ability to find one good provider of cervical cancer screening ?
	How satisfied are you with your knowledge of where and when to get screened for cervical cancer ?
	How satisfied are you with the amount of privacy you are given during a cervical cancer screening procedure?
Physical Accessibility	How satisfied are you with how convenient the cervical cancer screening clinic is to your home?
	How difficult is it for you to get to the cervical cancer screening clinic ?

(continued)	Question to Evaluate Patient Satisfaction
Accommodation	How satisfied are you with how long you have to wait to get a cervical cancer screening appointment?
	How satisfied are you with how convenient the cervical cancer screening clinic hours of operation are?
	How satisfied are you with how long you have to wait at the cervical cancer screening clinic ?
	How satisfied are you with how easy it is to get in touch with your cervical cancer screening provider ?
	How satisfied are you with the level of education and explanation specific to cervical cancer your cervical cancer screening provider gave you?
Affordability	How satisfied are you with your health insurance's coverage of cervical cancer screening ?
	How satisfied are you with the cervical cancer screening provider's prices?
	How satisfied are you with how soon you need to pay the bill for your cervical cancer screening services ?
Acceptability	How satisfied are you with the appearance of the cervical cancer screening clinic ?
	How satisfied are you with the neighborhood where your cervical cancer screening clinic is located ?
	How satisfied are you with the other patients you usually see at the cervical cancer screening clinic ?
	How satisfied are you with the general health education and guidance offered by your cervical cancer screening provider?

I have used the generic words “clinic” and “provider” here to illustrate that this survey should be given to patients who are screened through the Mujeres Móviles mobile cervical cancer clinics and to patients who are screened through both private and public health centers. To measure and evaluate the changes in cervical cancer screening access afforded by the Mujeres Móviles mobile cervical cancer clinics, the questions in Table 6-2 should be considered for use in a between-subjects experimental design where control and experimental groups of patients are designated and surveyed. Such an experimental design would allow Mujeres Móviles to isolate the changes in cervical cancer screening access due to their mobile cervical cancer clinics. For example, Mujeres Móviles might survey two control groups, one group of patients screened at

public health clinics and one group of patients screened at *private* health clinics, and one experimental group of patients screened at a *Mujeres Móviles mobile cervical cancer clinic*. The control and experimental groups would then be surveyed twice: once before they encounter their cervical cancer screening provider and once after they encounter their cervical cancer screening provider.

Mujeres Móviles has noted that they are concerned that patients are not fully honest with their true impressions of the mobile cervical cancer clinic, often biasing towards politeness. Therefore, the team should consider adapting these survey questions into a more acceptable format, which could be an interview guide read by an external evaluator or an observational checklist.

6.5 Summary of the Case Study of Mujeres Móviles

In this chapter, I have presented Mujeres Móviles as a case study of an organization leveraging HCD processes to improve access to cervical cancer screening. First, I provided background context on the state of health in Nicaragua. Then, I documented the history of Mujeres Móviles with a specific focus on their development of the mobile cervical cancer clinic.

I presented a journey through Mujeres Móviles' HCD process, starting with their personal inspiration in 2008, the beginning of the three Co-Founders working together in 2014, and continuing through my data collection which concluded in June 2019. Mujeres Móviles continues to operate today although I did not collect any data after June 2019. I discussed the intersection of Mujeres Móviles' HCD process and their considerations of accessibility. I analyzed the HCD phases where Mujeres Móviles began to consider and reconsider various dimensions of accessibility and I discussed how the team brought these considerations forward into their design journey. From this analysis, I discuss how Mujeres Móviles' accessibility considerations were always borne from concrete research conducted, either in the *Observe and Notice* phase or the *Make and Experiment* phase. The team considered accessibility due to their learnings from concrete research activities and they carried these considerations forward as they continually developed their mobile cervical cancer clinic.

Next, I used the ISO 9241-210 criteria to evaluate the “human-centeredness” of Mujeres Móviles' design process [85]. I found that Mujeres Móviles generally adhered to the criteria of HCD, although there is room for improvement in their HCD processes going forward. Particularly, the team should consider the next steps in their organization and develop a structured design process to move the organization forward. The team found great success in piloting their mobile cervical cancer clinic before implementation,

and they continue to gain useful feedback from patients, board members, and others. Should Mujeres Móviles choose to significantly change their offerings, the team should consider investing in another design process.

Finally, I explored how Mujeres Móviles considered accessibility as they were developing the mobile cervical cancer clinic, and I found that the team demonstrated a focus on all five dimensions of access. I then presented a framework the team might consider adopting to evaluate their patients' satisfaction with the mobile cervical cancer clinic. This framework, inspired by Penchansky and Thomas [22], [29], provides a set of survey questions Mujeres Móviles can ask of patients to assess their satisfaction with the accessibility provided by the mobile cervical cancer clinics. These questions can be asked in a variety of formats, depending on what is most acceptable for patients of the Mujeres Móviles mobile cervical cancer clinics.

Chapter 7

Cross-Case Analysis

In this chapter, I compare the case studies of InVia Technologies and Mujeres Móviles. First, I compare the two organizations, including the overarching similarities and differences in how their organizations operate. Then, I take a deeper look at the two programs to improve cervical cancer screening access that each organization created: InVia created ccScreen and Mujeres Móviles created the mobile cervical cancer clinic. I compare the design practices and considerations of accessibility that each organization employed while creating their cervical cancer screening program.

From these comparisons, I present a list of “best practices” of human-centered design (HCD) for accessibility. I use these best practices to develop two new frameworks to understand “HCD for accessibility.” The first framework poses a set of characteristics of HCD for accessibility. The second framework poses a process of HCD for accessibility.

7.1 Comparison of InVia and Mujeres Móviles

Chapter 5 presents an in-depth case study of InVia, an organization based in the United States (US) that is developing ccScreen, a technology to improve visual inspection with acetic acid (VIA) cervical cancer screening in India. Chapter 6 presents an in-depth case study of Mujeres Móviles, an organization based in Nicaragua that has developed and implemented a mobile cervical cancer clinic to deliver cervical cancer screening and treatment to women in rural Nicaragua. Table 7-1 presents a comparison of InVia and Mujeres Móviles. This comparison focuses on the organizational similarities and differences between InVia and Mujeres Móviles, and not on the comparison between the specific programs these organizations developed.

Table 7-1. Comparison of key features of two organizations that created programs to address cervical cancer screening access: InVia and Mujeres Móviles.

	InVia	Mujeres Móviles
Organization vision	To leverage technology towards health and societal benefit	To improve the health and well-being of women and girls across Nicaragua
Motivation to start organization	Technology searching for a problem to solve	Problem searching for a solution
Design output	Technological device	Service
Business model	For-profit	Non-profit
Embeddedness in location	All co-founders remote from India and distributed from each other	Two co-founders in-country (X and Y), one co-founder remote (Z)
Time spent working	All co-founders and team members work part time	Two co-founders (X and Z) work full time, as do all members of the team. Co-Founder Y works part time
Team composition	The four co-founders are biomedical engineers and are now pursuing medicine and research	Co-Founder X is a bioanalyst, Co-Founder Y has a background in community development, Co-Founder Z has a background in business and marketing
Familiarity with design	Co-founders were taught design in biomedical engineering course	Co-founders picked up their design practices while developing solutions
Ties to US	Yes, the co-founders live and were raised in the US	Yes, one co-founder (Z) lives in the US and two co-founders (Y and Z) were raised in the US
Ties to country of implementation	Co-Founder A has extended family living in India	Co-Founder X was born and raised in Nicaragua. Co-Founder Y has lived in Nicaragua since 2013
Ties to a university	Yes, the co-founders began their work with InVia during a biomedical engineering course	Yes, two co-founders (Y and Z) met through shared ties to a master's program, and collaborations with US university teams
Current funding source	Grants	Grants
Role of collaborators	Required to carry out clinical work and implementation strategy	Required to provide permission (the Ministry of Health [<i>Ministerio de Salud</i> , a.k.a. MINSA] and the Local Comprehensive Health Care Systems [<i>Sistemas Locales de Atención Integral de Salud</i> , a.k.a. SILAIS]) and are a consistent source of new ideas (Board Members)

Table 7-1 illustrates the key differences and key similarities between InVia and Mujeres Móviles. The first difference between the organizations is their relationship to technology: InVia's vision is to leverage technology towards societal benefit and their initial motivation to begin work on ccScreen was to apply technology to solve a globally impactful problem. Mujeres Móviles, on the other hand, does not prioritize the value of technology and has instead developed their innovation to connect existing resources (i.e., nurses who perform cervical cancer screening) with those who need it most (i.e., women living in rural Nicaragua). The co-founders started Mujeres Móviles based on a strong understanding of the problem to solve, while the co-founders started InVia based on a strong understanding of the type of solution they could create.

Another key difference between the organizations is how embedded they are within their target implementation locations. The four co-founders of InVia all live in the US and only Co-Founder A has a personal connection to India. Two out of three co-founders of Mujeres Móviles live in Nicaragua (Co-Founder X and Co-Founder Y), and Co-Founder X was born and raised in Nicaragua. Additionally, the majority of Mujeres Móviles' team works full time while none of the members of InVia work full time. Mujeres Móviles therefore exhibits more embeddedness in their implementation location than InVia, and they spend more time developing their solution. InVia, on the other hand, believes that their model of part-time remote work can serve as an example for others living in high-income countries like the US to apply their skills to address pressing needs in low- and middle-income countries (LMICs).

A third key difference between the organizations is the co-founders' varying educational backgrounds and familiarities with design. The four InVia co-founders all hold bachelor's degrees in biomedical engineering, and two co-founders (Co-Founder B and Co-Founder D) have gone on to pursue medicine while three co-founders (Co-Founder A, Co-Founder B who is in a joint MD/PhD program, and Co-Founder C) have gone on to pursue research. As part of their foundational biomedical engineering design course, the four InVia co-founders all learned HCD from their Engineering Advisor. The three Mujeres Móviles co-founders do not have formal training in HCD, and their professional backgrounds range from bioanalysis (Co-Founder X) to community development (Co-Founder Y) to marketing and business development (Co-Founder Z). The Mujeres Móviles co-founders picked up their HCD practices while creating the mobile cervical cancer clinic instead of being taught the HCD process in a class setting.

In addition to these key differences, there are several notable similarities between InVia and Mujeres Móviles. First, both organizations have strong ties to the US and to universities. All four InVia co-founders currently live in the US, conducting their organization's operations in India remotely and through regular trips. One Mujeres Móviles co-founder (Co-Founder Z) currently lives in the US and leverages her US

connections to foster new collaborations and to connect with advisors. Board Members 1, 3, 4, and 5 are all based in the US, and all four organizations that regularly collaborate with Mujeres Móviles are based in the US (see Table 6-1). Additionally, both InVia and Mujeres Móviles have strong connections to universities and these universities have educated, advised, and collaborated with the teams. The InVia co-founders met while in their university and two of their advisors, Engineering Advisor and Prototyping and Development Advisor, are affiliated with this university. The Mujeres Móviles co-founders met due to Co-Founder Y's and Co-Founder Z's shared master's program. Mujeres Móviles also collaborates with several other universities, including a team of researchers studying the stress associated with a pre-cervical cancer diagnosis and a team of students creating a mobile gynecological table.

A second similarity between InVia and Mujeres Móviles is their shared dependence on grant funding. Although InVia is a for-profit organization, they currently depend on grant funding to pay for the costs of researching and developing ccScreen. Mujeres Móviles depends solely on grants to fund their operations, as they do not charge patients anything to receive cervical cancer screening and treatment.

A final similarity between InVia and Mujeres Móviles is that both organizations rely on collaborators to carry out their missions. InVia relies on in-country collaborators to provide feedback on their designs and to eventually test and implement ccScreen. Because InVia team members do not live in India, they depend on their collaborators to provide crucial contextual insight. Mujeres Móviles works with two main types of collaborators: permission-givers and advisors. MINSA and SILAIS function as permission-givers, and Mujeres Móviles requires the permission of these organizations in order to carry out their mobile cervical cancer clinics. Mujeres Móviles also has a strong Board of Advisors who each provide feedback on existing operations and ideas to extend the work of Mujeres Móviles. Although InVia and Mujeres Móviles depend on their collaborators for different tasks, they share a reliance on their collaborations to drive their work forward.

7.2 Comparison of ccScreen and the Mobile Cervical Cancer Clinic

Table 7-2 presents a comparison of ccScreen, created by InVia, and the mobile cervical cancer clinic, created by Mujeres Móviles. This comparison focuses on the details of these two programs that both seek to improve access to cervical cancer screening.

Table 7-2. Comparison of project attributes of ccScreen and the mobile cervical cancer clinic.

	ccScreen	Mobile Cervical Cancer Clinic
Developed by	InVia	Mujeres Móviles
Implementation location	Across India	Rural Nicaragua
Format	Technological device	Service
Project sector	Technology, medical device, cervical cancer	Community development, cervical cancer
Primary design team	Four biomedical engineers	Bioanalyst (Co-Founder X), community development expert (Co-Founder Y), and business development expert (Co-Founder Z)
Design initiation	Co-founders were tasked to develop a device to address a clinical deficit. Cervical cancer was discovered as a clinical deficit of interest during background research	Co-Founder X's mother died of cervical cancer. Co-founders sought to address cervical cancer mortality in rural Nicaragua
Program vision	To provide automated, accurate, and accessible cervical cancer screening for clinics and hospitals in LMICs worldwide	To combine proactive outreach and sexual health education with cervical cancer screening and treatment procedures to bring health to women in rural Nicaragua communities
Implementation model	Sell ccScreen to healthcare administrators at either a flat rate or through a subscription. Clinicians either use ccScreen themselves or community health workers (CHWs) travel and screen women	Provide cervical cancer services to patients for free. Mobile cervical cancer clinics travel to communities in rural communities in Nicaragua
Current stage	Pre-implementation, preparing for clinical trials	Implemented and continuously iterated and improved

Table 7-2 highlights several key points of discussion. First, InVia and Mujeres Móviles had very different reasons for creating their respective cervical cancer screening programs. InVia created ccScreen out of an interest in applying their technical skills to to address a global health need. Mujeres Móviles created their mobile cervical cancer clinic based on the personal experience of Co-Founder X losing her mother to the disease. These different motivations help to explain the different program visions. InVia envisions ccScreen to automate and improve the quality of cervical cancer screening around the world. This vision can be enacted through a technological solution that scales to all LMICs around the world. Mujeres Móviles envisions their mobile cervical

cancer clinic to provide cervical cancer screening, treatment, and holistic sexual health education to women in rural Nicaragua. This vision can only be enacted through a service; there is a role for technology to play in providing outreach, education, and screening, but the combination of these aspects requires a contextualized service.

Second, InVia's and Mujeres Móviles' business models (Table 7-1) explain the organizations' different implementation models. InVia, a for-profit organization, intends to sell ccScreen in India and therefore InVia expects ccScreen to generate revenue. Mujeres Móviles, a non-profit organization, provides their services to clients for free.

Third, InVia and Mujeres Móviles are in different stages of developing and implementing ccScreen and the mobile cervical cancer clinic. InVia has been working to develop the ccScreen system since 2015, and ccScreen has not yet been implemented in India. The InVia team is refining the device to prepare for clinical trials and then clinical implementation. Mujeres Móviles has already implemented the mobile cervical cancer clinic, and they continuously iterate and improve upon the clinic. The mobile cervical cancer clinic was officially launched in 2015, two years after Co-Founder X and Co-Founder Y began to develop ideas for Mujeres Móviles. The differences in ccScreen's stage and the mobile cervical cancer clinic's stage can be explained by several factors. First, Mujeres Móviles has a dedicated full time staff who live in Nicaragua. This allows Mujeres Móviles to move quickly and to launch iterations rapidly. The InVia team began working on ccScreen as undergraduate students and continue to work on ccScreen throughout graduate school, which limits the amount of time they spend on ccScreen and limits their ability to frequently travel to India. Second, InVia is developing a new technology which requires a significant amount of research and development. It is much quicker for Mujeres Móviles to develop a new service and to put this service in practice than it is for InVia to develop a new device and to get the device tested, approved, and manufactured.

Although ccScreen and the mobile cervical cancer clinic were developed to address a similar need of limited access to cervical cancer screening in a low-resource context, the contents of ccScreen and the mobile cervical cancer clinic are extremely different. These differences can be understood by examining the attributes of InVia and Mujeres Móviles, including each organization's motivation to create their program and their approach to developing the program.

7.2.1 Human-Centered Design Practices to Create ccScreen and the Mobile Cervical Cancer Clinic

Table 7-3 presents a comparison of the HCD practices employed by InVia to create ccScreen and by Mujeres Móviles to create the mobile cervical cancer clinic. This

comparison focuses on the design processes to create these two programs, as I present in Section 5.3 and 6.3.

Table 7-3. Comparison of HCD practices employed by InVia and Mujeres Móviles to create ccScreen and the mobile cervical cancer clinic (respectively).

	InVia Creating ccScreen	Mujeres Móviles Creating the Mobile Cervical Cancer Clinic
Observe and Notice	<i>Design Phases 2, 5, and 14</i> - Interviews with clinicians in LMICs - Interviews with domestic clinicians - Interviews with cervical cancer screening stakeholders (e.g., hospital administrators) and experts - Interviews with partners and collaborators in India	<i>Design Phases 2, 4, 6, and 11</i> - Literature review of cervical cancer screening - Observations of MINSA - Interviews with women in a rural Nicaraguan community - Training in clinical practices (including VIA)
Frame and Reframe	<i>Design Phases 1, 3, 4, 6, 11, and 20</i> - Externally-presented problem frame (at beginning of biomedical engineering class) - Iterative narrowing of problem frame (global health to women's health to cervical cancer to VIA) - Matching skills to problem (choosing a problem amenable to technology) - Choose a target location: India - Analyze feedback to determine direction forward	<i>Design Phases 1, 5, and 10</i> - Personal motivation as problem frame - Position the solution as filling in the gaps in MINSA's status quo - Expand the frame of the project from narrow focus on cervical cancer to broader focus on holistic women's health
Imagine and Design	<i>Design Phases 7 and 9</i> - Divergent brainstorming session - Convergent assessment of ideas - Continued development of ideas	<i>Design Phases 3, 7, and 14</i> - Initial inspiration of screening in a suitcase - Development of a pilot strategy - Adapt existing educational tools to use in mobile cervical cancer clinic
Make and Experiment	<i>Design Phases 8, 10, 12, 13, 15, 16, 17, 18, and 19</i> - Feedback on sketches and models - Develop proof-of-concept device - Develop proof-of-concept mobile phone application - Refine proofs-of-concept - Test prototypes with stakeholders in India - Refine prototypes based on stakeholder feedback - Test interest in new programs with stakeholders in India	<i>Design Phases 8, 9, 12, 13, 15, 16, and 17</i> - Pilot test mobile cervical cancer clinic with rural community - Expand the boundaries of the solution to include education, analysis, and continued outreach - Refine model over time based on patient feedback - Refine model over time based on ideas from advisors - Launch new programs outside of the scope of cervical cancer

Activities Conducted in *Observe and Notice*

InVia and Mujeres Móviles exhibited fairly similar activities within *Observe and Notice*. Both organizations conducted research to understand the scope of the problem they aimed to solve, and then to conduct further research on the specific gaps in existing practices their solution should seek to fill.

InVia conducted broader research on the state of global health in general before conducting more focused research on cervical cancer and VIA. Additionally, InVia focused their research more on the process of cervical cancer screening in general at first before narrowing in on research about cervical cancer screening in India. Mujeres Móviles, on the other hand, began by knowing their target location and their target problem, and they therefore tailored their research early to the more specific topic of cervical cancer screening in rural Nicaragua.

InVia did not directly engage with cervical cancer screening patients while conducting their initial research. Instead, InVia primarily interacted with the direct users of their future solution: clinicians and health administrators who organize and conduct cervical cancer screening. Mujeres Móviles did engage with cervical cancer screening patients directly: the team interviewed women in a rural Nicaraguan community to understand what they would like in the mobile cervical cancer clinic.

Activities Conducted in *Frame and Reframe*

InVia framed and reframed their problem more often than Mujeres Móviles. InVia began their design process with an externally-presented problem frame of developing a solution to meet a global health need. They then iteratively narrowed their focus to women's health, cervical cancer, VIA, and VIA in India. The overall goal of this iterative framing was for InVia to match their technical skill sets to an appropriate problem, and therefore they chose to address a problem they felt was amenable to technology. InVia continues to reframe their problem, and they recently framed the feedback they received on ccScreen v3 during their trip to India in December 2018 into a set of steps forward to improve ccScreen and to develop their new programs.

Similar to InVia, Mujeres Móviles began their design process with a problem frame, but this problem frame was based on Co-Founder X's personal motivation to address cervical cancer screening in Nicaragua. This initial problem frame was therefore more narrow than InVia's initial problem frame. As they conducted their initial research, they framed the problem as a need to fill in the gaps of MINSA's cervical cancer screening process. After they piloted the first version of their mobile cervical cancer clinic, they reframed again to focus on holistic women's health in Nicaragua.

Overall, InVia started with a broad problem frame and then worked to narrow in. Mujeres Móviles started with a narrow problem frame and then broadened their focus after they implemented the first version of their solution. InVia's problem framing was

driven by their desire to match their technical skills to an impactful problem. Mujeres Móviles' problem framing was driven by their embeddedness in Nicaragua.

Activities Conducted in *Imagine and Design*

InVia generated ideas fewer times than Mujeres Móviles, but they applied much more structured methods of idea generation than Mujeres Móviles. InVia engaged in a structured brainstorming session where team members first shouted out hundreds of ideas and then the team converged on ideas that were feasible enough to carry forward. This diverge-converge process led InVia to develop ccScreen v1.

Mujeres Móviles did not engage in structured idea generation. They developed new ideas at three points in their design process, but there is no evidence that they applied any idea generation methods to develop these ideas. For example, Co-Founder Y discussed how his and Co-Founder X's first idea was to put everything needed for cervical cancer screening into a suitcase, but Co-Founder Y does not mention if they developed or considered any other ideas. This theme holds through the other examples of idea generation, including Mujeres Móviles developing their pilot strategy and bringing the power bracelet into their sexual health education module.

Activities Conducted in *Make and Experiment*

Both InVia and Mujeres Móviles spent a large portion of their design process building and testing their various ideas and prototypes. InVia created sketches and 3D models of their ideas to facilitate feedback from stakeholders. They then developed a functional version of ccScreen v1 to demonstrate the feasibility of their idea. They continued to refine and test their subsequent prototypes with stakeholders and eventually traveled to India to gain feedback from Indian clinicians on the ccScreen system. In their later phases of design, they also began to test their ideas for two new programs — a mobile health ecosystem and a biometric authentication device — with stakeholders in India.

Mujeres Móviles piloted an early version of the mobile cervical cancer clinic with a rural community in Western Nicaragua. This pilot test informed the team of the need to expand the boundaries of their solution to include sexual health education, high-quality analysis of samples, and proactive outreach to keep in touch with precancerous women. As Mujeres Móviles learns more from patients, they continue to see the value in launching programs outside of the narrow scope of cervical cancer. In addition to patient feedback as a prompt to refine the mobile cervical cancer clinic experiment with new ideas, the Mujeres Móviles Board of Advisors have also provided a number of suggestions that Mujeres Móviles has integrated into their programming.

Overall, InVia spent more time building and developing a functional version of ccScreen while Mujeres Móviles spent more time rapidly implementing, testing, and iterating different versions of the mobile cervical cancer clinic.

7.2.1.a Assessment of Human-Centered Design Practices and Recommendations for Future Human-Centered Design Practices

Table 7-4 presents an assessment of the “human-centeredness” of the design practices employed by InVia to create ccScreen and by Mujeres Móviles to create the mobile cervical cancer clinic. This comparison looks at how each organization adhered to each of the International Organization for Standardization (ISO) 9241-10 criteria for HCD, as I present in Sections 5.4.2 and 6.4.2. I include recommendations for each organization to consider going forward in their process of developing and implementing their programs.

Table 7-4. Comparison of “human-centeredness” of the design approach employed by InVia and Mujeres Móviles to create ccScreen and the mobile cervical cancer clinic (respectively).

	InVia Creating ccScreen	Mujeres Móviles Creating the Mobile Cervical Cancer Clinic
1. Adoption of multidisciplinary skills and perspectives	- Some variety of skills within biomedical engineering, design, and entrepreneurship. - Going forward, the team will need to broaden their within-team multidisciplinary skills to include perspectives of manufacturing and supply chains in India	- Multidisciplinary mix of clinical background (Co-Founder X), community development background (Co-Founder Y), and marketing background (Co-Founder Z). - Going forward, if Mujeres Móviles were to become invested in policy development (a position they could take given their increasing work across the Nicaraguan health system) they would benefit from a government for health policy perspective
2. Explicit understanding of stakeholders, tasks and environments	- Team explicitly focused on designing ccScreen to <i>fit into</i> existing clinical workflows, not to replace or supersede existing stakeholders, tasks, or environments - Usability testing of ccScreen v2 and v3 in India allowed the team to observe how clinicians in India perform VIA and how ccScreen fits into this process.	- Co-Founder X was born and raised in Nicaragua. Co-Founder Y has lived in Nicaragua since 2013 - Co-Founder X has firsthand experience witnessing MINSA's failure to provide adequate cervical cancer care - Eight months of research: observing MINSA, conducting a literature review of cervical cancer screening, and learning from patients

(continued)	InVia Creating ccScreen	Mujeres Móviles Creating the Mobile Cervical Cancer Clinic
3. Stakeholder-centered evaluation driven/refined design	- Each new version of ccScreen seeks to account for stakeholder feedback gained from previous versions of ccScreen - Going forward, InVia will need to broaden their evaluation to include metrics of ccScreen's clinical success. There is an opportunity for InVia to consider how stakeholders would like the system to be evaluated	- Continuous improvement allows Mujeres Móviles to refine their operations based on feedback they receive from stakeholders - Going forward, the team should consider developing an in-depth pilot study (based on the success from 2014) to either develop new ideas for the mobile cervical cancer clinic or to develop key areas of evaluation
4. Consideration of the whole stakeholder experience	- InVia focuses on the experience of three groups of stakeholders: CHWs who perform VIA, clinicians who review the screening results and make diagnoses, and administrators who coordinate screening and granting system access - InVia does not currently focus on the experience of patients - Going forward, InVia might consider leveraging ccScreen to overcome key barriers in the <i>patient's</i> ability to access cervical cancer screening	- Each iteration of the mobile cervical cancer clinic addresses more of the stakeholder experience - The mobile cervical cancer clinic program is an end-to-end service, starting with cervical cancer screening and continuing through cervical cancer treatment - Going forward, the team may find that in order to address the whole stakeholder experience, they must address the whole Nicaraguan health system and the culture of patriarchy in Nicaragua
5. Involvement of stakeholders throughout design and development	- InVia involves stakeholders to provide feedback on ccScreen - Going forward, InVia can consider involving stakeholders earlier in the design process, perhaps by hosting a stakeholder-centered idea generation or low-fidelity prototyping workshop, which could improve their designs and shorten the length of an iterative cycle	- Mujeres Móviles works with a range of stakeholders, including MINSA and SILAIS, patients, cytologists, advisors, and collaborators. Stakeholders provide feedback on the mobile cervical cancer clinic - Going forward, there is an opportunity for Mujeres Móviles to involve stakeholders to generate new ideas. Mujeres Móviles should consider facilitating inspiration and ideas from stakeholders

(continued)	InVia Creating ccScreen	Mujeres Móviles Creating the Mobile Cervical Cancer Clinic
6. Iterative process	- Design process based around an iterative cycle of developing ideas, creating prototypes, and testing prototypes with stakeholders in India. - Content of ccScreen has not changed much since v1 - Going forward, InVia can consider testing larger transformative iterations in addition to their current smaller iterations	- Design process involves small and frequent iterations. The team is frequently refining their practices and adding new programs - Content of the mobile cervical cancer clinic has not changed much since v1 - Going forward, Mujeres Móviles can consider testing larger transformative iterations in addition to their current smaller iterations

Overall, both organizations display some adherence to all HCD criteria. In the subsections below, I point out areas of future consideration or improvement for both organizations. Although I consider these organizations to be exemplars of HCD and accessibility, I note that there is always room to consider changing future processes to further improve the human-centeredness of each organizations' design process.

Adherence to 1. Adoption of multidisciplinary skills and perspectives

InVia's team of co-founders is composed of biomedical engineers. Within biomedical engineering, the co-founders have a range of interests including biosignals, cell and tissue engineering, and biomechanics. Additionally, the co-founders hold a number of separate interests in business model development, user experience / user interface (UX/UI), and electrical engineering. However, the team does not currently have any within-team perspectives on Indian supply chains or manufacturing, which will be required for the team to incorporate when they seek to implement. Overall, InVia requires skills in three main categories to meet their mission: members dedicated to identifying problems to solve (e.g., researchers, or those with lived experience in the problem), dedicated to solving those problems (e.g., engineering), and dedicated to delivering those solutions (e.g., sales).

Mujeres Móviles' team of co-founders is more multidisciplinary: Co-Founder X has a clinical background in bioanalysis, Co-Founder Y has a community development background in non-profits, and Co-Founder Z has a marketing background in health-oriented businesses. These perspectives seem sufficient for the current operations of Mujeres Móviles. However, it is possible that Mujeres Móviles will become more invested in policy development in Nicaragua, as they continue to broaden the scope of their operations to include more and more holistic change. Should they take

this position, they would benefit from an additional perspective of a team member with governmental or policy development experience.

Adherence to 2. *Explicit understanding of stakeholders, tasks and environments*

A major strength of InVia's and Mujeres Móviles' design processes is their explicit understanding of stakeholders, tasks, and environments.

As InVia was developing ccScreen, they focused on ensuring ccScreen would fit into existing clinical workflows, including tasks and environments. ccScreen seeks to amplify the impact of stakeholders as they conduct their tasks. Although InVia was not able to observe the clinical environment in India while developing ccScreen v1, they have been able to test subsequent iterations of the device, therefore furthering their understanding of how the solution relates to stakeholders, tasks, and environments.

Mujeres Móviles' understanding of stakeholders, tasks, and environments began with Co-Founder X's perspective being born and raised in Nicaragua and experiencing the cervical cancer care process firsthand. Co-Founder Y, born in the US, has lived in Nicaragua since 2013 and therefore both of these co-founders engage daily with the Nicaraguan culture, health system, and government. Beyond their lived experience, the Mujeres Móviles co-founders also engaged in an eight-month research process to observe MINSA in action, to conduct background research on cervical cancer screening, and to interview patients for their perspectives. These research activities all contributed to their deep understanding of stakeholders, tasks, and environments.

Adherence to 3. *Stakeholder-centered evaluation driven/refined design*

Both InVia and Mujeres Móviles display a strong adherence to incorporating stakeholder feedback in refining their designs. InVia travels to India regularly to gain feedback on the iterations of their device and then incorporates this feedback into the next version of ccScreen they develop. Mujeres Móviles has developed a "*continuous improvement*" process that consistently asks patients for feedback and then incorporates changes as needed into their mobile cervical cancer clinic. Additionally, Mujeres Móviles had success with a pilot study in 2014 that first asked stakeholders what they would want in a mobile cervical cancer clinic and then created a mobile cervical cancer clinic to meet these needs. This type of pilot strategy could be considered going forward for any larger changes the organization seeks to make.

Mujeres Móviles has more immediate and frequent access to their stakeholders than InVia does. Mujeres Móviles is therefore able to gain feedback much more regularly and rapidly than InVia. InVia, however, benefits from their ability to jump in and out of their research activities, as they are able to take time to digest feedback they receive and turn this feedback into design changes.

Adherence to 4. *Consideration of the whole stakeholder experience*

InVia primarily focuses on the experience of three groups of stakeholders: clinicians, health administrators, and CHWs. These three groups are the primary users of ccScreen. InVia currently does not address the experience of patients. This is a key area of future work for InVia: to better understand and address the experience of patients who receive cervical cancer screening in India and who interact with ccScreen.

Mujeres Móviles is quite successful in considering the whole stakeholder experience. Each version of their mobile cervical cancer clinic incorporates more of the stakeholder experience, including the framing of holistic women's health in Design Phase 10 (which led to the inclusion of broader sexual health education during mobile cervical cancer clinics) to the addition of the watch list in Design Phase 13 (which led to continuous follow-up with patients most at-risk of developing cervical cancer). Now, Mujeres Móviles sees the mobile cervical cancer clinic as an end-to-end service, beginning with preventive cervical cancer screening and continuing through patient advocacy during cervical cancer treatment. As I mention in *1. Adoption of multidisciplinary skills and perspectives*, Mujeres Móviles may soon find that in order to address more of the stakeholder experience, they must take on addressing issues within the Nicaraguan culture and health system at large.

Adherence to 5. *Involvement of stakeholders throughout design and development*

Both InVia and Mujeres Móviles primarily involve stakeholders in two phases: initial research on a problem, and evaluation of the solution to address that problem. Neither organization involves stakeholders at other points in the design process, by (for example) hosting stakeholders in an idea generation session or by asking stakeholders to help build prototypes of their ideas. This could be an area of improvement for both organizations going forward.

One particular area for both organizations to involve stakeholders is in developing an evaluation strategy. InVia is planning a formal evaluation as they test their device in clinical settings, and Mujeres Móviles is preparing for sophisticated impact evaluation analyses enabled by their improved data collection practices. As the organizations plan an impact evaluation, they should work with stakeholders to understand what stakeholders think are important areas of evaluation.

Adherence to 6. *Iterative process*

Both InVia and Mujeres Móviles structure their design process around an iterative cycle. They build their ideas, test prototypes with stakeholders, and incorporate stakeholder feedback to refine their ideas. Although both organizations engage in iteration, neither ccScreen nor the mobile cervical cancer clinic has changed significantly since its first

version. ccScreen v3 functions very similarly to ccScreen v1 and all the features of mobile cervical cancer clinic v1 are still present in mobile cervical cancer clinic v5. This is not necessarily a good or a bad thing, but it does demonstrate that InVia's and Mujeres Móviles' iterative processes have been focused on small and tight iterations.

Going forward, both InVia and Mujeres Móviles might consider testing much more “radical” iterations of their offerings to understand if these large changes would help or hinder their organizations' missions. This would be an ideal place to involve stakeholders: to envision big changes to the organization and to understand if these big changes should be undertaken currently.

7.2.2 Accessibility Considerations to Create ccScreen and the Mobile Cervical Cancer Clinic

Table 7-5 presents an assessment of how InVia and Mujeres Móviles considered various dimensions of accessibility when they created ccScreen and the mobile cervical cancer clinic, respectively. This comparison looks at how each organization considered *acceptability*, *affordability*, *physical accessibility*, *accommodation*, and *availability*, as I present in Sections 5.3 and 6.3.

Table 7-5. Comparison of considerations of accessibility employed by InVia and Mujeres Móviles to create ccScreen and the mobile cervical cancer clinic (respectively).

	InVia Creating ccScreen	Mujeres Móviles Creating the Mobile Cervical Cancer Clinic
Acceptability	Not addressed - ccScreen seeks to be <i>acceptable</i> to healthcare providers, but ccScreen does not address social acceptability of cervical cancer screening among patients in India	Large focus - Two strategies: (1) effective messaging to invite women to the screening events, and (2) broad health education to educate clients of the importance of sexual health services and cervical cancer screening
Affordability	Significant focus - InVia is committed to making ccScreen affordable to health administrators and clinicians - <i>Affordability</i> was a chief consideration in early phases of developing ccScreen	Limited focus - Commitment to providing screening to patients for free - Mujeres Móviles' goal is to minimize the cost of screening and treatment so they are able to pay less per person while retaining high quality

(continued)	InVia Creating ccScreen	Mujeres Móviles Creating the Mobile Cervical Cancer Clinic
Physical Accessibility	Limited focus - ccScreen enables <i>physical accessibility</i> of cervical cancer screening because the cervical scope is small and easy for the CHW to bring from place to place	Significant focus - <i>Physical accessibility</i> is the core of Mujeres Móviles' vision: bring cervical cancer screening services to women in rural Nicaragua
Accommodation	Large focus - Two strategies: (1) ccScreen fits into existing clinical practices, and (2) ccScreen improves the feasibility of VIA, therefore allowing the patient to receive screening results immediately after screening	Large focus - Multiple strategies: (1) Mujeres Móviles builds trust with patients, (2) delivers their health services through an all-women team, (3) provides education at all stages of the cervical cancer screening and treatment process, and (4) helps women navigate the Nicaraguan health system for further cervical cancer follow-up and treatment
Availability	Large focus - ccScreen's primary goal is to improve the quality and accuracy of existing cervical cancer screening procedures - InVia is concerned for patient privacy among CHWs, clinicians, and health administrators	Significant focus - The mobile cervical cancer clinic improves <i>availability</i> by improving health care quality, privacy, the timely provision of results, the timely provision of treatment, and continuous monitoring of precancerous patients

Consideration of *Acceptability*

InVia did not consider the *acceptability* of ccScreen. Through their usability testing, they strive to create a solution that is *acceptable* to healthcare providers, but they do not consider how patients find the solution *acceptable* or how the solution contributes to greater *acceptability* of cervical cancer screening in general.

Mujeres Móviles on the other hand has a large focus on the *acceptability* of the mobile cervical cancer clinic. Although they initially began by just focusing on the provision of cervical cancer screening, they realized in their early pilot testing that they would need to share broader sexual health education with patients in order to improve the patient's perception of their own health and their need to receive cervical cancer screening. Mujeres Móviles addresses acceptability in two main ways: through effective messaging to educate patients on the need to come to the mobile cervical cancer clinic, and through sexual health education provided to women.

Consideration of *Affordability*

InVia significantly focuses on the *affordability* of the ccScreen system. InVia's focus on *affordability* directly relates to their business model: there are a number of competitors in the space of cervical imaging, and InVia seeks to position ccScreen as less expensive but higher quality than their competitors. *Affordability* was a key focus early in InVia's idea generation and prototype development: the team sought to create a low-cost technology that would make a significant impact in LMICs.

Affordability was less a focus for Mujeres Móviles. Mujeres Móviles is committed to providing cervical cancer care to patients for free, meaning that they cover the cost of cervical cancer screening and treatment. Therefore, Mujeres Móviles has the incentive to minimize the cost of screening and treatment while still retaining quality. Currently, the organization spends less than \$10 per patient to deliver cervical cancer care.

Consideration of *Physical Accessibility*

InVia has a limited focus on *physical accessibility*. ccScreen enables *physical accessibility* by being small and mobile, and can therefore be transported by CHWs between multiple screening locations. Beyond this, ccScreen does not consider the *physical accessibility* of cervical cancer screening.

Mujeres Móviles foundational focus is on addressing the *physical accessibility* of cervical cancer screening. *Physical accessibility* is at the core of Mujeres Móviles vision for the mobile cervical cancer clinic: to bring cervical cancer screening to women in rural Nicaragua who otherwise cannot easily access health services. The mobile cervical cancer clinic travels to communities in rural Nicaragua, often setting up the clinic within walking distance of women in these rural communities.

Consideration of *Accommodation*

Accommodation is a large focus of InVia. InVia contributes to better *accommodation* of cervical cancer screening in two ways: (1) by fitting into existing clinic practices, and (2) by prioritizing VIA, a method that provides patients with screening results rapidly and without any further follow-up from healthcare providers.

Similarly, *accommodation* is a large focus of Mujeres Móviles. Mujeres Móviles has several strategies to improve the *accommodation* of patients in cervical cancer screening: they (1) focus on building trust with patients, (2) deliver health services through an all-women team, (3) provide education throughout the screening procedure, and (4) navigate the Nicaraguan health system from women. This fourth strategy is the best example of Mujeres Móviles expanding the boundaries of their mobile cervical cancer clinic to best accommodate the patient. Mujeres Móviles helps patients move up on the waiting list for cervical cancer treatment at cancer treatment centers in

Nicaragua. They also refer patients to other NGOs and organizations that can help the patient receive care, as needed.

Consideration of Availability

Availability is one of the largest focuses of InVia. After originally learning about the VIA screening method, InVia framed the problem as improving the quality and accuracy of VIA in order to improve its ability to be implemented in LMICs. ccScreen enables the *availability* of VIA in India and also improves the quality of VIA. Based on their preliminary testing of the ccScreen's lesion detection algorithm, InVia believes that ccScreen will improve the diagnostic sensitivity of VIA screening. Additionally, the ccScreen system allows for patient privacy, a key consideration within clinical quality and *availability*.

Mujeres Móviles focuses on improving the *availability* of cervical cancer screening in Nicaragua by focusing on five main aspects of *availability*: (1) high quality care, (2) assurance of patient privacy, (3) timely provision of cervical cancer screening results, (4) timely provision of treatment following a precancerous diagnosis, and (5) continuous monitoring of patients leading to improved *availability* of follow-up health services, like further testing, medication, and treatment.

7.2.3 Intersection of InVia's and Mujeres Móviles' Human-Centered Design Practices and Considerations of Accessibility

In Section 7.2.2, I describe how InVia and Mujeres Móviles considered different aspects of accessibility, and in this section I focus on how InVia's and Mujeres Móviles' considerations of accessibility were impacted by their HCD process.

In Section 5.3, I present a timeline of when InVia considered accessibility in their design process (Figure 5-4) and I present a diagram of where these considerations of accessibility were located within their overall design process (Figure 5-9). Similarly, in Section 6.3, I present a timeline of Mujeres Móviles' considerations of accessibility in their design process (Figure 6-9) and I present the design process model with their considerations of accessibility (Figure 6-11).

The most notable difference between how InVia and Mujeres Móviles considered accessibility within their broader design process is that InVia considered accessibility less often than Mujeres Móviles. InVia considered accessibility five times while Mujeres Móviles considered accessibility seven times. Within each consideration, InVia thought about more dimensions of accessibility (2 dimensions per consideration) than Mujeres Móviles (~1.86 dimensions per consideration). InVia did not consider all five dimensions

of accessibility, neglecting *acceptability*, while Mujeres Móviles considered all five dimensions at some point in their design process.

In the later stages of their design process, InVia's considerations of accessibility were tied to their trips to India. The InVia team was limited in their frequency of testing, given that they live in the US but needed to test ccScreen with clinicians in India. Most of the Mujeres Móviles team, on the other hand, lives in Nicaragua and they are more able to consistently interact with their stakeholders. Additionally, Mujeres Móviles has already implemented their mobile cervical cancer clinic while InVia is still developing ccScreen. Because the mobile cervical cancer clinic is already implemented, the Mujeres Móviles team is able to constantly evaluate how the accessibility of the mobile cervical cancer clinic can be improved. The InVia team does not yet have this luxury.

Despite this overarching difference in how InVia and Mujeres Móviles considered accessibility within their broader design process, there are three major similarities in how InVia and Mujeres Móviles considered accessibility. First, both organizations' considerations of accessibility originated in research (either *Observe and Notice* or *Make and Experiment*) and carried through into *Frame and Reframe* and *Imagine and Design*. Both teams learned about accessibility through "concrete" interactions with stakeholders in the bottom half of the Innovation Model [74] (Figure 2-9) rather than by developing an "abstract" sense of accessibility in the top half of the Innovation Model.

Second, both organizations shared a mindset of accessibility, and addressing barriers to cervical cancer care was a key driver for both organizations. InVia considered accessibility twice before their solution was developed. InVia considered *affordability*, *accommodation*, and *availability* in Considerations 1 and 2, which helped the team frame the problem they were trying to solve. These considerations then influenced how InVia developed ccScreen v1. Mujeres Móviles considered accessibility three times before developing their solution. Mujeres Móviles considered *physical accessibility*, *availability*, *accommodation*, and *acceptability* in Considerations 1 through 3, which helped them understand what features their solution should include. For both organizations, most of these considerations occurred after a phase of *Observing and Noticing*, with the exception of InVia's Consideration 2 which occurred after *Making and Experimenting* early ideas to facilitate feedback from stakeholders.

Third, both organizations shared a commitment to learning about accessibility when testing their solution. During their first trip to India, the InVia team considered the *physical accessibility* of their solution, and the team reconsidered the *accommodation*, *availability*, and *affordability* of their solution (Consideration 3). During their second trip to India, the InVia team reconsidered the *affordability* of their solution (Consideration 4) and they considered how their new programs would address *availability* (Consideration 5). Mujeres Móviles reconsidered the *acceptability* and *accommodation* of their solution (Consideration 4) after pilot testing the mobile cervical cancer clinic. While preparing for

the second version of their mobile cervical cancer clinic, Mujeres Móviles discovered the VIA screening method, and considered the *affordability* and *accommodation* (Consideration 5) of VIA before integrating it into their mobile cervical cancer clinic. After launching mobile cervical cancer clinic v2, two of Mujeres Móviles' advisors suggested ideas to improve the *accommodation* (Consideration 6) and the *acceptability* (Consideration 7) of the mobile cervical cancer clinic. Mujeres Móviles integrated their advisors' ideas into subsequent iterations of the mobile cervical cancer clinic.

In summary, InVia and Mujeres Móviles demonstrate a number of patterns related to accessibility and design, even though the details of their HCD processes and their solutions are quite different. These patterns provide lessons for other designers who seek to carry out an HCD process that considers accessibility. First, both organizations demonstrate the importance of considering accessibility early in the design process before the solution is actually developed as a way to frame the problem to be solved. Primary research on accessibility barriers (*Observe and Notice*) is a tool for other designers to use to understand the scope of the problem and to frame the eventual solution. Designers should conduct research with a mindset of accessibility, where designers have a keen eye towards understanding barriers to accessibility and to overcoming these barriers. Second, both organizations leverage the testing of their solutions as a way to consider and reconsider accessibility. Designers should engage in prototyping and testing (*Make and Experiment*) to understand how the solution addresses or does not address barriers to accessibility. Designers should conduct testing with an open mind and should seek critical feedback about how the solution could further improve accessibility. Third, Mujeres Móviles has created an ecosystem for advisors and other providers of feedback to develop new ideas to improve the accessibility of their solution. Designers who have implemented their solutions should encourage their advisors and other providers of feedback to suggest new ideas to drive the solution forward to further improve accessibility. InVia, who has not yet implemented their solution, should also consider creating this sort of open and creative ecosystem among their advisors and collaborators.

7.3 Best Practices of Human-Centered Design for Accessibility

The comparison of InVia and Mujeres Móviles, including the comparison of their organizational structures (Section 7.1) and the comparisons of how their solutions, ccScreen and the mobile cervical cancer clinic, were created (Section 7.2), gives rise to a set of “best practices” of HCD for accessibility. These best practices represent the

shared characteristics of HCD for accessibility that both InVia and Mujeres Móviles exhibited in creating ccScreen and the mobile cervical cancer clinic. Other designers who seek to carry out an HCD process that considers accessibility should consider following these best practices (BPs):

BP1. Adopt an accessibility mindset, considering multiple dimensions of accessibility.

BP2. Research the existing barriers to accessibility.

BP3. Create a solution to address multiple barriers to accessibility.

BP4. Test the solution to see if it addresses accessibility.

BP5. Refine the solution to better address accessibility.

7.4 New Frameworks of Human-Centered Design for Accessibility

The list of best practices of HCD for accessibility (Section 7.3), is a set of guidelines inspired directly from the in-depth case studies of InVia and Mujeres Móviles. In this section, I extend the applicability of these best practices by aligning them with existing HCD frameworks. I outline two new frameworks to capture the lessons from InVia and Mujeres Móviles and to broaden these lessons into the existing theory of HCD. The first framework is a set of criteria of HCD for accessibility (Section 7.4.1). The second framework is a process model of HCD for accessibility (Section 7.4.2).

7.4.1 Criteria of Human-Centered Design for Accessibility

The first framework I propose is a modification of the ISO 9241-210 criteria of HCD. I have edited each of the six ISO criteria to include considerations for accessibility in the design process. The edits are **bolded** in the list of criteria below, and each criteria addresses at least one best practice of HCD for accessibility, as I outline in Section 7.3.

1. Adoption of multidisciplinary skills and perspectives. **Team members adopt a mindset of accessibility.** (*Addresses BP1*)
2. Explicit understanding of stakeholders, tasks, and environments. **Understand the barriers to accessing existing solutions.** (*Addresses BP1 and BP2*)
3. Stakeholder-centered evaluation driven/refined design. **Design is refined by evaluating whether or not it sufficiently addresses accessibility.** (*Addresses BP4 and BP5*)
4. Consideration of the whole stakeholder experience. **Address the accessibility barriers stakeholders face.** (*Addresses BP3*)
5. Involvement of stakeholders throughout design and development. **Stakeholders share their perspectives on accessibility.** (*Addresses BP2*)

6. Iterative process. **Research on accessibility drives iterative problem framing and development of new designs.** (*Addresses BP2, BP3, BP4, and BP5*)

These six criteria can be thought of as principles to carry out HCD for accessibility. Designers who seek to develop solutions to improve accessibility should consider adhering to these six criteria.

7.4.2 Process of Human-Centered Design for Accessibility

The second framework I propose is a modification of Beckman and Barry's Innovation Model [74]. This framework (Figure 7-1) incorporates the two axes and the four phases of design proposed in the original model (Figure 2-9).

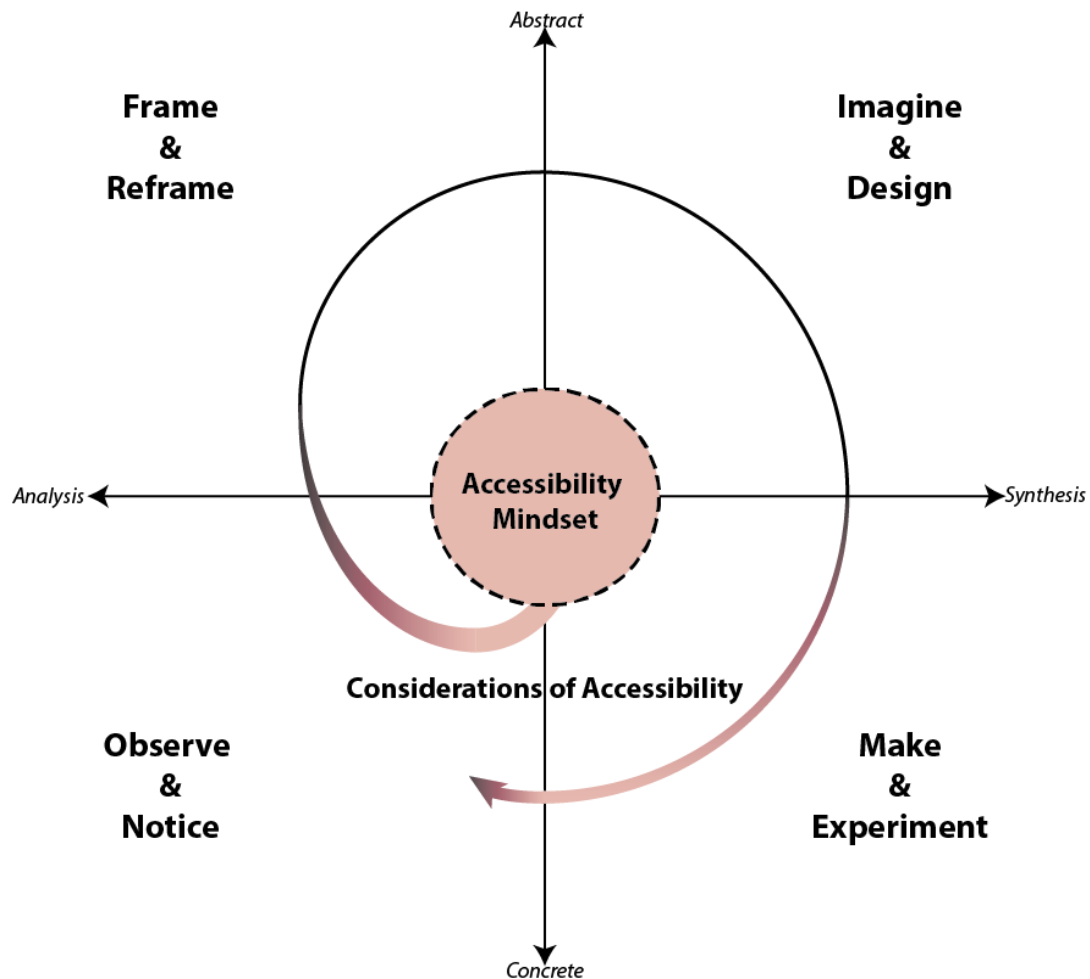


Figure 7-1. The iterative process of HCD for accessibility begins with an accessibility mindset. This mindset influences accessibility-minded research activities (*Observe and Notice*), which inform how the problem is framed (*Frame and Reframe*) and how ideas are generated (*Imagine and Design*). The ideas are then tested with accessibility in mind (*Make and Experiment*).

In this model, HCD for accessibility begins with an “accessibility mindset” where members of the design team are keenly interested in understanding the barriers to accessibility in existing solutions (*addresses BP1*). An accessibility mindset includes an awareness of the multiple dimensions of access: *acceptability, availability, physical accessibility, affordability, and accommodation*. The accessibility mindset pervades all phases of design. The design team then applies this mindset to consider accessibility through their research, beginning with *Observe and Notice (addresses BP2)*. This accessibility-minded research then informs how the team frames the problem (*Frame and Reframe*) and generates ideas to solve the problem (*Imagine and Design*) (*addresses BP3*). When the team builds and tests their ideas, they consider new dimensions of accessibility and reconsider dimensions previously considered (*addresses BP4*). The team then cycles through the process again and refines their solution to better address accessibility (*addresses BP5*).

Similar to the original Innovation Model, I do not prescribe that HCD for accessibility must travel in this linear fashion, with research leading to problem framing leading to idea generation leading to prototyping. Designers for accessibility may jump between phases, as InVia and Mujeres Móviles did (see Figure 5-9 and Figure 6-11).

7.4.3 Implications of the Criteria and Process of Human-Centered Design for Accessibility

The two frameworks I propose can be applied by future design teams who seek to design a solution to improve accessibility. A range of design teams can apply these frameworks to their projects. I have based my research on a specific health equity challenge: cervical cancer. Therefore, the most obvious set of design teams who might find use from these frameworks are design teams that seek to improve access to other health services that are currently inaccessible to vulnerable parts of the population. For example, design teams considering how to improve access to vaccinations could apply these frameworks to develop contextualized solutions for their particular location. In addition to the obvious applications in health, these frameworks could be applied to social equity challenges in general. For example, design teams considering how to improve access to healthy food, reliable energy, or clean water could apply these frameworks.

These frameworks extend the design community’s understanding of how design can and should consider “access” to the solutions it develops. Currently, the design community narrowly focuses on creating accessible user interfaces (e.g., ergonomic interfaces) but not on designing accessibility to the solution itself. The two frameworks I propose provide designers with a set of guidelines to conduct HCD for accessibility.

7.4.4 Evaluating Human-Centered Design for Accessibility

The two frameworks I have developed were generated from my case studies of InVia and Mujeres Móviles. Throughout this dissertation, I have considered InVia and Mujeres Móviles to be exemplars of applying an accessibility-minded HCD approach to develop cervical cancer screening solutions. To test the utility of the two frameworks I have developed, more work is needed to understand if HCD for accessibility *generally* leads to more accessible solutions. Therefore, I propose a theory of change (Figure 7-2) that links the *approach* of HCD for accessibility to the *goal* of improving accessibility.

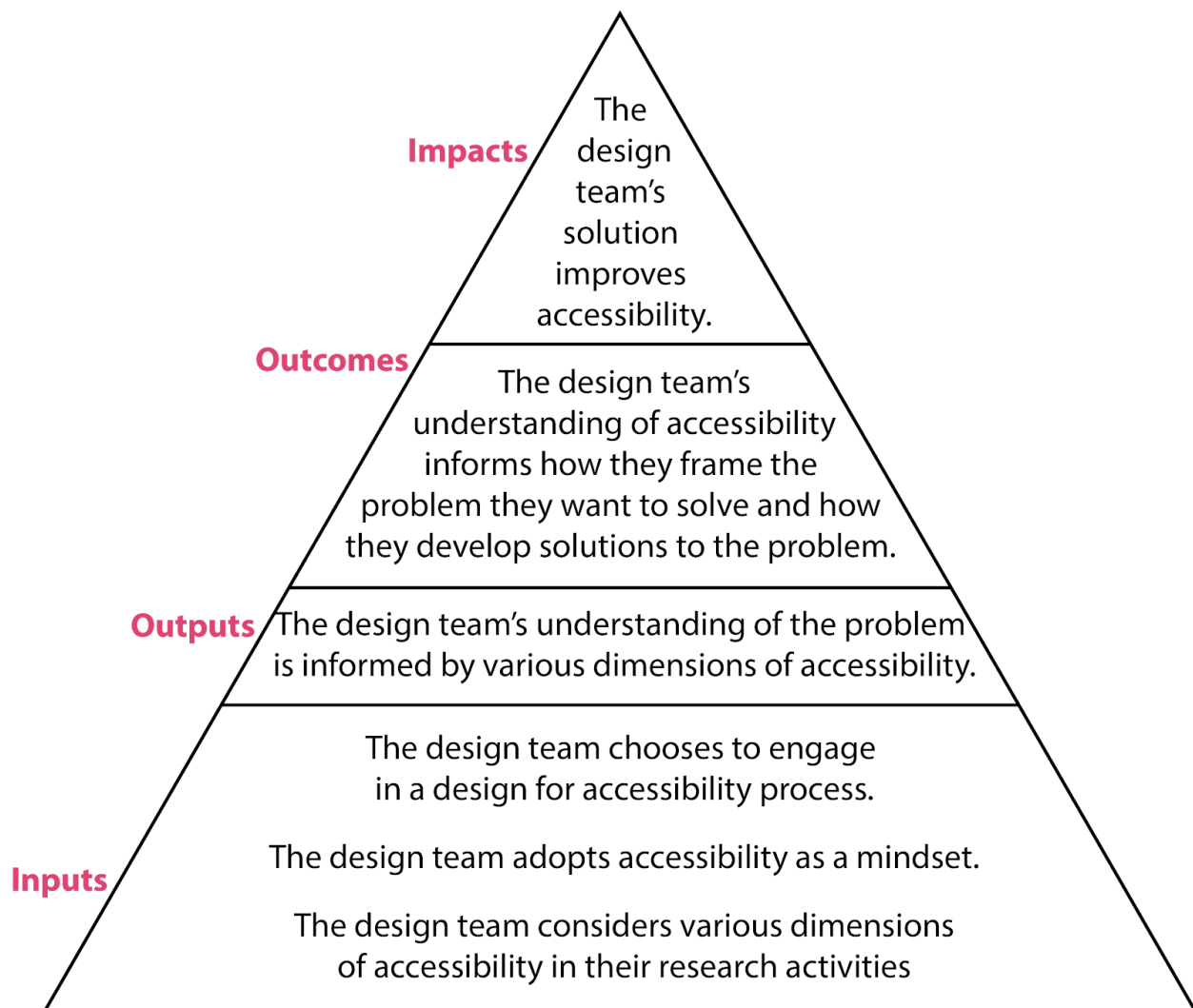


Figure 7-2. The approach of HCD for accessibility (inputs) is linked to the goal of improving accessibility (impacts). This theory of change can be used to evaluate the success of HCD for accessibility.

This theory of change provides a framework to evaluate the success of HCD for accessibility to reach its goal: to develop solutions that improve accessibility. The design

team can monitor the inputs, outputs, outcomes, and impacts of this theory of change throughout their process to understand if their accessibility-minded process leads to the creation of a solution that improves accessibility. The theory of change framework provides design teams a way to understand if their process led them to develop more accessible solutions. This type of evaluation is necessary to understand the utility of HCD for accessibility as a process.

7.5 Summary of Cross-Case Analysis of InVia Technologies and Mujeres Móviles

In this chapter, I have compared the two in-depth case studies I presented in this dissertation: InVia and Mujeres Móviles. I first compared the overall organizational characteristics of InVia and Mujeres Móviles, including several key differences in how they approached the process of creating a solution to improve access to cervical cancer screening. InVia worked in the US to develop a new technology, ccScreen, to improve cervical cancer screening in India. Mujeres Móviles worked in Nicaragua to develop a service, the mobile cervical cancer clinic, to improve cervical cancer screening in rural Nicaragua.

Next, I compared the processes that InVia and Mujeres Móviles employed to develop ccScreen and the mobile cervical cancer clinic. Both organizations followed an HCD process that was informed by multiple considerations of accessibility. The organizations prioritized different dimensions of accessibility, and the teams demonstrated different ways of conducting HCD. InVia spent a significant amount of time conducting preliminary research on global health challenges and cervical cancer before narrowing their focus to address the *affordability*, *accommodation*, and *availability* of cervical cancer screening in India. Mujeres Móviles began their process with a focus on improving the *physical accessibility* and *availability* of cervical cancer screening in rural Nicaragua. Mujeres Móviles was then able to rapidly build and test various prototypes of their service delivery model, while InVia has taken more time to develop the appropriate technological tools to test with stakeholders in India.

Based on these comparisons of InVia's and Mujeres Móviles' approaches to conducting HCD for accessibility, I developed a set of five best practices. These best practices represent the characteristics of HCD for accessibility that both InVia and Mujeres Móviles exhibited as they created ccScreen and the mobile cervical cancer clinic. From these best practices, I created two new frameworks of HCD for accessibility: a set of HCD for accessibility criteria and a process model of HCD for

accessibility. These frameworks can be applied by other designers who seek to consider and improve accessibility in developing their solutions.

Finally, I presented an acknowledgment of the further work that must be done to evaluate the two HCD for accessibility frameworks I created. I proposed a theory of change model that links the process and characteristics of HCD for accessibility with the end-goal of HCD for accessibility: the solution that is designed with an HCD for accessibility process does in fact improve accessibility. This theory of change can be modified by design teams who apply HCD for accessibility in their own work so they can monitor and evaluate whether or not their process is creating the intended impact.

Chapter 8

Dissertation Summary and Future Work

I began this dissertation by discussing how global disparities in health access create global health disparities. The current COVID-19 pandemic has illustrated and exacerbated the stark global disparities in access to health care [1], [2]. More generally, countries with a low Socio-Demographic Index (SDI) tend to have a lower Healthcare Access and Quality (HAQ) index [21]. A person's life expectancy depends on where that person was born and raised [26]. These global health disparities demand our collective attention and problem-solving.

Human-centered design (HCD) offers an approach to address global health disparities. HCD emphasizes creative problem-solving and comes from a rich academic and practice-oriented tradition, with applications in the creation of consumer products, experiential services, social equity challenges, and — more recently — global health. HCD has been applied to create a range of solutions from the first computer mouse [77] to a clinical decision support tool to better integrate tuberculosis care for patients living with HIV in Kenya [93].

While HCD is a promising approach to address global disparities in health access, I demonstrated in my literature review (Chapter 2) that HCD requires modification in order to fully handle the complexities of global health accessibility. “Accessibility” is not adequately captured in the characteristics or processes of HCD; HCD currently focuses on addressing the accessibility needs of a small group of stakeholders who use the solution, but not on the accessibility needs of all those who may interact with or benefit from the solution. In order to effectively apply HCD to address health access, we need to develop a new understanding of how HCD can improve accessibility for a holistic group of stakeholders. Therefore, my goal in this dissertation has been to integrate accessibility as a core principle in HCD so that HCD can be applied to address a broader range of accessibility challenges.

To ground my research in a concrete accessibility challenge, I have focused this dissertation on studying the role of HCD in improving access to cervical cancer screening. Cervical cancer is an illustrative example of global disparities in health access. Cervical cancer is a largely preventable disease, yet 300,000 women around

the world die of cervical cancer every year, and ninety percent of these deaths occur in low- and middle-income countries (LMICs) [23], [24]. Global disparities in access to cervical cancer screening, including the Pap smear and visual inspection with acetic acid (VIA), contribute to the global disparities in cervical cancer incidence and mortality. In Chapter 3, I presented preliminary work I have engaged in to apply HCD to improve access to cervical cancer screening in Ghana. In Chapters 5 and 6, I presented case studies of organizations applying HCD to improve cervical cancer screening access: InVia Technologies in India (Chapter 5) and Mujeres Móviles in Nicaragua (Chapter 6).

The two case studies covered in this dissertation unpack in detail the ways in which HCD might be modified to support the development of accessible solutions to address the problem of cervical cancer mortality. My in-depth analysis of these two cases (Chapter 7) yielded a set of criteria of HCD for accessibility, as well as a process model illustrating how to carry out HCD for accessibility.

The first framework I created was a set of criteria of HCD for accessibility. These criteria can be thought of as principles of carrying out HCD for accessibility. These criteria are based on the International Organization for Standardization (ISO) 9241-210 criteria of HCD [85], and I included an accessibility consideration to each criteria, shown in **bold** in the list below:

1. Adoption of multidisciplinary skills and perspectives. **Team members adopt a mindset of accessibility.**
2. Explicit understanding of stakeholders, tasks, and environments. **Understand the barriers to accessing existing solutions.**
3. Stakeholder-centered evaluation driven/refined design. **Design is refined by evaluating whether or not it sufficiently addresses accessibility.**
4. Consideration of the whole stakeholder experience. **Address the accessibility barriers stakeholders face.**
5. Involvement of stakeholders throughout design and development. **Stakeholders share their perspectives on accessibility.**
6. Iterative process. **Research on accessibility drives iterative problem framing and development of new designs.**

The second framework I created was a modification of Beckman and Barry's Innovation Model [74]. This framework (Figure 7-1 is reprinted below) demonstrates how the process of HCD for accessibility begins with an "accessibility mindset" where the design team is keenly interested in understanding multiple barriers to accessibility in existing solutions. An accessibility mindset includes an awareness of the multiple dimensions of access that Penchansky and Thomas presented [22]: *acceptability, availability, physical accessibility, affordability, and accommodation*. The design team applies their accessibility mindset to consider accessibility through their research, beginning with *Observe and Notice*. Their accessibility-minded research then informs how the team

frames the problem (*Frame and Reframe*) and generates ideas to solve the problem (*Imagine and Design*). When the team begins to build and test their ideas, they consider new dimensions of accessibility or reconsider dimensions they previously considered. As the team tests their solutions with accessibility in mind, they cycle through the process again and refine their solution to better address accessibility. While I have described these activities in a linear fashion, the design team is not limited to following this direct path of research leading to problem framing leading to idea generation leading to prototyping. The design team should jump between phases as they see fit, and they should iterate between cycles multiple times.

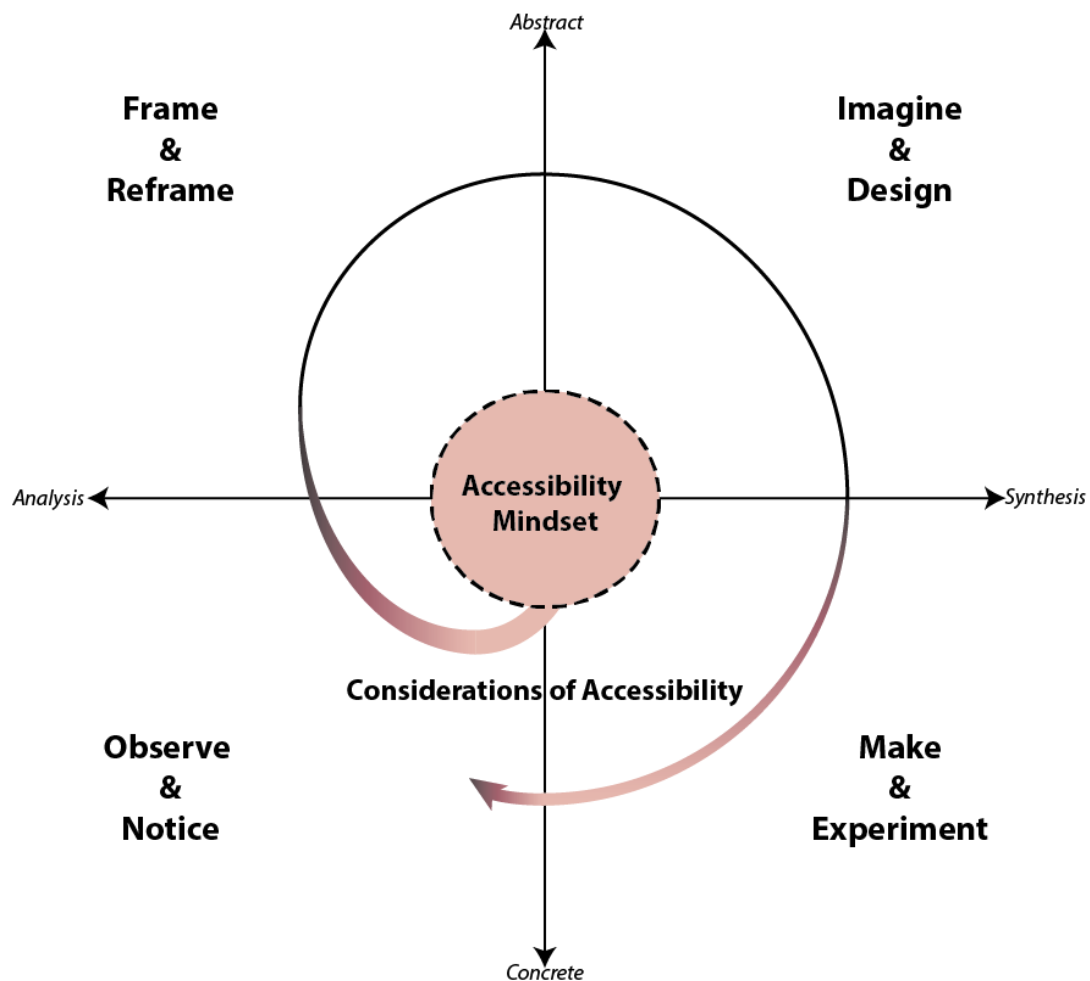


Figure 7-1. The iterative process of HCD for accessibility begins with an accessibility mindset. This mindset influences accessibility-minded research activities (*Observe and Notice*), which inform how the problem is framed (*Frame and Reframe*) and how ideas are generated (*Imagine and Design*). The ideas are then tested with accessibility in mind (*Make and Experiment*).

Design teams who seek to develop solutions to improve accessibility should consider adhering to the six criteria of HCD for accessibility presented in the first framework and

should consider adopting the process of HCD for accessibility presented in the second framework.

In Section 8.1 below, I summarize how I arrived at the creation of these two novel frameworks of HCD for accessibility. First, I summarize the findings and contributions of each case study. Then, I summarize how I carried out the comparative analysis across the two case studies. In Section 8.2, I propose future work that is needed to develop and validate the frameworks I have developed in this dissertation. Finally, in Section 8.3, I revisit the broader implications of this dissertation and I discuss how this work can be applied to other accessibility challenges outside of cervical cancer screening.

8.1 Summary and Contributions of Dissertation

Chapter 5: A Case Study of InVia Technologies

Chapter 5 presented a detailed account of InVia, an organization based in the United States (US) with the vision of leveraging technology towards health and societal benefit. I selected InVia as a case study for this dissertation based on the following considerations: InVia has created a cervical cancer screening program located in an LMIC (India) with a high burden of cervical cancer; InVia's cervical cancer screening program is still active today; and based on my preliminary conversations with InVia, I learned that InVia applied a human-centered approach to design their cervical cancer screening program. After selecting InVia as a case study, I then conducted research over a period of two years, including interviews with three co-founders, analysis of twelve pages of internal documentation, and 100 hours of in-person observation with the team in India and 50 hours of remote observation with the team's weekly meetings. I collected data in three categories: the context of the cervical cancer screening program, the process to create and implement the program, and the outcomes of the program. I then coded and analyzed this data to uncover how InVia conducted their design work and how they considered accessibility throughout their design process.

InVia began work in 2015 as part of an undergraduate class project to create ccScreen, their solution to improve access to cervical cancer screening in India. Eventually, InVia hopes to implement ccScreen in India and then expand their solution into other LMICs around the world. ccScreen is a technological solution that aims to automate and to improve the accuracy of the VIA cervical cancer screening method. InVia envisions that ccScreen will be used by community health workers (CHWs) in India who can use the ccScreen system to assist them in making accurate diagnoses of whether or not a patient has suspected precancerous cervical cells.

The ccScreen system was designed with accessibility in mind. The InVia team considered accessibility at five distinct points in their design process. Throughout these considerations, InVia addressed four of Petchansky and Thomas' five dimensions of accessibility [22]: *availability, accommodation, affordability, and physical accessibility*. InVia did not address the *acceptability* of ccScreen.

The InVia team followed a human-centered approach when designing ccScreen. The team spent time in all four phases of the Innovation Model [74]: *Observe and Notice, Frame and Reframe, Imagine and Design, and Make and Experiment*. Additionally, the team adhered to all six ISO HCD criteria [85]: *adoption of multidisciplinary skills and perspectives; explicit understanding of stakeholders, tasks and environments; stakeholder-centred evaluation driven/refined design; consideration of the whole stakeholder experience; involvement of stakeholders throughout design and development; and iterative process*.

The main contribution of Chapter 5 is that it presented an example of a technology-driven organization seeking to improve cervical cancer accessibility first in India and then around the world. The InVia team exemplified how teams can apply their technical skills to address a complex global challenge in a location different from where the team lives.

Chapter 6: A Case Study of Mujeres Móviles

Chapter 6 presented a detailed account of Mujeres Móviles, an organization based in Nicaragua with the vision of improving the health and well-being of women and girls across Nicaragua. I selected Mujeres Móviles as a case study for this dissertation based on the following considerations: Mujeres Móviles has created a cervical cancer screening program located in an LMIC (Nicaragua) with a high burden of cervical cancer; Mujeres Móviles' cervical cancer screening program is still active today; Mujeres Móviles' cervical cancer screening program has a different primary goal and approach to addressing cervical cancer screening access than InVia; and based on my preliminary conversations with Mujeres Móviles, I learned that Mujeres Móviles applied a human-centered approach to design and implement their cervical cancer screening program. After selecting Mujeres Móviles as a case study, I then conducted research over a period of one and a half years, including interviews with three co-founders and nine team members, analysis of 83 pages of internal documentation, and 100 hours of in-person observation with the team in Nicaragua. As with InVia, I collected data in three categories: the context of the cervical cancer screening program, the process to create and implement the program, and the outcomes of the program. I then coded and analyzed this data to uncover how Mujeres Móviles conducted their design work and how they considered accessibility throughout their design process.

Mujeres Móviles began work in 2013 to create the mobile cervical cancer clinic, their solution to improve access to cervical cancer screening in Nicaragua. Mujeres Móviles has implemented several iterations of their mobile cervical cancer clinic, and they hope to continue refining their solution to best meet the sexual and reproductive health needs of women and girls in Nicaragua. The mobile cervical cancer clinic aims to combine proactive outreach and sexual health education with cervical cancer screening and treatment to bring health to women in rural Nicaragua. The mobile cervical cancer clinic travels to rural communities in Nicaragua to provide both Pap smear and VIA, depending on the age and history of the patient. Mujeres Móviles nurses educate patients on cervical cancer screening and on women's health (e.g., menstruation and breast cancer). Mujeres Móviles then provides the patients with their screening results and provides treatment (i.e., cryotherapy) to patients during a separate visit.

The mobile cervical cancer clinic was designed with accessibility in mind. The Mujeres Móviles team considered accessibility at seven distinct points in their design process. Throughout these considerations, Mujeres Móviles addressed all five of Penchansky and Thomas' dimensions of accessibility [22]: *physical accessibility, accommodation, acceptability, availability, and affordability*.

The Mujeres Móviles team followed a human-centered approach when designing their solution. The team spent time in all four phases of the Innovation Model [74]: *Observe and Notice, Frame and Reframe, Imagine and Design, and Make and Experiment*. Additionally, the team adhered to all six ISO HCD criteria [85]: *adoption of multidisciplinary skills and perspectives; explicit understanding of stakeholders, tasks and environments; stakeholder-centred evaluation driven/refined design; consideration of the whole stakeholder experience; involvement of stakeholders throughout design and development; and iterative process*.

The main contribution of Chapter 6 is that it presented an example of a grassroots, community-based organization seeking to improve cervical cancer screening accessibility in their own community. The Mujeres Móviles team exemplified how teams can engage deeply on a topic with members of their community and deliver highly contextual services to best meet the needs of community members.

Chapter 7: Cross-Case Analysis

Chapter 7 presented a comparison of InVia and Mujeres Móviles. InVia and Mujeres Móviles are very different organizations, evidenced most visibly by (1) their relationship with technology: InVia has created a technological solution while Mujeres Móviles has created a solution that does not depend on a novel technology; (2) their embeddedness within their target implementation location: InVia plans to implement in India but lives in the US while Mujeres Móviles lives and has implemented in Nicaragua; and (3) their varying familiarity with a formal design process: InVia developed the idea for ccScreen

during a university design class while Mujeres Móviles developed the mobile cervical cancer clinic without any formal training in design. Additionally, InVia is a for-profit business and aims to sell ccScreen to clinicians while Mujeres Móviles is a non-profit organization and provides their services to women for free. ccScreen has not yet been implemented and InVia is preparing for clinical trials, while the mobile cervical cancer clinic has been implemented and Mujeres Móviles continues to evolve the mobile cervical cancer clinic in practice.

Although InVia and Mujeres Móviles are quite distinct in terms of their organizational structure and their choice to pursue a particular solution type, the organizations demonstrated a number of similarities. InVia and Mujeres Móviles both followed an HCD approach in creating their solution. While their processes were fairly similar, InVia spent more time building a functional version of ccScreen while Mujeres Móviles spent more time rapidly iterating and implementing several versions of the mobile cervical cancer clinic. Both organizations designed their solution with accessibility in mind and each organization addressed multiple dimensions of accessibility in creating their solution.

The similarities in InVia's and Mujeres Móviles' approaches led me to develop a set of five best practices of HCD for accessibility: *adopt an accessibility mindset, considering multiple dimensions of accessibility, research the existing barriers to accessibility, create a solution to address multiple barriers to accessibility, test the solution to see if it addresses accessibility, and refine the solution to better address accessibility*. I then applied these best practices to existing HCD frameworks (the ISO criteria [85] and the Innovation Model [74]) to create two new frameworks of HCD for accessibility. The first framework I developed proposed a set of criteria of HCD for accessibility and the second framework I developed proposed a process model of how to conduct HCD for accessibility. I closed this study upon completing my analysis and my comparison to extant literature. The frameworks I developed are emergent "hypotheses" I put forth for future study.

The main contribution of Chapter 7 is that it proposed two new frameworks of HCD for accessibility generated from a rigorous comparison of two in-depth case studies of InVia and Mujeres Móviles. These frameworks can be applied, evaluated, and continually developed going forward. I describe future work in Section 8.2 below.

8.2 Future Work in Human-Centered Design for Accessibility

The foundational research I have presented in this dissertation proposes a novel set of frameworks to understand the role of HCD in creating accessibility. Further work is needed to continue developing and validating the HCD for accessibility frameworks I have developed. I envision several future studies.

First, I recommend conducting an impact evaluation of InVia and Mujeres Móviles to assess how each organization's HCD for accessibility process contributed to the successes and failures in their outcomes. This evaluation would improve an understanding of how HCD contributes to metrics of accessibility.

Second, I recommend conducting additional case studies of different organizations working to improve access to cervical cancer screening, which would extend my current work to include a wider range of organizations, including established for-profits, foundations, US based non-profits, and multinational organizations. These additional case studies would improve the applicability of the HCD for accessibility frameworks to include a broader range of organization types.

Third, I recommend additional case studies of organizations that are working on a challenge other than cervical cancer screening, which would extend the applicability of my current work to include a broader range of accessibility-related issues. Accessibility-related issues include issues of health accessibility and more general issues of accessibility, as I discuss in Section 8.3 below. These additional case studies would further improve the applicability of the HCD for accessibility frameworks by including a broad range of applications.

8.3 Broader Implications of Human-Centered Design for Accessibility

While I have focused on health accessibility in this dissertation, accessibility itself is a much broader issue. As we continue to face complex global challenges — like addressing global hunger, navigating towards a clean energy future, and continuing to address basic water sanitation across the globe — we need to ask ourselves if the communities who need solutions the most can actually access the solutions that are developed. I have shown through the case studies of InVia and Mujeres Móviles how HCD can be applied with a specific focus on accessibility. I have proposed two new

frameworks to shift our understanding of what HCD is and how it can be applied to improve the accessibility of solutions developed.

In this dissertation, I have demonstrated that in order for HCD to create more broadly accessible solutions, HCD must better integrate a holistic understanding of accessibility. The two HCD for accessibility frameworks I have developed include accessibility as a core principle (Figure 2-12 is reprinted below). This revised vision of HCD can be applied not only to address global health equity and accessibility, but to address the many social equity and accessibility challenges facing our world now and in the future.

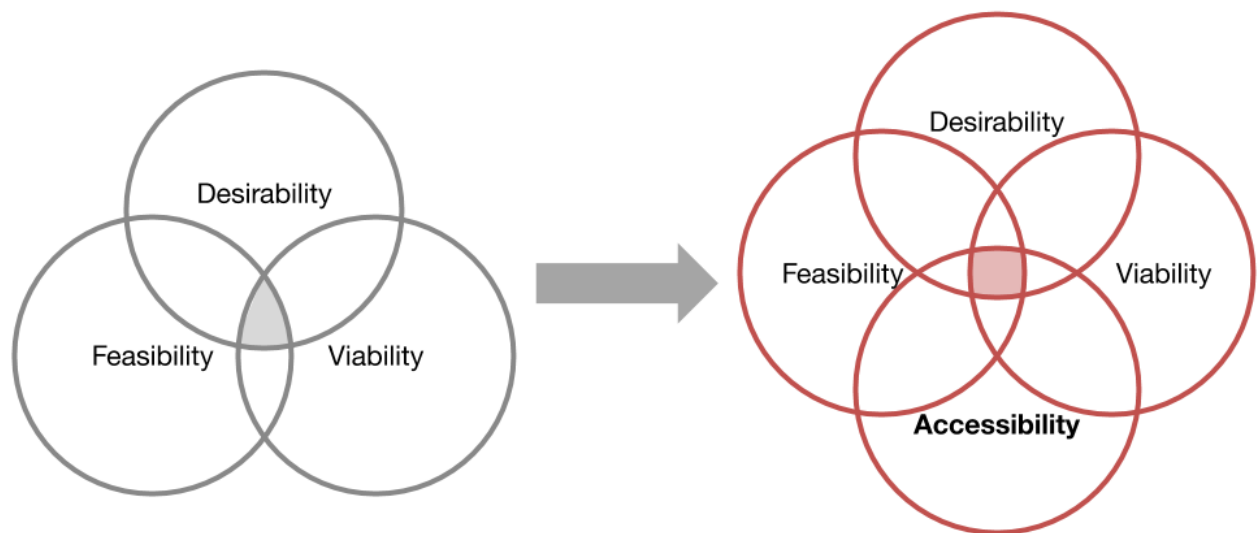


Figure 2-12. HCD with the addition of *accessibility* as a core principle. Source: figure created by the author, adapted from [76].

References

- [1] Y. Ji, Z. Ma, M. P. Peppelenbosch, and Q. Pan, "Potential association between COVID-19 mortality and health-care resource availability," *Lancet Glob. Health*, vol. 8, no. 4, p. e480, Apr. 2020, doi: 10.1016/S2214-109X(20)30068-1.
- [2] M. Lazzerini, E. Barbi, A. Apicella, F. Marchetti, F. Cardinale, and G. Trobia, "Delayed access or provision of care in Italy resulting from fear of COVID-19," *Lancet Child Adolesc. Health*, vol. 4, no. 5, pp. e10–e11, May 2020, doi: 10.1016/S2352-4642(20)30108-5.
- [3] World Health Organization (WHO), "WHO and Costa Rica preview technology pooling initiative to ensure access to COVID-19 health products for all," May 15, 2020.
<https://www.who.int/news-room/detail/15-05-2020-who-and-costa-rica-preview-technology-pooling-initiative-to-ensure-access-to-covid-19-health-products-for-all> (accessed Jul. 10, 2020).
- [4] World Health Organization (WHO), "WHO countries agree 'equitable and timely access' to coronavirus vaccine, 'comprehensive evaluation' of response," May 19, 2020. <https://news.un.org/en/story/2020/05/1064442> (accessed Jul. 10, 2020).
- [5] U. Johansson-Sköldberg, J. Woodilla, and M. Çetinkaya, "Design Thinking: Past, Present and Possible Futures," *Creat. Innov. Manag.*, vol. 22, no. 2, pp. 121–146, Jun. 2013, doi: 10.1111/caim.12023.
- [6] IDEO.org, "Tools." <https://www.ideo.org/tools> (accessed Feb. 21, 2020).
- [7] IDEO.org, "The Nail Salons Where Girls Can Safely Plan Their Futures." <https://www.ideo.org/project/diva-centres> (accessed Feb. 21, 2020).
- [8] US Agency for International Development (USAID), "Human-Centered Design," Aug. 06, 2018. <https://www.usaid.gov/cii/human-centered-design> (accessed Feb. 21, 2020).
- [9] US Agency for International Development (USAID) and Bill & Melinda Gates Foundation, "Design for Health." <https://www.designforhealth.org/> (accessed Jul. 10, 2020).
- [10] US Agency for International Development (USAID) and Dalberg, "Engage HCD." .
- [11] J. Kramer, "Human-Centered Design for Development: Characterizing the Research Landscape," University of California, Berkeley, 2016.
- [12] N. Li, J. Kramer, P. Gordon, and A. Agogino, "Co-author network analysis of human-centered design for development," *Des. Sci.*, vol. 4, p. e10, 2018, doi: 10.1017/dsj.2018.1.
- [13] L. Nilsson, T. Madon, and S. S. Sastry, "Toward a New Field of Development Engineering: Linking Technology Design to the Demands of the Poor," *Procedia Eng.*, vol. 78, pp. 3–9, 2014, doi: 10.1016/j.proeng.2014.07.032.
- [14] D. I. Levine, A. M. Agogino, and M. A. Lesniewski, "Design thinking in development engineering," *Int. J. Eng. Educ.*, vol. 32, no. 3, pp. 1396–1406, 2016.
- [15] United Nations (UN), "Millennium Development Goals," 2000.
<https://www.un.org/millenniumgoals/> (accessed Feb. 21, 2020).

- [16] United Nations (UN), "Sustainable Development Goals," 2015.
<https://sustainabledevelopment.un.org/> (accessed Feb. 21, 2020).
- [17] Centers for Disease Control (CDC), "Achievements in Public Health, 1900-1999: Control of Infectious Diseases," Jul. 30, 1999.
<https://www.cdc.gov/mmwr/preview/mmwrhtml/mm4829a1.htm/> (accessed Feb. 21, 2020).
- [18] Centers for Disease Control (CDC), "Ten Great Public Health Achievements --- Worldwide, 2001-2010," Jun. 24, 2011.
https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6024a4.htm?s_cid=mm6024a4_w (accessed Feb. 21, 2020).
- [19] Institute for Health Metrics and Evaluation (IHME), "GBD Compare," IHME, University of Washington, Seattle, WA, 2017. Accessed: Dec. 09, 2019. [Online]. Available: <http://ihmeuw.org/51nq>.
- [20] World Health Organization, "Health is a fundamental human right," Dec. 10, 2017.
<https://www.who.int/mediacentre/news/statements/fundamental-human-right/en/> (accessed Nov. 23, 2019).
- [21] R. M. Barber *et al.*, "Healthcare Access and Quality Index based on mortality from causes amenable to personal health care in 195 countries and territories, 1990–2015: a novel analysis from the Global Burden of Disease Study 2015," *The Lancet*, vol. 390, no. 10091, pp. 231–266, Jul. 2017, doi: 10.1016/S0140-6736(17)30818-8.
- [22] R. Penchansky and J. W. Thomas, "The concept of access: definition and relationship to consumer satisfaction," *Med. Care*, vol. 19, no. 2, pp. 127–140, Feb. 1981, doi: 10.1097/00005650-198102000-00001.
- [23] M. Arbyn *et al.*, "Estimates of incidence and mortality of cervical cancer in 2018: a worldwide analysis," *Lancet Glob. Health*, vol. 8, no. 2, pp. e191–e203, Feb. 2020, doi: 10.1016/S2214-109X(19)30482-6.
- [24] F. Bray, J. Ferlay, I. Soerjomataram, R. L. Siegel, L. A. Torre, and A. Jemal, "Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries," *CA. Cancer J. Clin.*, vol. 68, no. 6, pp. 394–424, 2018, doi: 10.3322/caac.21492.
- [25] World Health Organization (WHO), "WHO guidelines for screening and treatment of precancerous lesions for cervical cancer prevention," World Health Organization, 2013. Accessed: Dec. 09, 2019. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/94830/9789241548694_eng.pdf;jsessionid=24B70960795BBCC841452B8E2A681D08?sequence=1.
- [26] Gapminder.org, "Life expectancy versus Income." <https://bit.ly/2sbOdne> (accessed Jul. 10, 2020).
- [27] P. Braveman, "What are health disparities and health equity? We need to be clear," *Public Health Rep. Wash. DC* 1974, vol. 129 Suppl 2, pp. 5–8, Feb. 2014, doi: 10.1177/00333549141291S203.
- [28] World Health Organization (WHO), "About social determinants of health." https://www.who.int/social_determinants/sdh_definition/en/ (accessed Mar. 05, 2020).
- [29] J. W. Thomas and R. Penchansky, "Relating satisfaction with access to utilization

- of services," *Med. Care*, vol. 22, no. 6, pp. 553–568, Jun. 1984, doi: 10.1097/00005650-198406000-00006.
- [30] World Health Organization (WHO), "Human papillomavirus (HPV) and cervical cancer," Jan. 24, 2019.
[https://www.who.int/en/news-room/fact-sheets/detail/human-papillomavirus-\(hpv\)-and-cervical-cancer](https://www.who.int/en/news-room/fact-sheets/detail/human-papillomavirus-(hpv)-and-cervical-cancer) (accessed Dec. 03, 2019).
 - [31] Centers for Disease Control (CDC), "HPV Fact Sheet," Aug. 20, 2019.
<https://www.cdc.gov/std/hpv/stdfact-hpv.htm> (accessed Jul. 14, 2020).
 - [32] U.S. National Institute of Health (NIH), National Cancer Institute (NCI), "HPV and Cancer," Jan. 10, 2020.
<https://www.cancer.gov/about-cancer/causes-prevention/risk/infectious-agents/hpv-and-cancer> (accessed Jul. 14, 2020).
 - [33] World Health Organization (WHO), "Report on global sexually transmitted infection surveillance, 2018," World Health Organization, 2018. Accessed: Jul. 14, 2020. [Online]. Available:
<https://apps.who.int/iris/bitstream/handle/10665/277258/9789241565691-eng.pdf>.
 - [34] E. Petrosky *et al.*, "Use of 9-valent human papillomavirus (HPV) vaccine: updated HPV vaccination recommendations of the advisory committee on immunization practices," *MMWR Morb. Mortal. Wkly. Rep.*, vol. 64, no. 11, pp. 300–304, Mar. 2015.
 - [35] World Health Organization (WHO), "Human papillomavirus (HPV)," Mar. 2018.
<https://www.who.int/immunization/diseases/hpv/en/> (accessed Oct. 15, 2019).
 - [36] Centers for Disease Control and Prevention (CDC), "HPV Vaccine Recommendations," Dec. 15, 2016.
<https://www.cdc.gov/vaccines/vpd/hpv/hcp/recommendations.html> (accessed Oct. 15, 2019).
 - [37] M. Kohli *et al.*, "Estimating the long-term impact of a prophylactic human papillomavirus 16/18 vaccine on the burden of cervical cancer in the UK," *Br. J. Cancer*, vol. 96, no. 1, pp. 143–150, Jan. 2007, doi: 10.1038/sj.bjc.6603501.
 - [38] Centers for Disease Control and Prevention (CDC), "HPV Vaccine Safety and Effectiveness," Nov. 22, 2016.
<https://www.cdc.gov/vaccines/vpd/hpv/hcp/safety-effectiveness.html> (accessed Oct. 15, 2019).
 - [39] Mayo Clinic, "Pap smear," Jun. 25, 2020.
<https://www.mayoclinic.org/tests-procedures/pap-smear/about/pac-20394841> (accessed Jul. 14, 2020).
 - [40] U.S. National Institute of Health (NIH), National Cancer Institute (NCI), "HPV and Pap Testing," Dec. 20, 2019.
<https://www.cancer.gov/types/cervical/pap-hpv-testing-fact-sheet> (accessed Jul. 14, 2020).
 - [41] Mayo Clinic, "Colposcopy," Apr. 04, 2020.
<https://www.mayoclinic.org/tests-procedures/colposcopy/about/pac-20385036> (accessed Jul. 14, 2020).
 - [42] C. Sauvaget, J.-M. Fayette, R. Muwonge, R. Wesley, and R. Sankaranarayanan, "Accuracy of visual inspection with acetic acid for cervical cancer screening," *Int. J.*

- Gynecol. Obstet.*, vol. 113, no. 1, pp. 14–24, Apr. 2011, doi: 10.1016/j.ijgo.2010.10.012.
- [43] M. Arbyn *et al.*, “Worldwide burden of cervical cancer in 2008,” *Ann. Oncol.*, vol. 22, no. 12, pp. 2675–2686, Dec. 2011, doi: 10.1093/annonc/mdr015.
 - [44] L. Denny, M. Quinn, and R. Sankaranarayanan, “Chapter 8: Screening for cervical cancer in developing countries,” *Vaccine*, vol. 24, pp. S71–S77, Aug. 2006, doi: 10.1016/j.vaccine.2006.05.121.
 - [45] J. Sherris, C. Herdman, and C. Elias, “Cervical cancer in the developing world,” *West. J. Med.*, vol. 175, no. 4, pp. 231–233, Oct. 2001, doi: 10.1136/ewj.175.4.231.
 - [46] S. DeWeerd, “A global drive to eliminate cervical cancer,” *Nature Index*, Apr. 22, 2020.
 - [47] M. T. Hall *et al.*, “The projected timeframe until cervical cancer elimination in Australia: a modelling study,” *Lancet Public Health*, vol. 4, no. 1, pp. e19–e27, Jan. 2019, doi: 10.1016/S2468-2667(18)30183-X.
 - [48] S. Cousins, “Why Rwanda could be the first country to wipe out cervical cancer,” May 30, 2019.
 - [49] A. L. Beavis, P. E. Gravitt, and A. F. Rositch, “Hysterectomy-corrected cervical cancer mortality rates reveal a larger racial disparity in the United States: Corrected Cervix Cancer Mortality Rates,” *Cancer*, vol. 123, no. 6, pp. 1044–1050, May 2017, doi: 10.1002/cncr.30507.
 - [50] World Health Organization (WHO), Ed., *Cervical cancer screening in developing countries: report of a WHO consultation*. Geneva: World Health Organization, 2002.
 - [51] World Health Organization (WHO), *Comprehensive cervical cancer control: a guide to essential practice*. 2014.
 - [52] D. Sipp, I. H. Frazer, and J. E. J. Rasko, “No Vacillation on HPV Vaccination,” *Cell*, vol. 172, no. 6, pp. 1163–1167, Mar. 2018, doi: 10.1016/j.cell.2018.02.045.
 - [53] J. Wigle, E. Coast, and D. Watson-Jones, “Human papillomavirus (HPV) vaccine implementation in low and middle-income countries (LMICs): Health system experiences and prospects,” *Vaccine*, vol. 31, no. 37, pp. 3811–3817, Aug. 2013, doi: 10.1016/j.vaccine.2013.06.016.
 - [54] H. A. Simon, *The Sciences of the Artificial*. Cambridge, Mass.: MIT Press, 1969.
 - [55] D. A. Schön, *The reflective practitioner: how professionals think in action*. New York: Basic Books, 1983.
 - [56] R. Buchanan, “Wicked Problems in Design Thinking,” *Des. Issues*, vol. 8, no. 2, p. 5, 1992, doi: 10.2307/1511637.
 - [57] H. W. J. Rittel and M. M. Webber, “Dilemmas in a general theory of planning,” *Policy Sci.*, vol. 4, no. 2, pp. 155–169, Jun. 1973, doi: 10.1007/BF01405730.
 - [58] Lawson, *How Designers Think*, 4th ed. Routledge, 2006.
 - [59] N. Cross, *Design thinking: understanding how designers think and work*, Engl. ed. Oxford: Berg, 2011.
 - [60] N. Cross, “Designerly Ways of Knowing: Design Discipline Versus Design Science,” *Des. Issues*, vol. 17, no. 3, pp. 49–55, Jul. 2001, doi: 10.1162/074793601750357196.

- [61] K. Krippendorff, *The semantic turn a new foundation for design*. Boca Raton: Taylor & Francis, 2006.
- [62] T. Brown, "Design thinking," *Harv. Bus. Rev.*, vol. 86, no. 6, Jun. 2008.
- [63] T. Brown and B. Katz, *Change by design: how design thinking transforms organizations and inspires innovation*, 1st ed. New York: Harper Business, 2009.
- [64] T. Kelley and J. Littman, *The art of innovation: lessons in creativity from IDEO, America's leading design firm*, 1st ed. New York: Currency/Doubleday, 2001.
- [65] T. Kelley and J. Littman, *The ten faces of innovation: IDEO's strategies for beating the devil's advocate & driving creativity throughout your organization*. New York: Currency/Doubleday, 2005.
- [66] D. Dunne and R. Martin, "Design Thinking and How It Will Change Management Education: An Interview and Discussion," *Acad. Manag. Learn. Educ.*, vol. 5, no. 4, pp. 512–523, Dec. 2006, doi: 10.5465/amle.2006.23473212.
- [67] R. L. Martin, *The design of business: why design thinking is the next competitive advantage*. Boston, Mass: Harvard Business Press, 2009.
- [68] R. Boland and F. Collopy, Eds., *Managing as designing*. Stanford, CA: Stanford Business Books, 2004.
- [69] R. Buchanan, "Human Dignity and Human Rights: Thoughts on the Principles of Human-Centered Design," *Des. Issues*, vol. 17, no. 3, pp. 35–39, Jul. 2001, doi: 10.1162/074793601750357178.
- [70] J. Giacomini, "What Is Human Centred Design?," *Des. J.*, vol. 17, no. 4, pp. 606–623, Dec. 2014, doi: 10.2752/175630614X14056185480186.
- [71] M. Steen, "Human-Centered Design as a Fragile Encounter," *Des. Issues*, vol. 28, no. 1, pp. 72–80, Jan. 2012, doi: 10.1162/DESI_a_00125.
- [72] E. Reynolds Brubaker, C. Jensen, S. Silungwe, S. Sheppard, and M. Yang, "Co-Design in Zambia - An Examination of Design Outcomes," in *Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 1: Resource-Sensitive Design | Design Research Applications and Case Studies*, Vancouver, Canada, 25.08 2017, pp. 259–268.
- [73] M. K. Harder, G. Burford, and E. Hoover, "What Is Participation? Design Leads the Way to a Cross-Disciplinary Framework," *Des. Issues*, vol. 29, no. 4, pp. 41–57, Oct. 2013, doi: 10.1162/DESI_a_00229.
- [74] S. L. Beckman and M. Barry, "Innovation as a Learning Process: Embedding Design Thinking," *Calif. Manage. Rev.*, vol. 50, no. 1, pp. 25–56, Oct. 2007, doi: 10.2307/41166415.
- [75] IDEO, "About IDEO." <https://www.ideo.com/about> (accessed Feb. 20, 2020).
- [76] IDEO, "Design Thinking Defined." <https://designthinking.ideo.com/> (accessed Jul. 10, 2020).
- [77] IDEO, "Creating the First Usable Mouse." <https://www.ideo.com/case-study/creating-the-first-usable-mouse> (accessed Feb. 20, 2020).
- [78] A. Ha, "Design Firm Adaptive Path Acquired by Capital One," *TechCrunch*, Oct. 02, 2014.
- [79] McKinsey & Company, "Landing LUNAR," Jun. 01, 2015. <https://www.mckinsey.com/about-us/new-at-mckinsey-blog/landing-lunar> (accessed

- Feb. 20, 2020).
- [80] E. Kim, "Salesforce adds to its \$4 billion spending spree by quietly buying another company," *Business Insider*, Sep. 14, 2016.
 - [81] IBM, "IBM Design Research." <https://www.ibm.com/design/research/> (accessed Jul. 10, 2020).
 - [82] Kaiser Permanente, "Garfield Innovation Center." <https://garfieldcenter.kaiserpermanente.org/> (accessed Jul. 30, 2020).
 - [83] University of California, San Francisco (UCSF), "UCSF Clinical Innovation Center." <https://cic.ucsf.edu/home> (accessed Jul. 10, 2020).
 - [84] U.S. Office of Personnel Management (OPM), "Lab OPM." <https://lab.opm.gov/> (accessed Jul. 10, 2020).
 - [85] International Organization for Standardization (ISO), "ISO 9241-210: Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems," 2010.
 - [86] A. Salter and B. S. Tether, "Innovation in Services: Through the Looking Glass of Innovation Studies," Advanced Institute of Management (AIM) Research, Apr. 2006.
 - [87] L. Kimbell, "From user-centred design to designing for service," presented at the Design Management Conference, London, 2010, Accessed: Jul. 15, 2020. [Online]. Available: http://www.lucykimbell.com/stuff/DMI2010_kimbell_draft.pdf.
 - [88] L. Kimbell, "The turn to service design," *Des. Creat. Policy Manag. Pract.*, pp. 157–173, 2009.
 - [89] P. G. Yock, Ed., *Biodesign: the process of innovating medical technologies*, Second edition. Cambridge ; New York: Cambridge University Press, 2015.
 - [90] M. Altman, T. T. K. Huang, and J. Y. Breland, "Design Thinking in Health Care," *Prev. Chronic. Dis.*, vol. 15, p. 180128, Sep. 2018, doi: 10.5888/pcd15.180128.
 - [91] A. N. Bazzano, J. Martin, E. Hicks, M. Faughnan, and L. Murphy, "Human-centred design in global health: A scoping review of applications and contexts," *PLOS ONE*, vol. 12, no. 11, p. e0186744, Nov. 2017, doi: 10.1371/journal.pone.0186744.
 - [92] J. Vechakul, B. P. Shrimali, and J. S. Sandhu, "Human-Centered Design as an Approach for Place-Based Innovation in Public Health: A Case Study from Oakland, California," *Matern. Child Health J.*, vol. 19, no. 12, pp. 2552–2559, Dec. 2015, doi: 10.1007/s10995-015-1787-x.
 - [93] C. Catalani *et al.*, "A Clinical Decision Support System for Integrating Tuberculosis and HIV Care in Kenya: A Human-Centered Design Approach," *PLoS ONE*, vol. 9, no. 8, p. e103205, Aug. 2014, doi: 10.1371/journal.pone.0103205.
 - [94] J. van Hoof *et al.*, "Exploring Innovative Solutions for Quality of Life and Care of Bed-Ridden Nursing Home Residents through Codesign Sessions," *J. Aging Res.*, vol. 2015, pp. 1–14, 2015, doi: 10.1155/2015/185054.
 - [95] IDEO, "Health and Wellness." <https://www.ideo.com/work/health-wellness> (accessed Jul. 16, 2020).
 - [96] frog design, "Healthcare." <https://www.frogdesign.com/sector/healthcare-service-strategy> (accessed Jul. 16, 2020).
 - [97] Dalberg Design, "What do we do?" <http://www.dalbergdesign.com/work> (accessed

- Jul. 16, 2020).
- [98] M. J. Roy, C. Donaldson, R. Baker, and S. Kerr, "The potential of social enterprise to enhance health and well-being: A model and systematic review," *Soc. Sci. Med.*, vol. 123, pp. 182–193, Dec. 2014, doi: 10.1016/j.socscimed.2014.07.031.
 - [99] Design for Health, "About Us." <https://www.designforhealth.org/new-page-99> (accessed Jul. 16, 2020).
 - [100] T. Brown, "Why You Should Talk Less and Do More," Oct. 30, 2013. <https://designthinking.ideo.com/blog/why-you-should-talk-less-and-do-more> (accessed Jul. 16, 2020).
 - [101] Design for Health, "Common Principles of Design & Global Health." <https://www.designforhealth.org/design-principles-in-global-health> (accessed Mar. 06, 2020).
 - [102] I. Holeman and D. Kane, "Human-centered design for global health equity," *Inf. Technol. Dev.*, vol. 26, no. 3, pp. 477–505, Jul. 2020, doi: 10.1080/02681102.2019.1667289.
 - [103] H. Persson, H. Åhman, A. A. Yngling, and J. Gulliksen, "Universal design, inclusive design, accessible design, design for all: different concepts—one goal? On the concept of accessibility—historical, methodological and philosophical aspects," *Univers. Access Inf. Soc.*, vol. 14, no. 4, pp. 505–526, Nov. 2015, doi: 10.1007/s10209-014-0358-z.
 - [104] M. F. Story, "Maximizing Usability: The Principles of Universal Design," *Assist. Technol.*, vol. 10, no. 1, pp. 4–12, Jun. 1998, doi: 10.1080/10400435.1998.10131955.
 - [105] Visualize, Inc., "Visualize." <http://www.visualizecc.org/> (accessed Jul. 10, 2020).
 - [106] K. H. Sienko, E. E. Kaufmann, M. E. Musaaazi, A. Sabet Sarvestani, and S. Obed, "Obstetrics-based clinical immersion of a multinational team of biomedical engineering students in Ghana," *Int. J. Gynecol. Obstet.*, vol. 127, no. 2, pp. 218–220, Nov. 2014, doi: 10.1016/j.ijgo.2014.06.012.
 - [107] I. Mohedas, S. Daly, and K. Sienko, "Design Ethnography in Capstone Design: Investigating Student Use and Perceptions," *Int. J. Eng. Educ.*, vol. 30, no. 4, pp. 888–900, 2014.
 - [108] B. N. L. Calys-Tagoe, J. M. K. Aheto, G. Mensah, R. B. Biritwum, and A. E. Yawson, "Cervical cancer screening practices among women in Ghana: evidence from wave 2 of the WHO study on global AGEing and adult health," *BMC Womens Health*, vol. 20, no. 1, p. 49, Dec. 2020, doi: 10.1186/s12905-020-00915-9.
 - [109] M. R. Young, J. M. Kramer, J. B. Chu, J. V. Hong, K. H. Sienko, and C. M. Johnston, "A Cervical Cancer Screening Trainer for Use in Low-Resource Settings," *Int. J. Serv. Learn. Eng. Humanit. Eng. Soc. Entrep.*, vol. 11, no. 1, pp. 1–18, Jun. 2016, doi: 10.24908/ijlsle.v11i1.6323.
 - [110] The Center for Theory of Change, "What is Theory of Change?" <https://www.theoryofchange.org/what-is-theory-of-change/> (accessed Feb. 18, 2020).
 - [111] R. K. Yin, *Case study research: design and methods*, Fifth edition. Los Angeles: SAGE, 2014.
 - [112] K. M. Eisenhardt, "Building Theories from Case Study Research," *Acad. Manage.*

- Rev., vol. 14, no. 4, pp. 532–550, Oct. 1989, doi: 10.5465/amr.1989.4308385.
- [113] Al Jazeera News, “Nicaragua unrest: What you should know,” *Al Jazeera*, Jul. 17, 2018.
 - [114] The World Bank, “Population, total,” *The World Bank*, 2018.
https://data.worldbank.org/indicator/sp.pop.totl?most_recent_value_desc=true
 (accessed Apr. 14, 2020).
 - [115] The World Bank, “GDP (current US\$),” *The World Bank*, 2018.
https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?most_recent_value_desc=true
 (accessed Apr. 14, 2020).
 - [116] J. Hickel, “How Britain stole \$45 trillion from India,” *Al Jazeera*, Dec. 19, 2018.
 - [117] B. Henderson, “Indian Independence Day: everything you need to know about Partition between India and Pakistan 70 years on,” *The Telegraph*, Aug. 15, 2017.
 - [118] Institute for Health Metrics and Evaluation (IHME), “GBD Compare: India,” IHME, University of Washington, Seattle, WA, 2017. Accessed: Dec. 09, 2019. [Online]. Available: <https://vizhub.healthdata.org/gbd-compare/#>.
 - [119] I. Gupta and M. Bhatia, “The Indian Health Care System,” *The Commonwealth Fund*. <https://international.commonwealthfund.org/countries/india/> (accessed Apr. 14, 2020).
 - [120] Global Health Data Exchange, “Socio-demographic Index (SDI),” *Institute for Health Metrics and Evaluation (IHME)*, Mar. 31, 2019.
<http://ghdx.healthdata.org/record/ihme-data/gbd-2015-socio-demographic-index-sdi-1980–2015> (accessed Apr. 14, 2020).
 - [121] J. Ferlay *et al.*, “Global Cancer Observatory: Cancer Today,” International Agency for Research on Cancer, Lyon, France, 2018. Accessed: Apr. 14, 2020. [Online]. Available: <https://gco.iarc.fr/today/>.
 - [122] N. Kaka *et al.*, “Digital India: Technology to transform a connected nation,” McKinsey Global Institute, Mar. 2019. Accessed: Apr. 26, 2020. [Online]. Available: <https://www.mckinsey.com/~media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Digital%20India%20Technology%20to%20transform%20a%20connected%20nation/MGI-Digital-India-Report-April-2019.ashx>.
 - [123] VentureWell, “Lean Launchpad.” <https://venturewell.org/lean-launchpad/> (accessed Jul. 10, 2020).
 - [124] P. Blumenthal, “Visual Inspection of the Cervix Flash Card Set,” Jhpiego, 2003. Accessed: Mar. 07, 2020. [Online]. Available: http://resources.jhpiego.org/system/files/resources/cecap_flashcards_0.pdf.
 - [125] Unique Identification Authority of India, “What is Aadhaar,” *Unique Identification Authority of India, Government of India*, Jan. 24, 2019.
<https://uidai.gov.in/what-is-aadhaar.html> (accessed Apr. 26, 2020).
 - [126] A. Bingham *et al.*, “Factors affecting utilization of cervical cancer prevention services in low-resource settings,” *Salud Pública México*, vol. 45, pp. 408–416, 2003, doi: 10.1590/S0036-36342003000900015.
 - [127] R. Arguello, B. Nietschmann, M. S. Orozco, F. D. Parker, and T. W. Walker, “Nicaragua,” *Encyclopædia Britannica*. Encyclopædia Britannica, inc., Mar. 21, 2020, Accessed: May 05, 2020. [Online]. Available: <https://www.britannica.com/place/Nicaragua>.

- [128] The World Bank, “Nicaragua,” *The World Bank*, 2018.
<https://data.worldbank.org/country/nicaragua> (accessed May 05, 2020).
- [129] BBC News, “Nicaragua country profile,” *BBC News*, May 31, 2018.
- [130] M. Sequeira, H. Espinoza, J. J. Amador, G. Domingo, M. Quintanilla, and T. de los Santos, “The Nicaraguan Health System,” PATH, Seattle, WA, 2011. Accessed: Apr. 28, 2020. [Online]. Available:
<https://path.azureedge.net/media/documents/TS-nicaragua-health-system-rpt.pdf>.
- [131] M. Jarquín and K. M. Thaler, “Two years after Nicaragua’s mass uprising started, why is Daniel Ortega still in power?,” *The Washington Post*, May 01, 2020.
- [132] Institute for Health Metrics and Evaluation (IHME), “GBD Compare: Nicaragua,” IHME, University of Washington, Seattle, WA, 2017. Accessed: Dec. 09, 2019. [Online]. Available: <http://ihmeuw.org/53rv>.
- [133] I. Mathauer, E. Cavagnero, G. Vivas, and G. Carrin, “Health financing challenges and institutional options to move towards universal coverage in Nicaragua,” World Health Organization, Background Paper 24, 2010. Accessed: Apr. 28, 2020. [Online]. Available:
<https://www.who.int/healthsystems/topics/financing/healthreport/24Nicaragua.pdf>.
- [134] A. Fitzpatrick and R. Thornton, “The Effects of Health Insurance within Families: Experimental Evidence from Nicaragua,” World Bank, Policy Research Working Paper 8115, 2017. Accessed: Apr. 28, 2020. [Online]. Available:
<https://openknowledge.worldbank.org/handle/10986/27613>.
- [135] R. L. Thornton, L. E. Hatt, E. M. Field, M. Islam, F. Solís Diaz, and M. A. González, “Social security health insurance for the informal sector in Nicaragua: a randomized evaluation,” *Health Econ.*, vol. 19, no. S1, pp. 181–206, Sep. 2010, doi: 10.1002/hec.1635.
- [136] The World Bank, “Tackling Teenage Pregnancy by Enhancing Youth Socioeconomic Opportunities in Nicaragua,” The World Bank, 136882, May 2019. Accessed: May 18, 2020. [Online]. Available:
<http://documents.worldbank.org/curated/en/118641557834881604/pdf/Tackling-Teenage-Pregnancy-by-Enhancing-Youth-Socioeconomic-Opportunities-in-Nicaragua-Completion-Report.pdf>.