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Centering Culture in Health:

Developing Culturally Safe Technology for Early Childhood Health Promotion,

A community-based approach to technology design for child development support

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Abstract

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Chair of the Supervisory Committee:

Associate Professor Julie A. Kientz

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My dissertation investigates the potential of health technologies to improve child health outcomes while emphasizing diversity and equity. I explore both how mobile health interventions can be beneficial for parents and caregivers, and the potential risks if these technologies are not designed to be equitable and inclusive, drawing on prior work across the design of technologies created for parenting, child development, and early childhood health promotion. I explore the application of cultural safety, an approach to health services delivery, to sensitize technologies to the experiential differences between diverse children and families. My research highlights how current design and research practices often overlook the diverse experiences and contexts of families from diverse cultural backgrounds by surveying existing technologies and connecting with parents. I then demonstrate how we can integrate cultural safety into our practices by developing a heuristic evaluation method and collaborating with local parent communities to create a technology prototype that integrates the cultural safety approach. Overall, my dissertation offers a new lens for improving early childhood health technologies. By practicing cultural safety, we can ensure more equitable health outcomes for marginalized children and families by respecting the diversity of human experiences.

Acronyms

ecHPT = Early Childhood Health Promotion Technology
HTP = Heuristics for Technologies used by Parents
CBR = Community-Based Research
CAB = Community Advisory Board
PD = Participatory Design
HCI = Human-Computer Interaction
HCD = Human-Centered Design

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Dedication

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Chapter 1: Introduction

Technology-based health interventions have the potential to be powerful tools in reducing disparities in child development. They have already demonstrated impact through increasing access to healthcare resources, improving care coordination, and empowering parents and caregivers with knowledge. Further, the scalability and affordability of these technologies, particularly mobile health, mean that they can reach wider populations sooner. This widespread adoption could significantly advance early childhood health outcomes globally.

However, these technologies could also contribute to health inequities if not designed with inclusivity in mind, particularly for marginalized communities. Existing studies have highlighted potential risks such as exacerbating health disparities due to technology access and literacy barriers (Smith & Magnani, 2019), perpetuating algorithmic biases and harms (Khera et al., 2023), overburdening the existing healthcare infrastructure (Willems et al., 2021), and raising concerns over data privacy (Galvin & DeMuro, 2020). In the Human-Computer Interaction (HCI) field, while there is a strong push for making technology more inclusive for diverse cultural backgrounds through globalization, these approaches have focused on creating technologies that provide experiences based on very narrow views of culture. Relying on simple cultural classifications can lead to stereotyping and may not accurately reflect the diversity within cultures. For example, researchers have used approaches that classify cultures along different dimensions (e.g., Hofstede's cultural dimensions theory (Hofstede et al., 2005), and then suggest specific design changes that align with those dimensions.

However, these approaches fail to consider the diversity of people within cultures. By externally deciding for people in those cultures how their culture is classified, and then deciding how to design based on that classification, we risk imposing a limited and potentially inaccurate representation of their cultural experiences onto them. Hofstede's approach and others risk assuming that technology created using those classifications will be effective for anyone within those cultures, which is unlikely based on the diversity of people within cultures. To create technologies that are truly inclusive and effective for diverse communities, we need to move beyond these simplistic cultural classifications. Instead, we should engage in a more nuanced and participatory approach that considers the full range of diversity within cultures and empowers individuals to shape their technology experiences.

Medical researchers, technologists, private companies, government, and global health institutions are working to develop technologies that can support early childhood health (Hall & Bierman, 2015). By working together, these organizations can create more effective, ethical, and equitable early childhood health technologies. Given the immense potential benefits, it is crucial to ensure that these technologies are designed and implemented in ways that prevent furthering health inequity. Since these technologies are already being utilized by parents (Jeong et al., 2021), and recommended by health professionals and health systems (Richardson et al., 2019), and there is a push for innovation in this space (Montazami et al., 2022), it is imperative to carefully consider the ethical implications of these systems and work proactively to address them. My dissertation specifically addresses the limitation of existing cultural frameworks, like

Hofstede's, which rely on broad classifications that may miss the nuances of diverse experiences within cultures.

Unlike Hofstede's framework, which assigns broad guidance for cultural considerations, I move beyond concepts like cultural scores or averages and delve into the rich nuances of experiences within cultures. Further, Hofstede's model informs design based on pre-determined categories, which risks overlooking the specific needs and perspectives of marginalized communities. Instead, I prioritize social justice and health equity by directly engaging with marginalized communities in King County, Washington, directly partnering with families to understand their specific needs and contexts. This human-centered approach will inform the design of health technologies that are truly inclusive and culturally safe. This approach also empowers these communities to actively shape the technology in response to their needs. For example, involving parents in the design process can help identify potential biases in language or functionalities that might exclude certain communities. Overall, my research aims to contribute to the creation of mobile health technologies that are effective and beneficial for all children and families, regardless of their backgrounds.

This dissertation examines the potential of health technologies to improve child health outcomes by assisting and guiding parents. I explore how mobile-based systems, for example, mobile apps, texting programs, mobile-optimized websites, or chatbots, can be beneficial, while also exploring how certain technologies may worsen disparities if not accessible to and meaningful for marginalized families. Additionally, I investigate how current approaches to technology research and design, and the content of technologies themselves, contribute to a view of technology and healthcare that overlooks the knowledge, experience, and context of families. This lack of cultural safety can lead to technologies that are not only less effective but also potentially harmful to the communities they aim to support.

Based on my experiences working directly with parents in King County, Washington, I have witnessed firsthand the impact of cultural safety and the importance of ensuring that health technologies are designed with an understanding of diverse family contexts. Given that the goal of the health technology field is to develop universally accessible technologies, adopting cultural safety as an approach to research and design can help identify and resolve the tensions that may arise, ensuring the ethical application of technology for early childhood health support. My work aims to emphasize that for early childhood health technologies to truly improve health outcomes, they need to be designed with equity and cultural safety in mind, which means acknowledging the complexities of families' lived experiences.

1.1 Cultural Safety as a Guiding Principle

My interest in cultural safety stems from its critical theoretical perspective that highlights power imbalances and social inequities within the healthcare system. It emphasizes the importance of addressing issues such as culturalism, racialization, and promoting social justice. The concept of cultural safety was first developed by Māori nurse leaders and educators in New Zealand in the early 1990s. It aimed to transform the training of health professionals by providing them with a deeper understanding of the impact of colonial structures on Māori communities, ultimately leading to healthcare practices that empower and respect Māori people (Dyck & Kearns, 1995).

I am particularly interested in how cultural safety can inform technology design. Current approaches often focus on making technology culturally relevant by assuming that people from the same culture will adopt the same technology. However, cultural safety challenges this assumption by emphasizing the importance of creating culturally safe environments that respect and affirm the unique experiences and identities of diverse cultural groups. I believe that we can design technology to understand and respond to differences between people in the same cultural backgrounds. By considering individual variations within cultural groups, we can create technologies that are more inclusive and adaptable to diverse needs. Further, technology can create a space where people from diverse cultural backgrounds feel that their unique perspectives, experiences, and knowledge are valued. This requires a deep understanding of cultural diversity and a commitment to designing technologies that are sensitive to and inclusive of all cultural groups. By incorporating principles of cultural safety into technology design, we can create experiences that affirm and empower individuals from diverse backgrounds. This approach acknowledges the complexities of identity and context that shape how people engage with technology and contributes to more equitable and effective health interventions.

Families are particularly interesting when thinking about cultural diversity. The concept of "family" varies widely across cultures, with different definitions, structures, and expectations shaping how people understand and experience family life. In some cultures, extended families with multiple generations living together are common (Klokker & Jaeger, 2022) while others consider nuclear families with parents and children normal (Sarkisian & Gerstel, 2012). Some cultures embrace single-parent households or blended families more readily than others as well (Chiu & McBride-Chang, 2010). Cultural expectations can also define how families' function, with clear hierarchies and roles in some spaces, and more egalitarian approaches in others (Sillars, 1995). These diverse family structures and dynamics are shaped by cultural values surrounding practices like religion, education, discipline, and communication.

As families become increasingly multilingual, communication styles can vary across languages and cultures, adding another layer of complexity to family interactions. This diversity within families is deeply connected to child development and has significant implications for a child's sense of self, identity, and cognitive growth. A child's cultural background plays a strong role in shaping their sense of self, and exposure to different traditions, languages, and values within the family can help them understand their personal heritage and develop a unique identity (Lau & Yeung, 1996). Children raised in culturally diverse families also learn how to navigate different social norms and communication styles, which can stimulate their cognitive development, making them more flexible thinkers, adaptable to new situations, and better problem solvers (Legare et al., 2018). Further, when a child's cultural background is valued and celebrated within the family, it improves their self-esteem and confidence, as they feel a sense of belonging and security in their identity (Spencer, 1984). By acknowledging and affirming the diverse cultural influences within a family, we can support better child development outcomes by providing health recommendations that are aligned with their lived experiences.

As we continue to create technologies for promoting child development, it is crucial to consider the specific contexts in which families use these technologies. Cultural backgrounds are not monolithic, and within a single group, families may have diverse socioeconomic situations, religious beliefs, or languages spoken at home, for example. Failure to consider this richness of experience risks widening existing disparities and further marginalizing communities by creating technologies that exclude them. By adopting approaches that focus on respect, equity, and dismantling power imbalances between health systems, technology, and families, we can transform how these technologies address disparities in child development. Cultural safety provides valuable guidelines for creating healthcare spaces that empower patients and make them feel respected, trusted, and heard. I believe these guidelines can be extended to the design of health technologies as well. Further, we should engage in a more nuanced and participatory approach that considers the full range of diversity within cultures and across cultures, as well as the unique needs and contexts of individual families, and empowers them to shape their experiences with technology. This could involve collaborating with diverse groups of people during the research and design process, actively soliciting their input and feedback, and designing interfaces and content that are adaptable and can be tailored to affirm and celebrate the diversity of cultural backgrounds, individual needs, and family needs.

My dissertation proposes using cultural safety as a research and design approach to create technologies that center families and their unique needs. I demonstrate that cultural safety is highly compatible with the human-centered design process, which already emphasizes empathy, inclusivity, and human-centeredness. By incorporating cultural safety principles, we can further sensitize researchers and designers to the complexities of identity and context that influence how families engage with and benefit from technology. To integrate this approach, I have engaged with both academic and industry technologies for early childhood health promotion, as well as with parents in a local community and technology designers and researchers. This multifaceted approach has provided valuable insights into the diverse needs and experiences of families and has informed the development of culturally safe technology design practices.

1.2 Community-Based Research and Marginalized Communities

Community-based research (CBR) methods, such as participatory design and co-design, allow for deeper conversations about the social, cultural, and environmental factors that influence people's behaviors and needs (Israel et al., 2017). By engaging with people in their own environments, these methods help researchers understand the contextual nuances of how individuals interact with their communities and the tools they use for support (Satcher, 2005). Traditional research methods that do not capture these contextual nuances are likely to miss key aspects of people's experiences related to technology use. Furthermore, community-based research emphasizes the empowerment of people through collaborative processes, which can lead to more authentic insights and a stronger sense of community ownership. This increased sense of ownership can enhance the adoption and integration of technology within a community (Harrington et al., 2019). By involving people directly in research and design from the beginning, solutions become more relevant to their actual needs and contexts, leading to more effective and equitable technologies; I used the CBR approach in my dissertation to uphold these values.

1.3 Research Questions

To ensure that early childhood health technologies are highly effective for diverse communities, there is a need to consider approaches that are different from current practices. Relying on existing models that have not adequately addressed inequities may actually widen disparities and further marginalize certain groups. My dissertation encourages researchers and designers to embrace cultural safety as a guiding principle for researching and designing technologies with diversity, intersectionality, and equity in mind. By centering on cultural safety, we can create a framework that acknowledges the complexities of identity and context, and ensures that the needs, beliefs, and values of all families are considered.

In this dissertation, I empirically document the impact of engaging with cultural safety in the research process, design process, interface, and content of an early childhood health technology. This evidence-based approach will provide concrete examples and insights to guide others in implementing cultural safety practices. My dissertation provides guidelines for conducting research that promotes cultural safety and for creating and evaluating culturally safe technologies. These guidelines will be based on a thorough analysis of existing literature and case studies.

My dissertation centers on these research questions:

1. **How do health technologies risk perpetuating child development inequities if they do not consider the unique contexts, needs, and values of families?** This question highlights the potential harm that can occur when technologies are developed without a deep understanding of the diverse realities of child development. Failing to account for the specific experiences and beliefs of different families can lead to technologies that are less effective or even actively harmful for certain groups.
2. **How can cultural safety be integrated throughout the design and research processes of health promotion technologies?** This question addresses the practical challenges of applying cultural safety principles in the real-world development of technologies. It will explore strategies for ensuring that cultural safety is not just a goal, but guiding principles at every stage of the research and design process.
3. **In what ways does community-based research (CBR) promote cultural safety in research engagements with marginalized populations?** This question investigates a specific approach to community participation in research that has proven effective in many fields, particularly in the health field. CBR emphasizes partnerships with communities, empowering local voices and knowledge.
4. How can a cultural safety approach:
    a. **Prevent health technologies from perpetuating health inequity:** By proactively identifying and addressing potential biases and gaps in the research and design, we can ensure that technologies do not inadvertently reinforce

existing disparities. This requires a constant critical examination of our roles as researchers and designers in perpetuating inequity through our practices.

b. **Promote more meaningful and safe engagements between people and technology:** By prioritizing cultural safety, we can create technologies that are not only effective tools but also respectful and empowering experiences for families. This means designing interfaces and content that affirm diverse identities and make all families feel welcome and valued.

1.4 Thesis Statement and Dissertation Contributions

This dissertation presents five studies that investigate these questions through engagement with the people who are the intended users of these technologies (parents), and the people building and evaluating these technologies (researchers and designers). These studies are multi-pronged, recognizing that the experiences and perspectives of both parents and designers are crucial for creating effective and equitable health technologies.

The studies reveal a need to focus on the broader context of children and their families, and approach child development promotion by acknowledging and responding to the diversity of families' lived experiences as it pertains to child development. This highlights the importance of moving beyond generic or one-size-fits-all approaches and instead tailoring interventions and supports to the unique realities and needs of different families.

This dissertation presents this central thesis:

- **For early childhood health promotion technologies to improve outcomes for marginalized children, they need to attend to the greater social, political, economic, and historical contexts that affect children and their families.** Existing design and research frameworks often fail to adequately consider the influence of culture on parents' and families' health perceptions and experiences. They may inadvertently perpetuate stereotypes or provide experiences that do not resonate with or support the diversity of family backgrounds.
- **As such, additional frameworks are needed that center cultural safety in the content, design, and research processes for early childhood health promotion technologies.** By prioritizing cultural safety, we can create technologies that respect and affirm the identities and experiences of all families, making them more likely to be effective and inclusive.

Specifically, this dissertation makes the following contributions:

- **Reveals significant gaps and potential biases in current research and design practices of early childhood health promotion technologies, highlighting the need for a more nuanced and inclusive perspective:** This is supported by a systematic literature review, content analysis of child development support apps, and focus groups with parents, where I show how these technologies are unlikely to respond to the diversity of family experiences, and risk widening health disparities.

- **Provides a framework for researching and designing early childhood health promotion technologies to focus on cultural safety:** This involves a shift from merely adding cultural elements to technology, to fundamentally rethinking processes and priorities to center on respect for diversity and inclusion. This framework emphasizes collaboration with diverse communities, active solicitation of their perspectives, and the creation of interfaces and content that affirm and celebrate cultural differences.
- **Demonstrates how this cultural safety approach can be applied in practice:** The dissertation includes a development and validation study of heuristics for technologies that parents use, and a case study showing how these guidelines can transform the design and content of a conversational agent for early childhood health promotion. These practical examples provide concrete insights and a roadmap for other researchers and designers aiming to create more culturally safe and effective technologies.
- **By centering on cultural safety, this dissertation offers a new lens for examining and improving early childhood health technologies.** It challenges existing practices and provides a strong foundation for creating designs that are not only technically effective but also socially and culturally responsive. This has the potential to lead to more equitable health outcomes for marginalized children and families, by ensuring that technologies are developed with a deep understanding of and respect for the diversity of human experiences.

1.5 Dissertation Overview

The following chapters synthesize several empirical studies that I have conducted. Across these studies, I create a path forward for technology in child development support, by focusing directly on cultural safety.

Chapter Two provides more details about the research context and related literature. I start by providing background on the King County context, discussing the unique challenges and opportunities within this diverse region of Washington State. I then explore related literature in early childhood health technologies, examining how mobile technologies have been used in this space and identifying potential risks of widening health inequities if not carefully designed. This literature review highlights the need for a shift in approaches, from simply incorporating technology into existing practices, to deliberately centering cultural safety in the design and research processes. The chapter continues by exploring the concept of cultural safety, its roots in nursing education and its relevance for health technologies. I highlight the gap in the HCI field's understanding of culture and the potential for cultural safety practices to address health inequities. The chapter concludes by outlining my methodological approach, which draws inspiration from Community-Based Participatory Research (CBPR). By actively engaging with local communities and challenging existing power structures, I aim to create technologies that are truly responsive to the diverse needs and experiences of families.

Chapter Three provides a motivation for my work through an assessment of the current research and design practices involved in creating early childhood health technologies. I conducted a systematic literature review and content analysis of existing technologies, revealing significant gaps and opportunities for improvement. This chapter highlights the need for a more nuanced and inclusive approach, one that goes beyond generic solutions and instead centers on the unique experiences and perspectives of diverse families.

In ***Chapter Four***, I document the key learnings from a community-based research project with First Five Years and Beyond, a community organization supporting parents in low-income communities in South King County. Through this engagement and research with the community, I gained valuable insights into the challenges faced by parents in accessing and utilizing technology for child development support. This experience illuminated the importance of co-design and collaboration with the families who are intended users of the technologies, highlighting how their unique needs and perspectives must be at the forefront of effective interventions.

Chapter Five presents the development of a heuristic evaluation method for health equity in child development apps for parents. This chapter explores the benefits and limitations of a new set of heuristics for specifically evaluating health technologies aimed to support parents in navigating their children's developmental progress. These heuristics are designed to provide clear guidelines for identifying both positive features that promote health equity and potential problem areas that could widen disparities if not addressed.

In ***Chapter Six***, I explore how cultural safety as an approach to designing CAs may improve how it caters to diverse family needs. To do this, I collaborated with parents to create a set of requirements for a child development support chatbot, and developed an early prototype that represented their ideas to gain additional feedback, and feedback from expert evaluators. This co-design process was central to ensuring that the technology was rooted in the real experiences and priorities of diverse parent communities.

Chapter Seven reflects on the research presented in the dissertation. I explore the benefits and challenges of researching and designing for cultural safety, drawing on my own experiences and insights from the studies. This reflection helps to illuminate both the promise and the complexity of centering cultural safety in the development of early childhood health technologies. In Chapter Eight, I conclude the dissertation by summarizing the contributions of the research to the computing field and health technology field. I then suggest future work on extending the cultural safety framework to other fields (inside and outside of health), and technology innovation more broadly. My focus on the future of innovation in this area underscores the potential impact of cultural safety practices, not just for improving early childhood health outcomes, but for transforming how technology is developed and deployed across various domains.

Chapter 2: Background and Related Work

2.1 Research Context: Early Childhood Health Promotion in Washington State

Despite global and country-wide efforts to intervene early in child development, disparities in child development continue to persist, signaling that there is a need for new approaches to address disparities (Robinson et al., 2017). Disparities in child development are often indicative of broader and historical inequities in the social determinants of health and healthcare systems (Sanders-Phillips et al., 2009). For example, marginalized families are more likely to live in poverty, limiting their access to nutritious food, safe housing, quality education, and healthcare (Mendoza, 2009). Racism and discrimination in healthcare settings have also historically led to disparities in the quality of care that marginalized people receive, especially for people of color (Bailey et al., 2017). These experiences, as well as the historical exploitation, torture, unethical medical experimentation, and manipulation of these communities in medical practice, have profoundly damaged trust in modern medicine for marginalized communities. Experiments like the Tuskegee Syphilis study (Heintzelman, 2003) or forced sterilization (Reilly, 2015), which lasted for decades, has instilled both fear, skepticism, and sense of vulnerability about medical research and practice for marginalized communities.. This lack of trust and comfort when engaging with healthcare systems significantly increases the vulnerability of children and their families with these backgrounds or identities.

In 2016, Governor Jay Inslee established the Washington State Blue Ribbon Commission on the Delivery of Services to Children and Families. The commission was tasked with recommending the structure for a new state department focused on improving services and outcomes for children, youth, and families. This initiative reflected a recognition of the persistent disparities in child development and the need for innovative approaches to address them. The commission reviewed research, heard from stakeholders, and studied data on the status of children, youth, and families in Washington. From this work, they identified that state services were not organized in a way that achieved the best outcomes for families, parents and families facing challenges should be offered appropriate services earlier to improve children's healthy development, protect them from harm, and disrupt multigenerational trauma (Commission, 2016). This finding underscored the importance of early intervention and the potential benefits of a more equitable approach to service delivery.

This commission led to the establishment of the Department of Children, Youth, and Families (DCYF) in 2017. DCYF's vision is "to ensure that Washington state's children and youth grow up safe and healthy- thriving physically, emotionally, and academically, nurtured by family and community". This vision recognizes the interconnectedness of children's well-being and the support structures in place within their communities. Since then, DCYF has launched several initiatives and partnerships with state and local agencies, tribes, and community organizations (Department of Children). These efforts aim to reorganize services and provide support earlier for children, youth, and families. Early intervention is a key priority, with services including home-visiting programs, developmental screening tools in multiple languages, and community-based programs that are culturally sensitive and accessible. Local researchers and healthcare professionals have also been deeply involved in collaborating with parents and families to create new models of care that meet the needs of families in marginalized communities (Institute, n.d.). Help Me Grow Washington is one particularly successful initiative, a collaboration of local organizations, parents, caregivers, service providers, community partners, and professionals (Washington, n.d.). In 2023, they fulfilled 16,999 support requests, helping 12,850 children and 1,456 pregnant people gain access to basic needs resources. The success of initiatives like Help Me Grow demonstrates the potential impact of collaborative efforts that prioritize community engagement. Across these initiatives and partnerships, community engagement is a strong priority. The successes of these initiatives demonstrate the potential impact of future collaborative efforts. My research aligns with this collaborative spirit by directly engaging with communities through the research and design process. Further, DCYF emphasizes culturally sensitivie and accessible programs; my research on culturally safe technologies complements these efforts by ensuring that technologies are adaptable and meet the specific needs of diverse communities.

In 2023, the city of Seattle was identified as the second healthiest city in the United States, based on metrics like access to healthy food and quality of public healthcare (McCann, 2024). However, a Community Health Needs Assessment (CHNA) conducted in King County the same year revealed disparities in health outcomes and access to care in Seattle (Community, 2024). These findings highlight the fact that while progress has been made, significant inequities persist, particularly for racially and economically marginalized communities. The CHNA identified that these communities experience the highest rates of infant mortality and low birth weight, and are also the least likely to access early and adequate prenatal care. They are also less likely to be insured. These disparities reflect deeper systemic issues with access to healthcare, the quality of care received, and the overall health and supportiveness of living conditions.

To gain a better understanding of the factors contributing to these disparities, the CHNA team engaged directly with the community in listening sessions. Communities in King County shared that challenges with accessing basic needs like food and housing continue to be an issue, and that the COVID-19 pandemic had exacerbated these challenges (Community, 2024). These insights underscore the need for culturally sensitive interventions that address the unique experiences and priorities of diverse families. In the report, they shared five key themes from listening sessions with these communities:

1. **Access to Food and Nutrition Information:** Communities want more opportunities to learn how to eat healthier.
2. **Access to High-Quality, Fresh, and Cultural Foods:** Rising food costs, proximity to grocery stores, and transportation are barriers to healthy food.
3. **Access to Mental and Behavioral Health Services:** Cost, cultural alignment of providers, stigma, and appointment availability are barriers to mental health care.

4. **Climate Change Impacts on Food Security and Mental Health:** Ways that extreme weather events impact family emotional health and make it difficult to access food.
5. **Community Protective Factors:** Ways that the community supports one another (e.g., sharing food, providing transportation to access healthcare or food).

The challenges highlighted by the community indicate that their primary concerns with meeting basic needs continue, which are likely to have significant implications for child development. Below, I provide a table contextualizing these challenges to child development, and opportunities to better support families (Table 1). In many of the examples shared below, providing additional services is highlighted as a key challenge. While my research does not directly provide more services, it could potentially address one key aspect of why services are underutilized: a potential lack of awareness and accessibility of services. For example, cost, cultural alignment of providers, stigma, and appointment availability are barriers to mental health care. These factors, along with a lack of awareness about existing services, can contribute to underutilization. Parents who are struggling with mental health may have additional difficulty with providing consistency and nurturing care for their children. My research on culturally safe and accessible technologies can address this challenge. For instance, these technologies could raise awareness about existing mental health services and make them more accessible. Mobile apps or chatbots informed by community needs could provide information about local resources, appointment scheduling features, or directly provide culturally relevant support materials. Relatedly, ways that extreme weather events, such as floods and droughts, impact family emotional health and make it difficult to access food. While early warning systems can help communities prepare for these events, emotional and food security challenges often arise after the event happens. Unaddressed mental health and food access needs can lead to more stressful environments, which can negatively impact both parents and children. As such, solutions should provide mental health care and food services at the family level that directly addresses the aftermath of extreme weather events. Services that improve access to food should also consider the impact of extreme weather events and integrate with early warning systems where possible to provide additional support.

Table 1: Mapping King County Community Needs to Child Development Support Opportunities

Challenges Identified by King County Community	**Child Development Support Opportunity**	**Outcome**
Access to Food and Nutrition Information: Communities want more opportunities to learn how to eat healthier.	When parents lack knowledge about the specific nutrients children need as they grow and develop, it can be difficult for parents to make informed choices about their children's diet. Because this community wants more opportunities to learn how to eat healthier, new solutions could include specific information about children's nutritional needs as they grow and develop.	Improved child nutrition and health, broadly. Improved physical and cognitive child development and growth.
Access to High-Quality, Fresh, and Cultural Foods:	A lack of access to fresh, nutritious, and cultural foods can lead to deficiencies in essential nutrients, which can impact both physical and cognitive development.	

Rising food costs, proximity to grocery stores, and transportation are barriers to healthy food.	The community expressed that food costs, proximity, and transportation are barriers, indicating that helping families locate and access affordable, healthy food is crucial.	
Access to Mental and Behavioral Health Services: Cost, cultural alignment of providers, stigma, and appointment availability are barriers to mental health care.	Parents who are struggling with mental health may have additional difficulty to provide consistent and nurturing care for their children. Addressing this challenge for families should focus on providing affordable, culturally-aligned, and accessible mental health care that is parent-focused.	Improved parent capacity to engage in behaviors that support their child's healthy development.
Climate Change Impacts on Food Security and Mental Health: Ways that extreme weather events impact family emotional health and makes it difficult to access food.	As mentioned, unaddressed mental health and food access needs can lead to more stressful environments, which can negatively impact both parents and children. Solutions should provide mental health care at the family level that directly addresses extreme weather events. Services that improve access to food should consider the impact of extreme weather events.	
Community Protective Factors: Ways that the community supports one another (e.g., sharing food, providing transportation to access healthcare or food).	When communities share resources and provide support, it creates a more stable environment for families. Approaches should strengthen the ties within the community, by facilitating communication and coordination within these networks.	More resilient communities that can better support children's development.

At the same time, Seattle is a hub of technology innovation and usage, and there is ongoing research happening on integrating technology into early childhood health promotion at the local and global levels. Seattle Children's Research Institute dedicates several labs to technology innovation that fosters child development (Institute, n.d.). Scholars at the University of Washington are also deeply involved in research regarding families, child development, and technology (Engineering, 2023; Washington, 2016). On a global scale, researchers have been exploring technology as a means to improve parent education, increase early intervention, and improve the quality of healthcare that families receive (Hall & Bierman, 2015). Many of these technologies have focused on bridging the gap. For example, in Low- and Middle-Income countries, technology-based interventions have focused on addressing shortages and limited access to child development specialists by offering remote consultations, developmental screenings, and educational resources through mobile apps or texting (Hall et al., 2014; Muñoz & Arriaga, 2015).

Throughout this research, it is clear that these technologies hold promise for bringing care to children and families sooner (Hall & Bierman, 2015). Still, the problems of scaling and deploying these technologies to reach a wider audience persist (Sanner et al., 2012). Furthermore, it is unclear how well these technologies can be adapted to understand and serve more diverse populations (Yuwen et al., 2021). Parallel to academic research, technology professionals have been involved in creating child development support technologies. While these technologies are widely available through app stores, it is unclear who is using them and how they are impacting disparities in child development (Davis et al., 2017). Many of these technologies are not regulated in the health information they provide, which raises concerns about their accuracy and potential to misinform parents (Hassanaly & Dufour, 2021; Montazami et al., 2022).

More broadly, it is possible that these technologies are not being leveraged in ways that can reduce health disparities. As mentioned, technologies could ensure that access to healthcare is geographically and socioeconomically equitable, that health information and education are personalized, and that preventative care and early intervention are accessible and affordable. Achieving these aims, however, requires deliberate consideration and response to the differences in population needs. Existing approaches often focus on specific aspects like access or education, but fail to consider the bigger picture of family needs and contexts. Research has shown that "one-size-fits-all" approaches in technology can actually *increase* inequity, by assuming that all populations have the same needs, and thus neglecting the more nuanced aspects of health inequity (Siek et al., 2019; Veinot et al., 2019). This approach assumes a level of homogeneity within populations, neglecting the significant diversity in experiences like socioeconomic background, cultural practice, and access to resources that exist within families. Generic features or information designed with this assumption might not resonate or be helpful for all communities. Further, these approaches often rely on top-down design approaches, where researchers and developers create the technology without significant input from the target communities. This can lead to technologies that are misinformed and incapable of addressing the real challenges faced by families. For child development and family technologies to have meaningful impact on health equity, they should aim to provide more targeted experiences that consider the full range of family circumstances. My research employs collaborative research and design methods that addresses these limitations by directly engaging with marginalized communities. Through methods like co-design, we can gain a deeper understanding of the challenges faced by families and their specific needs, enabling us to design technologies that are not just accessible or informative, but also culturally safe and human-centered. By empowering families to shape the technology itself, we can ensure it directly addresses their unique challenges and preferences.

2.2 Overview of Early Childhood Health Promotion Technologies (ecHPTs)

Early childhood health promotion technologies (ecHPTs) are digital tools, devices, and systems that are designed to improve the health and well-being of young children. ecHPTs are represented in a variety of technology systems as well, including wearables, mobile apps, texting programs, games, and educational systems. These technologies can encompass a variety of applications:

1. Preventative health and wellness promotion (e.g., nutrition, physical activity, sleep, and dental health)
2. Developmental milestone screening and monitoring
3. Health condition management (e.g., chronic disease)
4. Communication (e.g., telehealth, social networking)

Within the last ten years, smartphones have become highly accessible and ubiquitous across demographics globally. More than 97% of adults (aged over 18 years) in the US own cell phones with texting capabilities, and 85% of the population in the US owns smartphones that can download and access apps, with these numbers growing rapidly, particularly for people aged <49 years, who are the most likely generation to include parents of young children (Sheet, 2019). Smartphones have also become advanced in their capabilities- even the most inexpensive devices include features that are consistent across all smartphones. For example, nearly all smartphones include touchscreens, cameras, sensors, internet connectivity, and geolocation services. Relatedly, mobile app stores offer a substantial platform for reaching larger audiences of people and disseminating health tools with minimal barriers (Van Veen et al., 2019).

ecHPTs have experienced rapid growth alongside the increased ubiquity of smartphones across demographics, a growing emphasis on preventive healthcare in the health field (i.e., focus on establishing healthy habits at younger ages), and broad technology advances (Meixner et al., 2019; Zehrung et al., 2021). With this rapid growth, researchers have explored the potential for wider-scale deployment of these technologies through studies, involving both parents and children (Mildon & Sellen, 2019), and healthcare workers (Early et al., 2019). Other studies have focused on the design specifications of systems aimed to track different aspects of child development needs, like oral hygiene (Khademian et al., 2020), sleep (Moon et al., 2017), and nutrition (Zarnowiecki et al., 2020). Further, these technologies show promise in being deployed for diverse communities (Beratarrechea et al., 2014; Chandler et al., 2021). By leveraging mobile technology, tailoring content to specific cultures and languages, and incorporating interactive features, ecHPTs can improve access to healthcare, increase engagement with health information, and promote positive health outcomes. Studies have shown promise in areas like chronic disease management and sexual and reproductive health, particularly in underserved communities. However, across these studies, there is a need for further research to ensure long-term user engagement and sustained positive health outcomes.

2.2.1 ecHPTs in Smartphones

ecHPTs have been developed and tested across computing, medical, and health informatics fields. While ecHPTs are demonstrated as feasible and efficacious in smaller-scale studies, few studies explore the long-term impact of these systems on families, or in changing broader health inequities (DeWitt, Kientz, Coker, et al., 2022). Longer term studies in other mobile health domains hint that there are issues with maintaining engagement over extended periods of time

(Vaghefi & Tulu, 2019), suggesting that the continued relevance of these systems are important in ensuring that they continue to have impact.

Researchers have extensively explored text messaging as a channel to deliver information and provide tracking of children's developmental health. Within this work, researchers have engaged with evaluating the feasibility of new systems and evaluating the impact of these systems on health outcomes or engagement metrics. Text4Baby is a well-known text messaging program that specifically targets underserved populations in the United States; their pilot evaluation demonstrated that participation in the program improved pregnant women's and newborn mother's sense of preparedness to engage in healthy behaviors with their child (Evans et al., 2012). Researchers expanded on the Text4Baby infrastructure to create an interactive developmental screening program for mothers from low-income communities in the United States, identifying that their program was both usable and acceptable when completing screening questionnaires (Johnson et al., 2019). Another feasibility study explored the use of texting messaging to identify and respond to developmental milestone delays for a community in Nairobi, and demonstrated that parents understood and had high adherence to texts about their child's milestones (Kitsao-Wekulo et al., 2021). However, a feasibility study of a text messaging program for infant feeding in China found that the program was usable, but had a low response rate to text messages (Li et al., 2013). Overall, text messaging has been demonstrated as a feasible and effective means to deliver early childhood health information. Early-stage studies indicate that ecHPTs using text messaging may be scalable in broader populations (i.e., internationally, across income levels) (Pila et al., 2019; Silverman-Lloyd et al., 2020). However, maintaining user engagement with text messaging over extended periods can be challenging (Mandal et al., 2022), and text messaging offers limited space for conveying complex information, or supporting complex dialogues between people, or within systems (Kornfield et al., 2023).

As an alternative, researchers have explored mobile apps as a communication channel that enables more complexity when tracking children's health. These systems have explored more in-depth developmental health tracking, collaboration between a child's caregivers, and providing more personalized guidance. BebeCODE presents a mobile app for collaborative developmental milestone tracking between parents: through their deployment study, they demonstrated that the system successfully helped parents in Korea reach consensus on their child's developmental milestones (Song et al., 2018). Consensus, in this context, refers to agreement between parents on how well their child is meeting developmental benchmarks. This is important because early detection of developmental delays is crucial for getting children the help they need. If parents disagree on their child's progress, it might delay seeking professional evaluation or intervention. Additionally, disagreements about a child's development can be stressful for parents. For example, @BabySteps delivers age-specific child development milestones through tweets, where parents can then reply with another tweet to confirm if their child is on-track with that milestone (Suh et al., 2014); this system was also explored through text messaging (Suh, Porter, et al., 2016). These deployment studies documented that both text messaging and tweets for tracking developmental milestones are feasible for parents in the United States. Another pilot study of mobile app Estrellita engaged mothers of preterm infants from diverse backgrounds and found that their system was usable and did not increase stress (Hayes et al., 2014). Overall, mobile apps are shown to be usable and engaging for parents as they navigate guidance about their children's health (Armenta et al., 2019; Hambidge et al., 2011).

It is clear that ecHPTs are promising technologies that can bring child health and development guidance to families sooner and in more engaging ways. While some studies, like those evaluating the Estrellita app (Hayes et al., 2014), have included participants from various backgrounds, ecHPTs have generally been evaluated with different communities globally and across income levels (Huang & Li, 2017; Li et al., 2013), and show promise in early usability and feasibility evaluations. However, despite ecHPTs being promising and potentially scalable for underserved communities, there has not yet been extensive research demonstrating how they perform in larger, diverse populations, which could indicate the differences in effectiveness across groups in the same population. Further, marginalized communities specifically have been excluded from early research and evaluation in this space, which reduces the generalizability of understandings of community-specific needs. For this reason, ecHPTs may have reduced effectiveness for communities that have not been previously included in these studies.

2.2.2 How ecHPTs risk widening health inequity

There are many intersecting factors that contribute to ecHPTs potentially worsening existing health inequity if deployed in certain settings. For example, a health mobile app designed to support parental stress may be ineffective or even harmful for low-income families who lack access to reliable internet or the necessary devices. Researchers have highlighted two dominant factors, which include the gaps in technology access and literacy (i.e., "The Digital Divide"), and the diversity of health needs across communities. "The Digital Divide" refers to the gaps present between technology usage between people due to differences in technology literacy and access (Saeed & Masters, 2021). For example, in the United States, while internet access has grown significantly over the last 20 years, a significant portion of the US population is not connected. As of 2020, four out of five people in the US have access to the internet at home, however, low-income households, rural communities, and people of color are disproportionately likely to lack access to the internet (Korovkin et al., 2023). A lack of access to and engagement with these technologies (particularly internet access and updated devices) has also contributed to differences in technology literacy (Amiel, 2006).

The Digital Divide has significant implications for the development of technology-based health interventions: if people do not understand or even have access to interventions, they are unlikely to benefit from it. This is particularly concerning for ecHPTs, as differences in a parent's access to meaningful health information could have lifelong impact for their child's health outcomes (DeWalt & Hink, 2009). Because health technologies are also delivering health information, they need to attend to the broader social and economic factors that contribute to disparities in health outcomes.

In 2009, White, Adams, and Heywood examined the literature documenting the planning and delivery of health interventions and identified that all the sub-processes in the research could widen inequality between groups in a target population (White et al., 2009). Coining the term "intervention-generated inequality" (IGI), they referenced the need to control for potentially "confounding effects of [socioeconomic status]" to avoid false conclusions about how health outcomes might change. Lorenc, Petticrew, Welch, and Tugwell extended the 2009 framework in 2014 to identify types of interventions that are more likely to increase health interventions (Lorenc & Oliver, 2014). In their work, they referenced the classification of health intervention approaches into 'upstream,' which focuses on social or policy-level determinants of health, or 'downstream,' which focuses on individual factors, like behavior, and cited other author's perceptions that downstream interventions are more likely to increase inequities than upstream. Later, Veinot and colleagues expanded on this work to address the applications of IGI specifically for health informatics (Veinot et al., 2019) and the role of upstream health informatics interventions to improve health equity. Veinot and colleagues demonstrated the profound impact health informatics interventions have on IGI and population health disparities in this work: that technology interventions could benefit some communities, but at the same time harm others who were already significantly disadvantaged.

Right now, most health interventions utilize a downstream approach to target health behaviors or assist individuals in managing illness. This approach focuses on the individual behaviors that people engage in. While this approach is effective for some specific populations and in specific health areas (Taj et al., 2019), focusing on individual behaviors tends to overlook the systemic factors that influence health; many health outcomes are due to factors that are beyond an individual's control (Garg et al., 2019). Children's health and development outcomes are also deeply intertwined with the systemic factors influencing their environment (Berry et al., 2021). Further, individual-focused health interventions are not compatible with family-level health experiences (Fedele et al., 2019). It is also essential to recognize that social determinants of health factors aggregate at the intersection of identities (e.g., income, race/ethnicity, education level) and have a multiplicative impact on health outcomes.

Broadly, health informatics research has addressed the potential risks of widening health disparities by engaging with marginalized communities (Carney & Kong, 2017). A majority of this work, however, has primarily addressed one or two forms of marginalization in their work, like race and ethnicity, or race and ethnicity *and* class (Baumann & Cabassa, 2020). While engaging with how these identities impact health and technology experiences is a step in the right direction, the complexity that comes from the intersection of these identities should not be overlooked. While one community may be classified as disadvantaged overall, the specific ways that disadvantage shows up in their lives can vary within the community; intersecting identities largely contribute to this. These disparities can appear across gender identity, income level, education, access to healthcare, languages spoken (Terui, 2017), immigration status, or being in an urban or rural population (Hartley, 2004). In the same way that researchers have found that "one-size-fits-all" approaches to health interventions are likely to be ineffective for diverse populations (Burgermaster et al., 2018; Kreuter et al., 1999), technologies should be tailored to address the specific needs and challenges faced by subgroups within marginalized communities.

To avoid widening health inequity, ecHPTs must be carefully designed and implemented. They should be accessible, human-centered, and relevant to the diverse needs of young children and their families across different socioeconomic contexts. For example, ecHPTs could support parental stress by providing evidence-based resources and coping strategies that are easily accessible and culturally relevant. However, without careful consideration of the Digital Divide and the interplay of social determinants of health, such technologies risk exacerbating existing disparities in access to and benefit from health interventions. By engaging with diverse stakeholders, including families from marginalized communities, and incorporating principles of health equity into the design process, ecHPTs can help to improve health outcomes and reduce inequities. The potential benefits of well-designed ecHPTs for promoting health equity are substantial, but the risks are equally significant. With attention to these factors, ecHPTs have the potential to be a powerful tool for advancing health equity in early childhood populations.

2.3 Shortcomings of Design Approaches for Cultural Diversity in HCI

The field of Human-Computer Interaction (HCI) faces significant challenges in designing technologies that are effective and inclusive across diverse cultures worldwide. While the concept of "culture" is multifaceted, most HCI research defines it as shared beliefs, values, and behaviors stemming from demographic identities, geographic locations, or patterns of behavior (Aryana & Øritsland, 2010). Identifying and understanding these cultural manifestations is essential, as neglecting cultural differences can lead to exclusion, reduced usability, and limited technology adoption. When cultural differences are ignored in design, they risk excluding or not being useful for certain populations. For example, usability and understandability of technology can be reduced when a technology is not culturally-relevant: icons and imagery can have different meanings across cultures, and when used incorrectly, can lead to confusion and frustration (Young, 2008). Technologies that do not resonate with a culture's values are also less likely to be adopted. Further, technologies that ignore cultural needs can exclude certain groups, limiting their access to information provided by that technology. Overall, neglecting culture in technology design can create barriers between technology and the people it is intended to support.

Cultural adaptation in HCI, through processes like localization, has been shown to improve global technology experiences. Localization involves tailoring not just language, but also values and social norms to create a culturally appropriate interaction context (Chroust, 2010). This approach allows designers to create interfaces that align with peoples' expectations and existing practices, promoting inclusivity and accessibility. Further, localization enables tailoring based on other user experience factors, which can include language, local time and date, or currency, alongside practices like globalization, which ensures that the core features of technology are universally usable.

Cultural adaptation in HCI extends beyond localization, as it considers the deeper aspects within culture, like meaning and mental models. Yaaqoubi presents Sturm's framework for Technology Language Culture Cognition for product localization, to understand what cultural adaptation can entail beyond tailoring things like language (Yaaqoubi, 2020). Within this framework, there are four layers of localization (ordered from least to most complex): technical, linguistic, cultural, and cognitive. These layers capture other aspects of the user experience where cultural considerations can be made, including things like meaning in symbols, graphics, and colors, or the mental models of how people expect to interact with technology, like menu structures or interaction style (Sturm, 2002). Integrating these layers into the technology design process requires a deeper understanding of culture and how it affects the attitudes and behaviors of people.

To understand differences between cultures, HCI researchers have adopted frameworks from other fields like psychology and anthropology. A plethora of frameworks exist to help researchers understand the consistencies in shared cultures (Ostrom & Ostrom, 2018). These frameworks categorize cultures based on the shared behaviors and values of people within certain locations. For example, Hofstede's cultural dimensions is a widely-used framework when designing for different cultures. The dimensions categorize cultures based on their degree of masculinity, individualism, and indulgence, among others (Soares et al., 2007). Hofstede's cultural dimensions framework can be used to gain insights into the values, preferences, and communication styles based on how cultures score. For example, cultures that score high on the Individualism scale may respond better to content that emphasizes personal achievement, while Collectivist cultures may prefer content that highlights group achievement.

By considering these factors, HCI professionals have designed technologies that are more intuitive and easier to navigate for a wider range of people, create content and functionality that better resonates with the values and expectations of target cultures, and become more inclusive of different groups of people (Yaaqoubi, 2020). However, these models are criticized for their inability to capture how cultures fluctuate, or to highlight the differences between people within the same culture (Courtright et al., 2011). It is also important to note that these benefits have been observed across cultures and locations on a global scale (Sun, 2012), and may not be representative of how these frameworks perform at more local scales (i.e., within the same country). Further, research studying culture is also demonstrating a shift from culture as the context where a person engages with technology, to a characteristic of the person using technology (Linxen et al., 2021).

While cultural adaptation is shown to improve global experiences with technology, there are some risks when adopting a categorization approach to understand culture, which make it a potentially harmful approach to integrate into the design of health technologies. First, there is a risk in oversimplifying culture and how individuals experience it. The notion of distinct, monolithic cultures can be limiting in capturing the nuances of an individual's lived experience. Despite some shared similarities with other people in the same culture, other aspects of identity shape how people interact with technology (e.g., ability, gender, age, income). Because current cultural frameworks do not provide space to explore the nuances of how individual identities change technology experiences, they risk encouraging a one-size-fits all approach in technologies.

The cultural adaptation approach also presents challenges in how it is enacted in the research and design process. To my knowledge, researchers have not yet critiqued the unbalanced power dynamic created between researchers and people using technology by applying overarching culture frameworks, but they have questioned the validity of these frameworks in defining culture (Minkov & Kaasa, 2021). In other fields, researchers have broadly questioned the position of researchers, especially in Western institutions, in the role of knowledge production when partnering with communities (Glass & Newman, 2015). By taking an authoritative role in determining how to design for culture, researchers may risk furthering the perspective of dominant cultures and risk further marginalizing non-dominant cultural experiences.

Researchers have proposed alternative approaches to engage with culture, to gain a more nuanced understanding of culture through direct engagement with people who identify with those cultures. For example, engaging in the human-centered design (HCD) process with a cultural lens can involve recruiting participants from diverse backgrounds, and ensuring their perspectives are heard during foundational design stages (Buchanan, 2001). Participatory design (PD) is another approach that actively involves members of the target culture as collaborators in the design process, and enables them to shape technology to align with their cultural values and practices (Spinuzzi, 2005).

While these approaches can encourage HCI researchers and designers to gain a more nuanced understanding of culture, these approaches may fall short when designing for technology experiences and content that is highly individualized, personal, and changing, like healthcare (Liang et al., 2021). Inherently, understanding cultural differences does not mean that we will design technologies that continue to respond to those differences in a meaningful way. None of the approaches mentioned (i.e., Hofstede's Cultural Dimensions, Sturn’s TLCC framework) inherently ensure that the technologies produced from those processes will provide experiences that continue to be culturally aligned over time. To address this challenge and design healthcare technologies that remain culturally relevant, researchers and designers need to move beyond static frameworks. A richer understanding of cultural needs requires a combination of user inputs and higher-level considerations. For example, these user inputs could include things like anonymized demographic data like location to help identify highly localized information, open-ended questions that enable technology to create insights using a bottom-up approach (i.e., information in the technology is derived directly from user inputs), collecting user feedback that reveals patterns or potential areas of cultural irrelevance, or longitudinal data collection by re-engaging with users to gather updated information. Beyond user inputs, researchers and designers should consider involving people around the user, like healthcare professionals or community leaders, who can provide insights into other cultural nuances and the potential for change within specific communities. More broadly, research and designers could explore the influence of emerging technologies to explore how to tailor healthcare experiences further for diverse communities.

My research responds to the shortcomings of these approaches in two ways. First, I emphasize cultural safety, which focuses on the power of individuals to define their cultural identity and determine how technology responds to their identity. This approach can encourage researchers to move away from determining how culture is relevant in technology for communities, and instead support communities in communicating how their cultures are relevant in technology. Second, I emphasize how cultural safety can provide the foundation for content and features of technology that can change with people over time, by continuing to respect the beliefs and values of individuals, regardless of what they are. This emphasis on cultural safety has significant implications for how technology is built and made available. For example, traditionally, research might determine how a certain culture interacts with technology, by creating technology experiences based on assumptions about cultural needs and how they translate into technology. My approach subverts existing power dynamics, empowering communities to define how their own cultures see and interact with technology. This leads to a more authentic and nuanced understanding. By centering cultural identity and self-definition, my approach ensures that individuals have agency in how technology responds to them. This can foster a sense of trust and ownership over technologies that current technologies sometimes lack, and improving the inclusivity of technologies in the world.

2.4 Theoretical Approach: Cultural Safety

Health inequities disproportionately burden marginalized populations, a consequence of centuries of colonization, violence, and discrimination that have hardened power imbalances and wealth disparities (Braveman et al., 2011). These historical injustices have shaped the determinants of health, access to healthcare, and quality of healthcare for these communities. As a result, marginalized groups often face worse health outcomes than their more privileged counterparts (Arcaya & Figueroa, 2017). The healthcare system plays a significant role in perpetuating these inequities. Healthcare professionals, despite their best intentions, can engage in practices that lead to biased and unequal care (Chapman et al., 2013). Unconscious biases, communication breakdowns, lack of patient empowerment, and lack of trust all contribute to healthcare experiences that are less equitable for marginalized patients (Ashton et al., 2003).

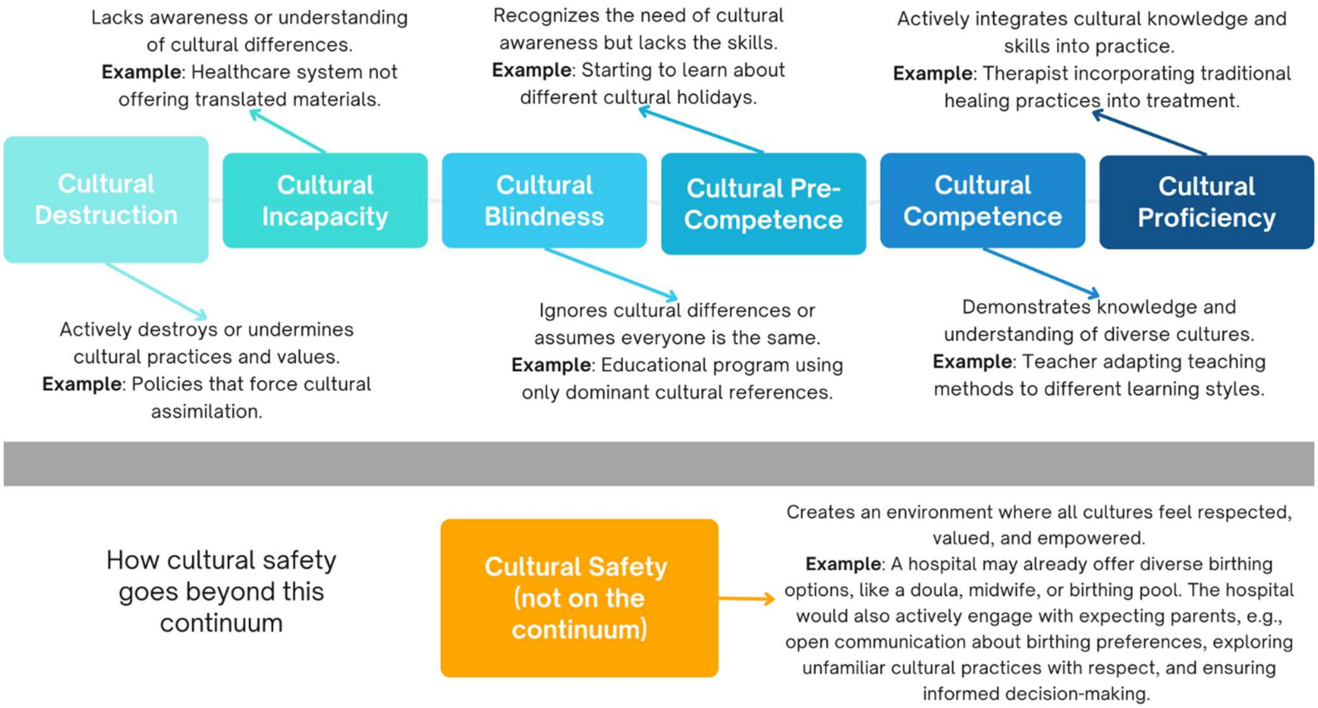
Healthcare organizations, professionals, and systems have a critical responsibility to create environments that minimize bias and dismantle discriminatory practices. This requires proactive efforts to address the social determinants of health, promote diversity and inclusion, and implement policies that ensure equitable treatment for all patients. By acknowledging and actively working to dismantle the structural racism that permeates the healthcare system, we can move towards a future where healthcare is truly accessible and effective for all populations.

To deliver appropriate and equitable healthcare for marginalized communities, we must adopt approaches that value and respect the nuances in the lived experiences of people navigating their health. Scholars have developed an abundance of approaches to achieve this aim, many of which have focused on culture to better understand the needs of different communities and how to tailor care to those needs. Culture is a highly abstract concept and has several meanings across disciplines. Culture is sometimes described as a pattern of human behavior, including thoughts, beliefs and values, actions and customs (Cross, 1989), and language supporting people as they navigate the world. Those patterns of behaviors are thought to be shared in a collective group due to geographic proximity, time, and shared human experiences. Culture is sometimes discussed in terms of race and ethnicity in health spaces, as it aligns with how people are frequently categorized in the field (Baldwin et al., 2006). However, culture is also dynamic; it changes following individual and group experiences over time (Wilkins & Dyer Jr, 1988).

2.4.1 Research Lineage of Cultural Safety

A rich research and practice lineage has led to the definition of cultural safety. Conversations about the relevance of culture in healthcare started with “cultural competence,” defined by Cross and colleagues in the United States in 1989. They state: “Cultural competence is a set of congruent behaviors, attitudes, and policies that come together in a system, agency, or among professionals and enable that system, agency, or those professionals to work together in cross-cultural situations” (Cross, 1989). Cross et al.’s description of cultural competence focused on individual healthcare professionals developing knowledge of all cultures (which is strongly aligned with the expectation for healthcare professionals to be ‘competent’ in their training), in order to tailor their care to people within those cultural backgrounds. Cross et al. placed cultural competence along a continuum starting with cultural destructiveness, where certain attitudes, policies, or practices are destructive to culture and thus harm individuals in those cultures. The opposite end of the continuum is cultural proficiency, where attitudes, policies, or practices promote cultural awareness (e.g., research on new treatment methods that include culture). The figure below illustrates the continuum of approaches for addressing culture in healthcare practice (Figure 1).

Figure 1: Continuum of Cultural Competence (as described by Cross, Bazron, Dennis)



The cultural competence approach has limitations (Curtis et al., 2019), specifically within its potential to reinforce harmful stereotypes by homogenizing groups of people and ignore the power dynamics that exist in healthcare interactions. It reinforces stereotypes by focusing on individual healthcare professionals developing a static understanding of diverse cultures. This approach also oversimplifies the complex ways that culture can influence health, and undermines the knowledge and lived experiences of people within those cultures. The cultural competence approach also assumes that patients have equal power in healthcare interactions, which is not always true (Kirmayer, 2012). A richer understanding of culture, recognizing its complex and abstract form, has led to the emergence of alternative approaches. Cultural safety, for example, emphasizes creating a healthcare environment that is safe and respectful for people of all cultures. It acknowledges the power imbalances in healthcare and works to empower patients by respecting their knowledge and creating space for them to share their experiences and perspectives. Cultural safety goes beyond individual competence. It requires healthcare organizations to critically examine their policies and practices to identify and address biases and barriers to equitable care (Johnstone & Kanitsaki, 2007). It promotes diversity and inclusion and ensures that the voices of marginalized communities are heard. Other approaches shared along the continuum have emerged as well. Cultural sensitivity, security, and respect all emphasize understanding and respecting patient’s cultural backgrounds, while cultural awareness, humility, and safety focus on ongoing learning and recognizing the complexities of culture (Lekas et al., 2020).

The development of cultural safety in healthcare parallels the direction of cultural adaptation in human-computer interaction (HCI). Both fields initially focused on a deficit model, where the onus was on patients/users to adapt to existing systems. In healthcare, cultural competence emphasized healthcare professionals gaining knowledge of all cultures, which often led to stereotyping. Similarly, HCI practice has relied on cultural frameworks like Hofstede's Cultural Dimensions Theory to categorize people, oversimplifying cultural diversity. Both fields have shifted toward more empowering approaches. Cultural safety in healthcare emphasizes respecting patient's knowledge and empowering them as active participants in their care. This mirrors the shift in HCI toward approaches like participatory design (PD), where target communities actively shape technology (understanding the need for collaborative processes) (Cooper et al., 2022). Both have recognized the limitations of one-size-fits-all solutions and aim to create technologies that respect individual and community needs. However, cultural safety can further technology innovation by encouraging designers and researchers to uphold the values of cultural safety in the user experience of technology.

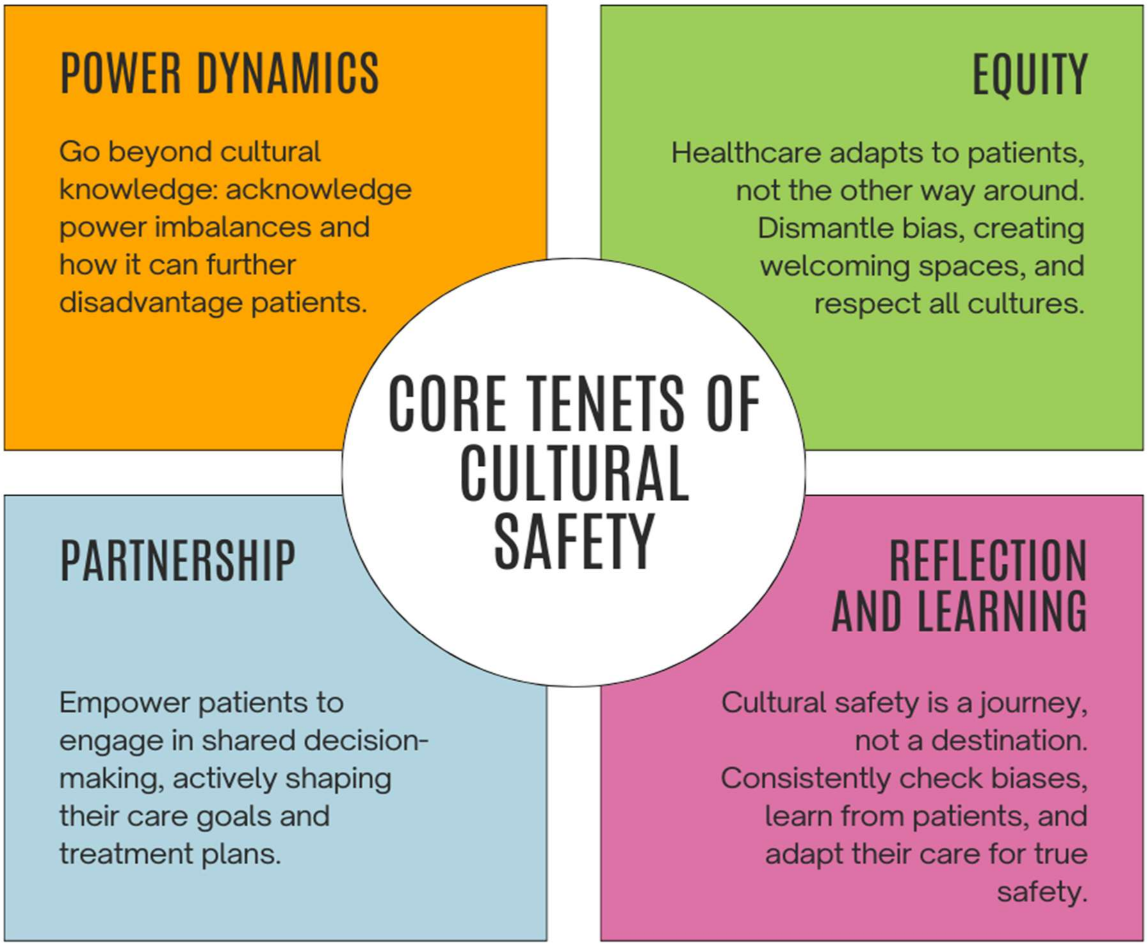
2.4.2 Definition of Cultural Safety

Cultural safety is a framework that contrasts with cultural competence by acknowledging power imbalances in healthcare and empowering patients to participate in their care actively and meaningfully. It emerged in New Zealand in the 1990s as a response to negative healthcare experiences among the Māori population and was defined by Papps, Ramsden, and Māori nurses as: "An environment which is safe for people: where there is no assault, challenge or denial of their identity, of who they are and what they need. It is about shared respect, shared meaning, shared knowledge and experience, of learning together with dignity and truly listening" (Papps & Ramsden, 1996).

The definition of cultural safety has four key components (illustrated in Figure 2):

- **Power Dynamics:** Cultural safety is not just about understanding diverse cultures, instead, it is about recognizing the power that healthcare professionals have over patients and being aware of how this power can be used unfairly. For nurses collaborating with Māori patients, cultural safety is more than just learning about Māori culture, as it requires a deep awareness of the power difference between the non-Māori healthcare professionals and the Māori patients they served.
- **Equity:** Cultural safety demands that healthcare systems adapt to meet the needs of diverse patients, rather than expecting patients to conform (assimilate) to a single standard of care. This involves dismantling practices that discriminate against certain groups and ensuring that healthcare environments are welcoming and respectful of all cultures (for example, offering diverse food options and access to spiritual leaders).
- **Partnership and Shared Decision-Making:** Cultural safety requires that nurses and patients work together as equals in making healthcare decisions, meaning that patients should be actively involved in setting their own care goals and making choices about their treatment plans.
- **Reflection and Continuous Learning:** Cultural safety cannot be achieved through a one-time effort; it requires healthcare professionals to constantly reflect on their own biases and assumptions, learn from their interactions with patients, and adapt their practices accordingly. This ongoing process of self-examination and growth is critical to providing safe care.

Figure 2: Core Tenets of Cultural Safety



Applying the principles of cultural safety to healthcare practice requires a fundamental shift in how healthcare professionals think and act. While achieving cultural safety requires a paradigm shift in healthcare practice, its application can be streamlined through specific strategies. First, a focus on cultural humility, as opposed to an exhaustive acquisition of cultural knowledge, is critical. This acknowledges the limitations of individual practitioners; understanding and emphasizes approach each patient as a unique person shaped by their cultural background and experiences. Instead of focusing solely on acquiring knowledge about different cultures, healthcare professionals must critically examine their own power and privilege and work to create healthcare environments that are equitable, respectful, and responsive to the needs of all patients (Brascoupé & Waters, 2009). This involves dismantling discriminatory practices, actively seeking out the perspectives of patients, and being open to constant growth and change. Second, fostering open communication through open-ended conversation is important as well. By actively listening to and soliciting the patient's perspective on health and preferred care approaches, healthcare professionals can gain valuable insights that enhance the quality of care provided. Third, recognizing and mitigating personal biases is important. Cultural safety also recognizes that Western medicine often clashes with the health beliefs of people from diverse cultural backgrounds. This calls for healthcare professionals to scrutinize their own perceptions of health and culture, and how biases might affect patient interactions, allowing for more objective and equitable decision-making. Further, leveraging available resources in healthcare organizations that might be available, like cultural safety training programs or patient navigators from diverse backgrounds, could augment the health professional’s capacity to deliver culturally safe care. Lastly, fostering collaboration with other health professionals from various cultural backgrounds could allow for the exchange of knowledge and insights, enriching the overall approach to healthcare practice. To deliver more effective care, healthcare professionals must decolonize their practice, consider power relationships constantly, engage in regular self-reflection on their biases, and empower patients to define the safety of their healthcare engagements. By integrating these strategies, cultural safety can become an efficient and integral aspect of healthcare practice that happens routinely, promoting a journey of continuous learning, adaptation, and ultimately, the delivery of respectful and effective care to a diverse patient population.

Healthcare professionals can take concrete steps to create a more culturally safe environment for patients. Scholars have recommended tangible practices, including reflecting on one's own background and potential biases, actively engaging with patients, using clear and respectful language, and acknowledging the importance of cultural beliefs in understanding health and illness experiences (Ball, 2008). They have also recommended that professionals should be prepared to use interpreters or translated materials to support communication with patients from diverse linguistic backgrounds and advocate for patients who experience discrimination to promote equity within the healthcare system (Taylor & Guerin, 2019). Ongoing education and collaboration with community organizations are also mentioned as essential to develop cultural competence and gain a deeper understanding of the populations served. Implementing these strategies can enhance trust between healthcare providers and patients, leading to improved health outcomes for all (Johnstone & Kanitsaki, 2007).

Papps and Ramsden argued that cultural safety represents a fundamental shift from the concept of cultural competence. Rather than focusing on developing healthcare professionals’ understanding of different cultures, cultural safety emphasizes creating systems and environments that make patients feel safe and respected (Papps & Ramsden, 1996). This shift acknowledged that health inequities are deeply ingrained in the structures of healthcare itself, not just the knowledge or attitudes of individual healthcare professionals. Brascoupé and Waters echo this perspective, emphasizing that the move from cultural competence to cultural safety is not a mere refinement, but a radical rethinking of how we approach cultural considerations in healthcare: "where the movement from cultural competence to cultural safety is not merely another step on a linear continuum, but rather a more dramatic change of approach. This conceptualization of cultural safety represents a more radical, politicized understanding of cultural consideration, effectively rejecting the more limited culturally competent approach for one based not on knowledge but rather power" (Brascoupé & Waters, 2009). They argue that cultural competence perpetuates power imbalances by burdening healthcare professionals with the responsibility of acquiring cultural knowledge and rectifying health disparities. This approach assumes that providers can adequately represent the diversity of patient experiences and risk stereotyping or minimizing individual voices. Further, cultural competence often treats this as a finite goal, neglecting the dynamic, ongoing nature of cultural understanding and engagement.

In contrast, cultural safety prioritizes active engagement with patients, listening to their perspectives, and dismantling discriminatory practices. It recognizes that true equity in healthcare requires challenging existing power structures and creating environments that support diverse needs. This perspective inspires me to engage in a critical examination of how health technologies are designed and used. For example, health apps that fail to align with a patient's beliefs or contexts can exclude important health insights and reinforce power imbalances. Researchers and designers must actively partner with communities, share decision-making, and continually reflect on their work to create technologies that truly support cultural safety. The shift from cultural competence to cultural safety is essential not just for improving patient outcomes, but for fundamentally transforming healthcare systems. It demands a reckoning with the ways power and inequity are embedded in our practices and a commitment to creating environments where all people feel respected, heard, and able to access the care they need.

As health technologies become increasingly integrated into the healthcare delivery, it is critical that these technologies also embody the principles of cultural safety. Just as healthcare professionals must reflect on their own backgrounds, engage with patients as equals, and adapt their approaches to respect diverse beliefs and experiences, health technologies should be designed and implemented with a commitment to cultural safety. My research contributes to this goal by providing a concrete example of how cultural safety principles can be applied in the design of health technologies, offering insights into practical strategies for promoting cultural safety in this context. Through this work, I aim to enhance the relevance and effectiveness of health technologies for diverse populations, ultimately contributing to better health outcomes and greater equity within our healthcare systems.

2.5 Methodological Approach

2.5.1 Context for Community-Engaged Research

A community can be defined as people connected by one or more of the following: geographic location, shared interests, or shared circumstances (Elizabeth Goodwin, 2018). Ahmed and Palermo define community engagement as “a process of inclusive participation that supports mutual respect of values, strategies, and actions for authentic partnership” (Ahmed & Palermo, 2010). Communities can also be considered groups of people likely to be impacted by research or decisions that research might inform.

The public health field has studied the role of environmental and social determinants of health (Sanders-Phillips et al., 2009). The field has also involved the public in research to identify and respond to health problems at the community and population level. Previously, this involvement was primarily through non-participatory methods and focused on assumptions about communities generated on data or observation (Nxumalo & Adair, 2019). As researchers have better understood the social, economic, and environmental foundations of health inequity, both researchers and health practitioners have called for community engagement to attend to complex, community-level experiences, particularly for marginalized communities (Wallerstein & Duran, 2006). Within health informatics research, there is substantial overlap with both the fields of medicine and human-computer interaction. Both fields highlight the importance of context and individual experiences to understand and identify pathways to improve health outcomes (Brewer et al., 2020). I think it is important to note that both context and personal experience can sometimes only be understood through the perspective of the person experiencing health.

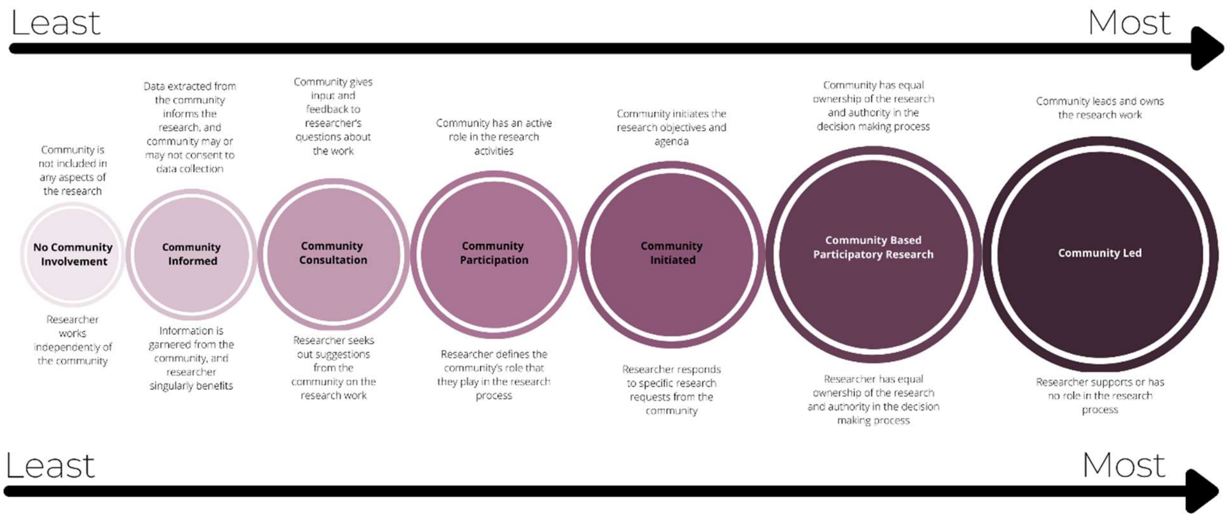
The history that follows medical research (i.e., experimentation) has cast a shadow on perceptions of research within marginalized communities specifically. Mistrust in research, misunderstandings of consent, and low rates of participation in medical research reduce the potential for more effective and relevant health systems. Technology designers have also called for more attention to the relevance of the ‘end-user’s’ perspective in early design processes to fully understand the contexts where technologies might operate (Mildon & Sellen, 2019). However, the institution of medicine (and of science) generally undermines the capacity for individuals to produce relevant knowledge in research. Community partnerships have demonstrated improvements in trust in research, understanding of consent, willingness to participate in research, and improved relevance of solutions generated (Harrington et al., 2019). Community-engaged research benefits the research partner and the community as well. Specifically, communities can benefit from leverage and shared power in the research process. In this way, communities communicate and ensure the consideration of social and cultural values and recognition of the contexts where needs are situated. In health interventions, community partners can also benefit from early access to the interventions created. Community-engaged methods are also a formal pathway for the voices of the community to be recognized in research processes and findings.

There is a broad continuum of community-engaged research. Following the framework developed by Key and colleagues (Key et al., 2019), Figure 3 illustrates the seven defined labels along the community engagement continuum. There are many risks in engaging in community-engaged research, mainly related to power, equity, and the potential to harm already vulnerable populations (Wallerstein & Duran, 2006). The continuum of community-engaged research documents the degree to which communities are involved meaningfully in research. This continuum is affected by the impacts of equity indicators and contextual factors in research partnerships (Wallerstein et al., 2005). The figure below demonstrates the impact of those factors within community-engaged research. A larger version of the figure is included in Appendix A.

Below, I explore a few approaches along the continuum. Community informed (CI) research refers to the process where a researcher takes information from a community (with or without their knowledge) and uses it to inform decisions within the research process. Most traditional research can be categorized in this way, where researchers hold the sole authority to decide the scope of research, research sites, methods, and terms of involvement for the community (Key et al., 2019). CI recognizes the relevance of community-level information but does not require capturing the community's perspectives beyond the scope of research objectives. In CI, communities function as data sources that the researcher interprets and decides the scope of implementation for. CI does not address the potential for bias and harm within the research process, and it undermines the value of community perspectives in developing research agendas, leading to potentially inauthentic engagements. I consider CI an extractionary practice, as the researcher can capitalize on their findings from a community. Still, opportunities for the community to benefit are not a required consideration for the researcher.

In the community participation (CP) research approach, community members are active in the research process by providing information to inform decisions, consulting and providing guidance on the research, and other responsibilities (e.g., being a part of an advisory board or supporting recruitment for research). This approach is the second along the continuum, which requires a research partnership with the community. CP requires the community's engagement in an advisory capacity (sometimes only once), where leverage in outcomes is not guaranteed. Still, there is value within the community's perspective of the research objectives (Key et al., 2019). Advising can also extend to data collection strategies, data analysis, and recommendations for dissemination of research findings. While CP involves communities to a much greater degree than CI, it introduces a new dimension of interaction that comes with risks when communities fill an advisory role. While researchers seek guidance on their research process, ultimately, all authority falls to the researcher to decide what to do with that guidance. Additionally, communities have no leverage to voice their concerns about research processes or possibly inaccurate community representations unless the researcher decides to ask about them specifically. CP can be borderline an extractionary and harmful relationship with communities excluded and marginalized further by research. For this reason, I believe that CP is one step away from CBPR: it recognizes that collaborative partnerships are essential in research but do not require attention or work to resolve power differences.

Figure 3: Continuum of Community Engagement



2.5.2 Community-Based Participatory Research

Community-Based Participatory Research (CBPR) is a cornerstone of my research approach. Inspired by the principles of cultural safety that emphasize shared decision-making and acknowledgement of power dynamics, CBPR promotes equitable partnerships between researchers and communities (Wallerstein & Duran, 2006). It emerged in response to the exclusion of community perspectives in research, particularly in health research (which has a long history of experimentation, exclusion, and exploitation). At its core, CBPR is about building meaningful relationships between researchers and communities, based on mutual respect and knowledge sharing. It aims for genuine collaboration, with community members participating in all stages of the research process, having power and leverage in the research outcomes (Israel et al., 2017). This includes identifying research questions and interpreting findings, for example, ensuring that the research is truly driven by the needs and priorities of the community. Several foundational works in CBPR describe that it takes the perspective that participatory research engagements have three connected goals: research, action, and education (Berge et al., 2009; Israel et al., 1998; Satcher, 2005; Wallerstein et al., 2005; Wallerstein & Duran, 2006). CBPR values inclusion, equity, and recognizing the strengths and assets within communities. It encourages action, education, and the production of new knowledge that can benefit the community. While challenges such as power imbalances and differing agendas between partners exist, CBPR emphasizes transparency, addressing historical power dynamics, and ongoing engagement to build trust.

Adaptations of CBPR principles have been applied to health technology research contexts. Unertl and colleagues outline key principles for CBPR in health technology research, including empowering partnerships, leveraging community strengths, sustainability, community-driven design, and knowledge sharing (K. M. Unertl et al., 2016). These principles ensure that health technology research is not only collaborative, but also equitable, inclusive, and centered on the needs of the communities it aims to serve. The full principles put forth by Unertl and colleagues are documented in Textbox 1.

Textbox 1: Principles of CBPR research for health technology contexts as defined by Unertl et al., 2016

1. **Empowering Partnerships and Building Capacity**
    a. Leveraging community strengths by building on existing assets and resources
    b. Creating opportunities for research and community members to learn from each other while addressing social inequalities
    c. Capacity building by equipping community organizations and members with research and technological skills
    d. Sustaining collaborative partnerships by working together throughout all research phases

2. **Sustainability and Shared Ownership**
    a. Clearly defining the ownership of research outputs and plans for technology upkeep
    b. Viewing research and partnership development as an ongoing and adaptable process

3. **Community-Driven Design and Impact**
    a. Integrate peoples' needs and preferences into the research process
    b. Ensuring that both research and the community mutually benefit from research findings
    c. Consider the positive aspects of the community and broader ecological impact

4. **Knowledge Sharing and Future Research**
    a. Share research knowledge broadly and through various methods (and multimodal), fostering future research opportunities

CBPR is closely related to HCI methods like participatory design (PD) and co-design, but with a strong emphasis on community empowerment, which sets it apart from other collaborative and participatory research methods. However, they have shared principles between them. All three approaches involve collaboration between researchers/designers and the target community. This collaborative approach is fundamental to all three methods, as it enables the creation of solutions that are more relevant, effective, and ultimately more successful because the target community has leverage in the process (Harrington et al., 2019). They all aim to create solutions (for example; healthcare interventions in CBPR, technologies in PD/co-design) that are tailored to the needs and context of the community. By centering the community's perspective, these methods ensure that the solutions are grounded in the lived experiences and can be more transformative and meaningful.

Further, all three methods involve active participation from the community through the research or design process. This ongoing involvement is crucial for maintaining the integrity of the collaborative process and ensuring that the community's voices are heard at every stage. This process can include activities like workshops, interviews, surveys, and ideation sessions (Satcher, 2005). Through these types of participatory practices, the community shifts from being a passive recipient of the research or design outcome into an active participant in the process itself. Relatedly, all three approaches acknowledge the power imbalance that can exist between researchers/designers and the target community. Recognizing this inequality is the first step towards creating a more equitable space where community voices are heard *and* valued. The approaches strive to create a space where community members are empowered to contribute their expertise and perspectives with equal leverage with researchers/designers. By challenging traditional research power dynamics, these methods create partnerships and shared ownership of the research or design process.

While sharing core principles with PD and co-design, CBPR has distinct features that set it apart as a powerful approach for community-based research and design. CBPR places a strong emphasis on empowering the community to take ownership of the research or design process. This empowerment moves beyond including communities in research to shifting the power dynamics in a form that centers the community's agency and capacity to drive the process. In this way, the community has a more central role in setting the research agenda, analyzing data, and disseminating findings. This meaningful engagement ensures that the findings are relevant and meaningful to the people that they aim to benefit. Additionally, CBPR goes beyond just creating a solution, by focusing on addressing the broader social issues and inequities affecting the community. By recognizing the systemic factors that shape people's lives, CBPR takes a holistic approach to addressing community needs. In CBPR, the research findings are often used to advocate for policy changes or community programs (Wallerstein & Duran, 2006). This focus on social change often leads to lasting community impact and structural improvements that benefit the entire community (Wallerstein et al., 2020).

The unique emphasis on community empowerment and social change makes CBPR a powerful tool for creating solutions that go beyond traditional HCI methods. By centering the community's voice and agency, CBPR ensures that the research or design process is not just about creating a product, but about transforming the systems that shape people's lives. This focus on empowerment and change sets CBPR apart as a vital approach for those working at the intersection of research, design, and social justice.

2.5.3 Community-Based Research

Community-Based Research (CBR) flourishes at the intersection of academic inquiry and community engagement. While a universal definition for CBR does not yet exist, core themes consistently emerge across its conceptualizations (Minkler, 2005). These principles guide the research process, fostering collaboration, equity, and social change through the research process. Here, I highlight six key principles I have observed across literature on community-based research (Glass & Newman, 2015; Israel et al., 1998; Jiang et al., 2019; Minkler, 2005; Strand et al., 2003). First, CBR dismantles traditional researcher-subject hierarchies. Researchers and community members work together as partners throughout the research journey, however this engagement can vary at the researcher's or community's discretion (e.g., from identifying research questions to interpreting findings and disseminating knowledge). Second, recognizing inherent power imbalances, CBR actively strives to create a space where all voices are heard and valued. This may involve capacity building within the community or ensuring informed consent throughout the research process. Third, the cornerstone of CBR lies in its responsiveness to community needs and interests. Research questions and priorities are shaped by the community's lived experiences and aspirations, ensuring the research addresses issues relevant to their context. However, whether the community is involved in shaping how the questions are aligned with their experiences can differ. For example, in my research, the research questions I created were a hybrid of the interests I had as well as the observations I made in the community context (including experiences like reading reports, attending meetings for community organizations, and conversations with leaders in the community). However, the questions I developed were ultimately developed without any input from the community members I worked with. Still because I embedded flexibility in the research process, it was still possible for community members to shift the research priorities and the practical ways that the research questions were explored (i.e., through the research methods having the capacity to change). By sharing the ways that I adhered to this principle in my research, I hope to illustrate how the CBR approach can be more abstract that the CBPR approach, which would require community engagement in more specific ways (e.g., by involving them at the start of the partnership.

The fourth principle that I observed is that CBR goes beyond mere data collection. It aims to empower the community by equipping them with research skills and knowledge. This fosters long-term sustainability and strengthens the community's ability to address future challenges. Fifth, CBR is not an academic exercise in isolation. Research findings are used to inform concrete actions and create positive change within the community. This could involve developing interventions, advocating for policy changes, or raising public awareness. And lastly, sixth, CBR is grounded in respect for the community's cultural values, knowledge systems, and ways of being. Researchers approach the community with humility, acknowledging the expertise and lived experiences of its members.

While CBR shares significant overlap with Community-Based Participatory Research (CBPR), some key distinctions emerge. CBPR often emphasizes a deeper level of community involvement, extending to setting research agendas, analyzing data, and disseminating findings. CBR might involve less intensive participation, with a focus on collaboration but researchers taking a stronger lead in some respects. CBPR has a strong emphasis on empowering the community to take ownership of the research process and its outcomes. This extends beyond participation to shifting power dynamics and centering the community's agency. CBR might focus on collaboration but may not explicitly aim for the same level of community empowerment. CBPR often has a more explicit focus on social change, aiming to use research findings to advocate for policy changes or develop community programs that address broader social issues and inequities. While CBR can still contribute to positive change, the focus might be more on addressing the immediate needs of the community. Overall, CBPR can be seen as existing on a spectrum with CBR. The specific approach taken depends on the research goals, the nature of the community partnership, and the available resources. Ultimately, both CBR and CBPR strive to create a more just and equitable world through collaborative research that empowers communities and drives positive change.

Within my work, I used the CBR approach as opposed to the CBPR approach because of the inherent focus on collaboration without the specific direction of how to be involved with the community. CBR fosters collaboration, with researchers potentially taking a strong lead in some areas, like developing the initial research question development and data analysis. This aligned well with my research's focus on co-creation, where parents actively participated in participated in refining research activities and co-creating the technology prototype. CBPR, with its emphasis on empowering the community to take ownership, might have led to parents being involved more heavily in defining the research goals and desired outcomes more broadly. Further, my developing knowledge in cultural safety and designing conversational agents was also relevant. CBR allows researchers to leverage their knowledge while incorporating community perspectives. Alternatively, the CBPR approach might have necessitated a more balanced approach where the community expertise would hold equal weight. I think considering that I was a graduate student at the time I completed this work, CBR offered a framework that was more suitable for me to develop and implement my knowledge in the research process (while practicing my research skills more broadly, like developing research questions or practicing data analysis). I think strong CBPR processes require the researchers to have a strong, confident command of their knowledge and expertise, such that they can be a stronger partner to the community. Overall, in my work, the CBR approach created a more collaborative environment where parents actively participated in the process. I think this approach created the necessary balance between community involvement and researcher guidance, which I think aligned well with the project goals overall and my experience level as a researcher.

2.5.4 Community Advisory Boards

A Community Advisory Board (CAB) is a group of individuals from a specific community who collaborate with researchers to guide, provide input, and recommend directions for research processes and outcomes. By fostering a true partnership between researchers and community members, CABs ensure that research is representative, ethical, and directly relevant to the needs of the communities they serve (Newman et al., 2011). The establishment, engagement, and partnership with a CAB are frequent components of Community-Based Participatory Research (CBPR) approaches. CABs can have a significant impact in all aspects of research, from the design of studies to the dissemination of findings, empowering communities to take ownership of the research process and ensuring that the results are meaningful and applicable to their lives. Depending on the research partnership, CAB members can include community leaders, advocates, or individuals with lived experiences that are relevant to the research topics.

Within health research, CABs are utilized in many different areas, including health services research (Quinn, 2004), and clinical trials (Cox et al., 1998). For example, in a study on diabetes management in African American communities, CAB members helped identify research priorities, co-design the intervention, and provided feedback on plans to disseminate research findings (Purnell et al., 2016). Similarly, in a study aimed to support stress management for women in Latina communities with breast cancer, CAB members were involved in identifying barriers to cancer screening, co-designing the health intervention, and providing feedback on methods for data collection (Nápoles et al., 2014). These case studies illustrate how CABs can lead to culturally tailored research designs and more effective communication of findings within specific communities. In some health research engagements, CABs may take on advisory roles, providing guidance on recruitment strategies, data collection methods, and dissemination plans. As clinical partners, CAB members evaluate research plans to ensure they are culturally competent and acceptable to the community, enhancing trust between researchers and the communities they serve. In clinical studies, CABs are sometimes formed to support designing study protocols, providing feedback on study materials, advising on informed consent processes, and assisting with recruitment (Cox et al., 1998). By involving community members in all aspects of research, CABs help to build trust, increase community participation, and improve health outcomes by developing culturally tailored interventions.

Building on the CBPR approach and CAB principles, my dissertation research aims to engage with communities in a meaningful way throughout the research process. I have partnered directly with the community in multiple projects and stages of my research. For example, in my partnership with First Five Years and Beyond (FFYB), we worked together before engaging in the research activities (documented in Chapter 4). During these meetings, I gained an understanding of their community organization and the parents they support. I learned about the different strengths of FFYB when supporting their families and collaborated with them to leverage those strengths in the research process. For instance, their staff and leadership reflect the cultural and linguistic backgrounds of the families they serve, so we involved the staff and leadership in the project to improve understanding and communication.

In another study (documented in Chapter 6) where I recruited families from the Seattle community, I directly involved families in advising the research and design content. Throughout my community engaged research, I have also ensured mutual benefit by keeping the communities I work with updated on the research progress and publications, by sharing my research findings and the design prototypes with the community. Right now, I am exploring ways to promote shared ownership of the research and embed the prototype we created within existing tools to ensure that families have access to it. Because this was surfaced as something the community wants, I want to leverage my resources as a technology professional to make the tool a reality. Part of this future work will be finding ways to re-engage with the community as a member of it, and not as a researcher from a university. Lastly, my research is committed to addressing the power differences between me and the community that I have partnered with. In Chapter 7, I reflect on the challenges that came up as I tried to engage with community-based research, and the limitations of this approach.

2.5.5 Systematic Literature Reviews

mHealth intervention research exists at the intersection of computing, health informatics, and medical disciplines, which are highly segmented and specialized. To identify trends across these fields, researchers have used the literature review method in many forms to survey existing research on mobile-based technologies and to examine opportunities for growth in the field. Berrouiguet et al (Berrouiguet et al., 2016) summarized the use of SMS text messaging as a health care tool for psychiatric disorders and reported evaluation methods and positive perceptions of SMS text messaging by participants. Lau et al (Lau et al., 2020) coupled a systematic search of mobile app stores with a literature review of psychosocial wellness. Bradway et al (Bradway et al., 2020) used a scoping literature review to identify the qualitative and quantitative methods used to evaluate mHealth systems for chronic disease self-management and identified the best practices for comprehensive evaluations of complex mHealth tools. Wang et al (Wang et al., 2020) conducted a *systematic review of systematic reviews* to evaluate the potential of mHealth interventions to support diabetes and obesity treatment and management. Although mHealth interventions are promising, they identified that further research is needed to establish long-term effectiveness. Anderson-Lewis et al (Anderson-Lewis et al., 2018) also evaluated mHealth interventions deployed in historically underserved and minority populations in the United States and recommended that research should expand to include mobile phone and tablet apps. To our knowledge, there have been no systematic evaluations of mHealth interventions designed to support early childhood health or evaluations that focus on how racial disparities potentially influence the effectiveness of these interventions. Our review intends to survey the work happening in computing, medical, and health informatics fields to identify opportunities to address racial disparities in the evaluation and design of health interventions. We also intend to bridge findings across disciplines to promote the effectiveness of delivery systems, design methods, evaluation methods, and reporting standards that future interventions might adopt.

2.5.6 Content Analysis

The content analysis method has been used to identify and evaluate mobile apps aimed to address specific health experiences. This method has been used in computing, medical, and health informatics literature to assess mobile health apps in multiple areas. Lukoff et al (Lukoff et al., 2020) completed an exploratory review of mindfulness apps and used their findings to engage mindfulness practitioners in conversations about the utility of those apps. Content analysis is also frequently used to evaluate apps related to pregnancy support and postnatal care and in the realm of child development support. Bry et al (Bry et al., 2018) documented the quality and scope of apps for child and adolescent anxiety and identified the need for apps that use advanced smartphone features and are of higher quality. Mangone et al (Mangone et al., 2016) documented the features and content of apps aimed to support people in pregnancy prevention, highlighting missed opportunities to inform people using the technologies of helpful information. Yu et al (Yu et al., 2022) documented the quality of pregnancy and postpartum apps available in both China and the United States by using the content analysis method, finding that many of these apps lacked evidence-based information and functions that supported mental health care. Garland et al (Garland et al., 2021) designed Psyberguide as another people-friendly resource that supports reviewing and recommending mental health apps. Researchers have also developed and applied evaluation frameworks in their analysis of consumer apps. Meyer et al (Meyer et al., 2021) used the “Four Pillars of Learning” framework to identify opportunities to improve educational apps supported by developmental science. Henson et al (Henson et al., 2019) developed a framework for evaluating mental health apps, specifically aimed to support patients and clinicians in deciding which apps best support treatment needs. Along that aim, Gordon et al (Gordon et al., 2020) developed an evaluation framework to support the implementation of apps in clinical practice.

2.6 Conversational Agents

Conversational agents (CAs) are dialogue systems that interact with people using natural language (Laranjo et al., 2018). CAs process the meaning and context of a person's input and generate an appropriate and relevant response. Conversations between CAs and people can include the exchange of messages, ideas, and information. Recently, advances in artificial intelligence, machine learning, and natural language processing have significantly improved CAs accuracy and understanding of natural language inputs. The flexibility of CAs enable them to support people with a variety of tasks, including searching the internet for information and setting reminders. For this reason, CAs are applied in many domains, including healthcare (Cevasco et al., 2024), education (Assayed et al., 2024), e-commerce, and entertainment. Like communication between humans, CAs can utilize different modalities to communicate with people, including text, speech, graphics, or video (Cevasco et al., 2024).

Related to this, CAs can have different levels of embodiment. For example, they can be voice-only, be represented by a graphic avatar, or exist as a physical robot (Luria et al., 2019). While CAs can exist in many forms, there are general factors that are known to influence people's experiences with them. Some factors that influence the acceptance, adoption, or usage of conversational agents parallel the factors that influence interpersonal communication, including personality or tone, communication style, and desire for control (Wutz et al., 2023). Other factors reflect guidelines that typically arise in human-computer interaction, like privacy and trustworthiness (Abdelhalim et al., 2024).

CAs have been used extensively in healthcare as well. Montenegro et al. surveyed conversational agents used in healthcare (Montenegro et al., 2019), and found that dermatology, hospital, therapy, cardiology, neurology, mindfulness, endocrinology, nutrition, and general practitioner support were the primary health domain areas being supported by conversational agents. Further, the health goals covered assistance, training, supporting the elderly, diagnosis, education and prevention. Kocaballi et al. completed a systematic review of personalization being used in conversational agents for healthcare (Kocaballi et al., 2019). Examples of personalization include tailoring language or communication style (including through text or audio), or targeting content based on past interactions with the person (e.g., following up on a concern raised in a prior conversation). In their work, they found that personalization was generally implemented without considerations of theoretical frameworks, and that personalization was not evaluated directly as a factor in changing health outcomes. However, personalization was demonstrated to improve the dialogue quality of the conversational agent, and lead to increases in a person's satisfaction and engagement. Personalization features can be particularly helpful for disenfranchised families specifically. CAs can bridge the gap for families who may not have readily available healthcare resources, empowering them to make informed decisions about child health, and offer an approachable and anonymous means to access healthcare information and support.

There are implications for implementing conversational agents in health contexts, however. Luxton purports that conversational agents may have significant risks of bias, harm, inequitable access, and privacy (Luxton, 2020). To address these risks, Luxton recommends that developers and providers of conversational agent services need to consider the safety, dignity, and respect of people to ensure that these technologies are used and applied ethically. Researchers have created frameworks for the ethical creation of CAs that put forth guidelines for creating and implementing them, as well as guidelines for health-specific conversational agents (Schlimbach & Khosrawi-Rad, 2022; Wambsganss et al., 2021). However, these guidelines have a strong focus on the technical aspects of CAs (e.g., data security and fairness), they do not explore the social and economic factors that influence experiences with technology and healthcare experiences. This can lead to CAs being trained on biased data, or be limited in their understanding of family contexts, and thus providing generic guidance that does not consider their specific needs. Overall, these guidelines are a starting point for designing CAs, but they need to evolve to consider the broader factors that contribute to health inequity. New frameworks can guide the development and implementation of CAs in a way that promotes equitable access and outcomes.

Conversational agents could also be a valuable tool for personalizing mobile interventions, especially those designed to provide support, information, and guidance on health topics. By tailoring the intervention content and communication style to individual users, for example, CAs could enhance engagement and effectiveness. Through conversation, CAs could assess user needs and goals by asking questions, analyzing language patterns, and tracking user interaction with the mobile interventions. Based on this assessment, CAs could then personalized the intervention by providing targeted information, reminders, or health content, and adjust their communication style (e.g., text or speech, formal or informal) to best suit the user’s preferences. Still, it is important to acknowledge that CAs that are trained or designed in biased ways may perpetuate those biases in their interactions. Further, their understanding of the social and cultural factors influencing health may also be limited; considering these limitations are critical to ensure that CAs are effective in personalizing mobile interventions.

2.7 Positionality

Cultural safety promotes self-reflection on the role of power and identity in how healthcare professionals show up in their interactions with patients. I am inspired to engage in the same reflection to understand how my biases and perspectives shape how I show up in my research practice. As I reflect on my own experiences navigating healthcare systems and financial hardship as a young Black woman who is also fat, I recognize how these intersecting identities shape my perspective. I am deeply aware that my position as a student at a research university in the United States further compounds my privileges.

My research approach is profoundly informed by my lived experiences. From my mom's teachings about the social and historical structures that create discrimination, to my own encounters with bias, I have developed a sense of how identity influences experience. However, I also acknowledge that my perspective may not fully capture the complexities of parents' lived experiences. For example, as a childless woman, I have not navigated the same systems parents in Seattle have, such as finding schools and affordable childcare.

Throughout my dissertation, I continually reflect on how my biases shape my communication and interpretation of my research. I am mindful of how my identity as a fat Black woman might influence my perceptions, even as I strive to approach my work with empathy and openness. I remain committed to cultural safety in my research practice, recognizing that my privileges must not make me unaware of the experiences of those with less power.

Chapter 3: Design, Research, and Content Opportunities in Mobile-Based Early Childhood Health Promotion Technologies

Health technologies have the potential to greatly improve access to care and outcomes for populations. However, if they are not carefully designed and implemented, they risk widening existing disparities and excluding marginalized populations. For early childhood health in particular, this is a critical issue with potentially lifelong differences in health outcomes, as access to early and quality healthcare is foundational to achieving equity in child health outcomes.

As mentioned, the digital divide, characterized by uneven access to the internet and devices (and the technical literacy associated with it), is a major barrier to the adoption of health technologies. In low-income and rural communities, for example, internet connectivity and device availability is generally limited. This excludes a significant portion of the population from accessing important health information and services delivered through technology platforms. Language is another significant barrier. Many health technologies rely on English in the interfaces and content, excluding people who do not speak English fluently. Relatedly, the use of complex explanations and medical terminology can further alienate people with lower reading and health literacy levels (Rademakers & Heijmans, 2018).

However, the lack of diversity and inclusion in the design and development of health technologies is the most detrimental. Without active engagement with marginalized communities, these technologies risk being agnostic of the diverse cultures, contexts, and identities that contribute to people having unique and highly individualized health experiences. By neglecting the diversity of health experiences, these technologies risk being inaccessible and ineffective for marginalized communities. This exacerbates health inequity by creating a system where the benefits of technology are uneven. Technologies that fail to resonate with or respect people’s lived experience disproportionately benefit certain communities and leave others behind (Ray et al., 2017).

Given the immense potential of health technologies to reach and benefit marginalized communities, it is imperative that we address these barriers and design technologies that are inclusive from the ground up. This means engaging these principles early in the design process (e.g., ideation and prototyping phases). Early attention to the needs of marginalized communities in the first stages of design processes can help prevent potential risks and mitigate harms associated with technologies (Kim M Unertl et al., 2016). Further, early engagement with the needs of diverse communities can ensure that these technologies are better aligned with their needs, setting a strong design foundation, and pushing future innovation to address healthcare needs as they evolve. Early childhood health promotion technologies offer a promising case. These technologies have been extensively studied in low- and middle-income countries (LMICs), among low-income populations, and within racial and ethnic minority groups

(Evans et al., 2015; Evans et al., 2012; Moon et al., 2017; Olson et al., 2016). This research suggests that these technologies can be highly effective when designed with sensitivity to the specific needs and contexts of these populations.

However, a closer examination of the current landscape reveals deeper issues with existing research and design practices. In this chapter, I present the results of a systematic review* of early childhood health promotion technologies developed and evaluated across computing, medical, and health informatics literature. By completing this review, I found that marginalized communities are underrepresented in research in this field, and that health equity is not consistently prioritized in the research and design objectives. This lack of focus on health inequity and the perspectives of marginalized communities is concerning, given the potential of these technologies to widen disparities.

I completed a content analysis* of available apps targeted toward parents as well (*This text is taken directly from published work with my co-authors: Julie Kientz and Kendra Liljenquist. As such, the wording "we" is used throughout to represent the collaborative effort between co-authors). This analysis revealed another concerning pattern in the design of these apps: a lack of consideration for cultural diversity. The majority of apps in this area use a "one-size-fits-all" approach, assuming that families are homogeneous in their child development needs. This approach excludes families with more diverse needs and fails to account for their unique perspectives and experiences. This exclusion can lead to apps not being suitable for children and families that come from diverse backgrounds, leading these families unsupported. Further, generic guidance from apps may be inaccurate or irrelevant to a specific families' context. This can mislead parents or lead to them missing important information about their child's well-being and development, which further causes harm and widens health inequity.

These findings support my central thesis that existing research and design frameworks fail to consider the significant role that culture plays in shaping family's health experiences. Specifically, these practices may not resonate with diverse backgrounds because their perspectives and knowledge have been absent from research. Consequently, the technologies designed may not represent their lived experiences. Further, the research prioritizes feasibility over designing for diverse contexts and has not been rigorously evaluated for marginalized communities. To rectify these issues, I suggest that we must adopt a cultural safety approach in the design and development of health technologies. Cultural safety tells us that patients should become active participants in their care, and because technology can potentially deliver care to them, they should be involved in the process as well. This involves actively seeking input from communities, throughout the entire research and design process. This process means acknowledging and respecting the lived experiences and knowledge of all people, not just the dominant cultural perspectives. While it is impossible to capture the lived experiences and knowledge of all people in any single study, this research aims to address a critical gap in existing research, which often prioritizes dominant cultural perspectives. By actively incorporating diverse voices, we can develop health technologies that are more culturally relevant and effective for a wider population.

By incorporating cultural safety, we can create health technologies that are more inclusive, equitable, and effective for all communities. This will require a shift in mindsets and a commitment to change from all professionals involved in the technology development process. Still, health technologies promise to transform healthcare and promote health equity. But to realize this promise, we need to ensure that these technologies are designed with care, inclusivity, and a deep commitment to reaching and benefiting all people.

In the next two paragraphs, I provide additional background on the challenges and opportunities surrounding access to information and interventions for promoting early childhood health. I highlight the importance of knowledge and resources for early childhood health, explore challenges faced by some families, and introduce mobile health interventions as a potential solution to address early childhood health disparities. I also emphasize a comprehensive approach that considers both health promotion strategies and the social factors that influence child development.

Early childhood health outcomes, such as social, motor, and cognitive development, largely depend on parental knowledge and behaviors. Both the American Academy of Pediatrics and the Centers for Disease Control provide guidelines for parents that educate them on health promotion strategies for their children (Hagan et al., 2017; Workgroup et al., 2021). These guidelines are often presented in local health centers, schools, or community sites (Fernandez-Jimenez et al., 2019). However, finding and acting on information about early childhood health can be challenging (Liljenquist & Coker, 2021; Sanders-Phillips et al., 2009). For families affected by racial and economic disparities, having access to information, care providers, and resources to support health-promoting behaviors is a substantial barrier to parental action (Robinson et al., 2017). Mobile phone–based interventions have been developed to provide parents education on child health topics (Psihogios et al., 2020). These interventions have been evaluated along demographic axes like socioeconomic status, and are shown to be feasible for deployment at a larger scale, especially in lower-resource areas (Johnson et al., 2019; Mildon & Sellen, 2019). However, many of these studies do not provide insights into the group differences within populations, which contributes to our limited understanding of how these interventions may perform in larger, more diverse populations. Further, the lack of research and accurate reporting across other demographic axes, like race or location, further limit our ability to derive an understand of population differences across studies.

The Bright Futures guidelines from the American Academy of Pediatrics for early childhood health promotion outline three areas of focus for comprehensive child development practice: (1) anticipatory guidance, (2) development and behavior screening, and (3) social determinants of health screening. Anticipatory guidance topics refer to proactive advice on activities that promote healthy growth, including nutrition, dental care, and physical activity (Combs-Orme et al., 2011; Hagan et al., 2017). Development and behavior screening includes tracking and monitoring milestones such as motor and cognitive development, growth, and communication skills (Development, 2020). Screening for social determinants of health includes monitoring the environment in which the child grows, including topics such as parent smoking behavior, housing, food security, and parent social support networks (Garg et al., 2016). Pediatric experts have referenced the importance of addressing all 3 topics in regular visits with pediatric patients to identify upstream factors that may affect development (Schickedanz & Coker, 2016) and to understand the challenges of parents when adhering to recommendations. There is an opportunity to address the effects of health inequity on experiences with mobile health (mHealth) technologies (Ray et al., 2017; Van Veen et al., 2019).

Intervening early (for children aged 0-5 years) in childhood health has been demonstrated to improve child outcomes (Hagan et al., 2017). For children born in environments that pose risks to their healthy development (e.g., food or housing insecurity), intervening early can offset the degree of impact those risks have on their health outcomes. By enabling parents and caregivers to engage in consistent and evidence-based behaviors that promote their child's healthy development, more at-risk children will have opportunities to overcome environmental challenges in their development. Children in at-risk environments are less likely to have access to regular pediatric visits (Workgroup et al., 2021). As such, parents and caregivers may need different types of support in being educated about their child's developmental milestones and engaging their child in activities that support them in meeting those milestones. Parents can find information about developmental milestones through internet searches, from pediatric clinics, at community centers, and other accessible locations (Fernandez-Jimenez et al., 2019). However, translating that information to parenting practices can be difficult and is often exacerbated by ambiguity in how to apply information in limited contexts (e.g., in food-insecure environments).

Fortunately, >97% of adults (aged >18 years) in the United States own cell phones with texting capabilities, and 85% of the population in the United States owns smartphones that can download and access apps, with these numbers growing rapidly, particularly for people aged <49 years, who are the most likely the generation to include parents of young children (Sheet, 2019). Researchers have studied the efficacy of phone-based interventions for early childhood health promotion through texting-based programs and mobile apps (Armenta et al., 2019; Evans et al., 2012; Olson et al., 2016). These apps support parenting practices, including tracking feeding, sleep, and diapers; tracking if a child is meeting essential developmental milestones; facilitating communication with healthcare professionals; finding and implementing health-promoting activities; and collaborating with relevant caregivers. These interventions were designed and tested following guidelines from health and computing fields, with content informed by evidence in the pediatric literature. These apps are also often tested in diverse populations to identify opportunities to promote health equity through design choices (Armenta et al., 2019). However, a critical gap exists in translating these research findings into real-world impact. Unfortunately, beyond testing in research contexts, many of these apps are not maintained or deployed to the public because of funding and organizational constraints (Higgins et al., 2018). While high smartphone ownership suggests the potential for widespread adoption, the lack of dissemination hinders the positive impact these interventions could have on public health, especially for families experiencing disparities in access to resources.

Most apps to which parents have access exist in the Apple App and Google Play stores, where app developer experience or qualifications vary widely. These app stores do not have comprehensive guidelines or regulatory oversight for the development of child health apps aside from legal restrictions on claims promising specific health outcomes (Shuren et al., 2018). App developers may not have access to or knowledge of how to apply design guidelines set by pediatric and human-centered computing researchers. The apps that parents have access to also may not be developed and tested with the same rigor as apps developed in research settings. Although most mobile apps provide a disclaimer that they are not meant to be used to diagnose and thus not directly responsible for health outcomes, they are particularly influential in parenting practice (de Cock et al., 2020; Zarnowiecki et al., 2020). For example, mobile apps can support parents to identify and document patterns in their child's health that would otherwise go unnoticed and prompt parents to communicate concerning health information to healthcare providers. At the same time, these apps can risk pathologizing health behaviors, raising unfounded concerns, performing self-diagnosis, and causing additional stress in families to micromanage their health. For these reasons, there is a need to critically examine apps aimed to support child development.

3.1 Systematic Literature Review of Early Childhood Health Promotion Technologies: Research and Design Practices

This systematic literature review aimed to document current research on mobile-based health promotion interventions and understand the methods used to design and evaluate these systems. As we focused on parent-facing interventions for early childhood health (ages 0-5 years), we also examined the opportunities for design and evaluation in this area to critically engage with the potential for racial disparities in intervention effectiveness. In this study, we aim to answer these research questions:

1. What are the design, evaluation, and reporting practices in computing, medical, and health informatics fields for early childhood health interventions?
2. What opportunities exist to address the risk of technology-generated disparities in early childhood health interventions' design, evaluation, and reporting practices?

3.1.1 Methods

3.1.1.1 Reporting Standards

We completed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist and confirm that the study is compliant. The full protocol for this study is available in Appendix B2.

3.1.1.2 Search Strategy

We completed a database search for full-text scholarly articles in medical, computing, and health informatics fields in February 2022 using the electronic databases PubMed, Embase, CINAHL Complete, ERIC, Compendex, Inspec, and ACM Digital Library. We coordinated with our university's health sciences library to identify these databases, as they are relevant to medicine, technology, and research at the intersections of health and technology, where we would expect to find the literature on mobile-based health interventions.

Our search strings included terms describing early childhood health, mobile technologies, and the parents and primary caregivers of young children. We refined and adapted the keyword strings to be compatible with the unique search mechanics of each database (e.g., using different typographic marks as search operators). The complete search strings by database are presented in Appendix B1. We limited our search to studies within the past 10 years (2011 to 2022) to reflect the rapid rate at which technology development and adoption evolves (Kratzke & Cox, 2012).

3.1.1.3 Selection Criteria

We included studies if they (1) presented and tested a mobile app, SMS text messaging system, or mobile website to be used by participants; (2) included a health scope related to anticipatory guidance, development and behavior screenings, or social determinants of health topic areas outlined in Bright Futures Guidelines for Health Supervision of Infants, Children, and Adolescents, fourth edition; (3) targeted parents or guardians of children aged 0 to 5 years directly as users; (4) included a study related to the practicality of the app for target users (e.g., usability, feasibility, pilot study, or randomized controlled trial); (5) were published within the past 10 years; and (6) are a completed, peer-reviewed journal paper or conference paper.

Studies were excluded if they (1) involved a study of a mobile app created to support pregnancy or postpartum health alone, (2) exclusively targeted other caregivers as end users for the system (e.g., day care providers, paid caregivers, nurses, and community health workers), or (3) consisted solely of randomized controlled trial protocol documentation. In addition, we excluded studies not written in English, government reports, articles, and opinion pieces.

3.1.1.4 Selection Process

The database search results were downloaded and organized in a spreadsheet and duplicates were removed. One researcher screened the search results by using the inclusion and exclusion criteria in 3 distinct groupings. First, we used the inclusion and exclusion criteria to screen the titles of the results. Next, we accessed the abstracts for the remaining results and applied the inclusion and exclusion criteria. Finally, we performed a full-text review of the remaining studies. The PRISMA flow diagram detailing the number of studies present in and after each phase is presented in Appendix B2.

3.1.1.5 Data Extraction

One researcher reviewed each full text of the included studies and documented the relevant information in a spreadsheet. This information included (1) titles, authors, country, and year of publication; (2) type of field the study was published in (e.g., computing, medical, and health informatics); (3) type of mobile technology the study evaluated (e.g., texting or SMS text messaging system or mobile app); (4) study design used to evaluate the technology; (5) target population; (6) number of participants recruited for the study and their reported demographics; (7) features and functionalities of the mobile technology; (8) sources for content in the mobile technology; (9) outcomes measured for the child; (10) reported parent perceptions of the technology and outcomes related to changes in parent knowledge and decision-making processes; and (11) reported outcomes for usability, feasibility, or acceptability.

3.1.2 Results

3.1.2.1 Selection and Inclusion of Studies

We screened 906 results from database searches and excluded 891 (98.3%) studies during the screening process. We removed 38 duplicates before beginning the screening process. During title screening, we excluded 83.3% (755/906) of studies. Of the remaining 151 studies, we excluded 73 (48.3%) studies during the abstract screening phase, leaving 78 (51.7%) papers for full-text screening. We excluded 6.9% (63/906) of studies during the full-text screening process, leaving 1.7% (15/906) studies that met the inclusion criteria. The image in Appendix B visually represents the number of studies excluded during each phase of the screening process.

3.1.2.2 Characteristics of the Included Studies

The full overview and characteristics of the studies are presented in Appendix B3. The publication dates ranged from 2014 to 2021, and most studies (9/15, 60%) were published in 2017, 2019, or 2020. Among the 15 studies, 11 (73%) were published in journals and 4 (27%) were peer-reviewed full conference papers.

All (15/15, 100%) the studies developed and contributed to a novel intervention. Overall, 7% (1/15) of studies evaluated an existing mobile app and iterated its design with feedback from parents (Armenta et al., 2019). Of 15 studies, 3 (20%) studies evaluated only the feasibility of the intervention (Huang & Li, 2017; Jacques et al., 2020; Olson et al., 2016), whereas 8 (53%) studies evaluated the intervention's potential to achieve specific health outcomes (Domek et al., 2016; Jiang et al., 2019; Khademian et al., 2020; Lozoya et al., 2019; Nezami et al., 2018; Nyström et al., 2017; Seyyedi et al., 2020; Zolfaghari et al., 2021). The technologies evaluated in these studies included 8 mobile apps (Armenta et al., 2019; Hayes et al., 2014; Jacques et al., 2020; Lozoya et al., 2019; Nolen et al., 2018; Nyström et al., 2017; Seyyedi et al., 2020; Zolfaghari et al., 2021), 4 SMS text message systems (Domek et al., 2016; Jiang et al., 2019; Khademian et al., 2020; Olson et al., 2016), 1 voice message system (Huang & Li, 2017), 1 website optimized for mobile devices (Nezami et al., 2018), and 1 social media platform (Suh et al., 2014). A total of 40% (6/15) of articles reported technical specifications for how they built and deployed the intervention (Jiang et al., 2019; Khademian et al., 2020; Nyström et al., 2017; Olson et al., 2016; Suh et al., 2014; Zolfaghari et al., 2021), 40% (6/15) of studies were conducted in the United States (Hayes et al., 2014; Lozoya et al., 2019; Nezami et al., 2018; Nolen et al., 2018; Olson et al., 2016; Suh et al., 2014), and 6% (1/15) of studies was dually conducted in the United States and Mexico (Armenta et al., 2019). Overall, 20% (3/15) of studies were conducted in Iran (Khademian et al., 2020; Seyyedi et al., 2020; Zolfaghari et al., 2021), and the remaining (5/15, 33%) studies were conducted in Cambodia (Huang & Li, 2017), China (Jiang et al., 2019), Guatemala (Domek et al., 2016), Sweden (Nyström et al., 2017), and

Switzerland (Jacques et al., 2020). The tables shared in the Appendices A3 and A4 provide detailed information about the study findings and technologies evaluated.

3.1.2.3 Features of the Technology Interventions

Among the studies that evaluated mobile apps, features included a tracking component for parent and child behaviors, articles about child health topics, reminder systems using push notifications (Hayes et al., 2014; Lozoya et al., 2019; Nolen et al., 2018; Zolfaghari et al., 2021), milestone questionnaires (Armenta et al., 2019), and data file generation for a physician to review (Hayes et al., 2014). SMS text messaging interventions provide anticipatory guidance for parents to save and review their child's health and development (Jiang et al., 2019; Olson et al., 2016), send reminders for in-person appointments (Domek et al., 2016), and request information about parent or child behavior status (Jiang et al., 2019). One intervention used the social media network Twitter, where parents would send tweets as responses to daily milestone questions (Suh et al., 2014). Another intervention sent parents prerecorded phone calls with information about milestones multiple days per week for a month (Huang & Li, 2017). One intervention also provided personalized summaries of the tracked content to parents by email (Nezami et al., 2018).

3.1.2.4 Methods Used for Design and Evaluation

Studies from medical fields have generally used experimental methods to evaluate the feasibility or effectiveness of interventions. Of the 15 studies, 5 (33%) used randomized controlled trials (Domek et al., 2016; Khademian et al., 2020; Nezami et al., 2018; Nyström et al., 2017; Seyyedi et al., 2020), 2 (13%) used a pretest-posttest design (Lozoya et al., 2019; Zolfaghari et al., 2021), and 1 (6%) engaged parents in qualitative interviews to hear their experiences (Lozoya et al., 2019). Moreover, 13% (2/15) of studies published in medical fields used a feasibility study to evaluate their intervention (Huang & Li, 2017; Olson et al., 2016). Studies published in computing fields have used methods from design disciplines to evaluate interventions. Furthermore, 13% (2/15) of studies asked participants to adopt the intervention in their everyday lives to understand its feasibility and acceptability. Of the 15 studies, 1 (6%) evaluation used a deployment study coupled with qualitative interviews (Suh et al., 2014), and the other used a technology probe and interviews, surveys, and a log analysis in their comprehensive evaluation (Hayes et al., 2014). The other computing study conducted a usability evaluation of their designs (Armenta et al., 2019). Studies published in health informatics fields have used interdisciplinary methods based on traditional computing and medical research. Of the 15 studies, 1 (6%) study experimentally measured changes in child weight and activity levels after the onset of the intervention (Jiang et al., 2019), 1 (6%) study conducted a feasibility evaluation (Jacques et al., 2020), and 1 (6%) acquired parent feedback through a usability study (Nolen et al., 2018).

3.1.2.5 Content Sources

A total of 20% (3/15) of studies from computing fields evaluated an intervention that supported parents in developmental milestone tracking (Armenta et al., 2019; Hayes et al., 2014; Suh et al., 2014). Of these 3 studies, only 1 (33%) (Armenta et al., 2019) mentioned its content sources for developmental milestone topics and related Spanish translations; however, another study referenced developing the intervention “based on a series of formative studies” (Hayes et al., 2014). Overall, 33% (1/3) of studies provided generic guidance for infants up to 28 days old and reported that they consulted local midwives for guidance (Huang & Li, 2017). The remaining studies addressed single-topic areas of early childhood health promotion.

Moreover, 26% (4/15) of studies focused on feeding- and nutrition-related content, 50% (2/4) of these studies were published in health informatics fields, and the remaining (2/4, 50%) studies were published in medical fields. Of these feeding and nutrition studies, 75% (3/4) reported how they developed the content for their intervention (Jacques et al., 2020; Jiang et al., 2019; Seyyedi et al., 2020) and 50% (2/4) studies (Jiang et al., 2019; Seyyedi et al., 2020) consulted both national guidelines for feeding and nutrition and relevant experts (pediatric dietitians or nutritionists). Of these 4 studies, 1 (25%) study consulted pediatric dieticians at a local hospital where they were recruited for their study (Jacques et al., 2020) and 1 (6%) study redirected attention to their related protocol paper for details on how they developed the intervention (Nezami et al., 2018).

Overall, 26% (4/15) of studies presented an intervention targeting pediatric oral health and related parenting behaviors, and of these, 4 studies, 3 (75%) were published in medical fields (Khademian et al., 2020; Lozoya et al., 2019; Zolfaghari et al., 2021). Of these 3 studies, 1 (33%) reported that they reviewed national guidelines for pediatric dentistry and had their system evaluated by oral medicine specialists, pediatric dentists, and electronic learning and programing technicians (Zolfaghari et al., 2021). The other (1/3, 33%) study reported that they consulted pediatric dentistry professors and an education management specialist to develop content for their intervention (Khademian et al., 2020). Furthermore, 33% (1/3) of studies did not report how they developed the content for the intervention (Lozoya et al., 2019). The remaining pediatric oral health study was published in a health informatics field, and the intervention was developed using the American Dental Association’s website (Nolen et al., 2018).

Of the 15 studies, 1 (6%) study targeted vaccine adherence and consulted the country’s Ministry of Public Health and Social Assistance, a health organization, and a special government project group focusing on vaccine adherence (Domek et al., 2016) and 1 (6%) study, which evaluated a speech- and language-focused intervention, did not report how they developed content for their intervention (Olson et al., 2016). None of the studies in this review evaluated an intervention that comprehensively addressed anticipatory guidance, development and behavior screening, and social determinants of health topics, as recommended in the Bright Futures Guidelines for Pediatricians (Hagan et al., 2017).

3.1.2.6 Demographics Reporting

Across all studies in this review, the number of adult participants enrolled in the study ranged from 8 to 58. The demographics-reporting formats varied across all studies; however, all studies included similar demographic characteristics. Studies published in medical and computing fields reported at least three of the following characteristics: child age and gender, parent age and gender, income level, parent education level, mobile phone ownership or familiarity, and race or ethnicity characteristics. None of the studies published in health informatics fields reported race or ethnicity data of their participant samples. Several studies lacked data on race and ethnicity, making it difficult to assess representation or marginalized groups. Some studies used alternative measures like education level, income level, or phone ownership. A total of 26% (4/15) of studies opted for nontraditional approaches to describe socioeconomic status: 1 (25%) study reported parental eligibility for a low-income support program (Olson et al., 2016), 1 (25%) reported parental use of rental accommodations (Jiang et al., 2019), 1 (25%) reported parental work status (Domek et al., 2016), and 1 (25%) reported parents' home or car ownership (Seyyedi et al., 2020). While these demographics provide some insights into the participant samples, they may not fully capture the complexities of socioeconomic disadvantage and the relationship to marginalization. Moreover, 20% (3/15) studies that examined feeding or nutritional outcomes also tracked child weight or BMI (Jiang et al., 2019; Nezami et al., 2018; Nyström et al., 2017). Overall, the limited race, ethnicity, and socioeconomic data in most studies makes it difficult to assess the representation of marginalized groups.

3.1.2.7 Impact of Mobile-Based Interventions for Parents and Children, organized by Publishing Fields

3.1.2.7.1 Computing Fields

Evaluation objectives varied across the studies. More than half (8/15, 53%) of the studies in this review did not report changes in parents' knowledge or decision-making processes (Armenta et al., 2019; Huang & Li, 2017; Jacques et al., 2020; Jiang et al., 2019; Nezami et al., 2018; Nolen et al., 2018; Nyström et al., 2017; Suh et al., 2014). Among the studies published in computing fields, 33% (1/3) of studies experimentally measured stress levels before and after the intervention and found that the intervention did not contribute to increased stress levels (Hayes et al., 2014). The same study found that their intervention scored high in their usability evaluations; parents reported ease of use during the onboarding process, and they appreciated seeing visualizations and parent-focused content (e.g., information about parents' mental health). Of the 3 studies, the other 2 (66%) published in computing fields did not report on outcomes related to parent or child behavior changes, as they focused on usability evaluations (Armenta et al., 2019; Suh et al., 2014) and 1 (33%) study reported that parents had difficulty with the delivery system of the intervention through Twitter, mentioning that syntax made the response process difficult, and parents did not like sharing their child's health information on a social network (Suh et al., 2014). However, the same study also reported that parents generally appreciated the accessibility of content in the intervention. The other study reported that parents struggled during interface testing, as discovery of new features (e.g., tracking milestones or creating a new profile) and related workflows were self-led, leading to parents perceiving the app as confusing and undirected (Armenta et al., 2019). The same study reported that parents preferred the ability to customize milestones that they share, increasing font size, and reviewing translations to Spanish, as they were not culturally relevant.

3.1.2.7.2 Health Informatics Fields

One interface-focused evaluation published in a health informatics field measured the intervention's impact on child BMI, which demonstrated that it did not significantly impact the BMIs of children in the study (Jiang et al., 2019). Another study examining the usability of their gamified mobile app found that parents believed the app could keep them informed about their child's oral health and support progress toward positive oral health behaviors (Zolfaghari et al., 2021). The same study found that parents thought the app was user-friendly, although the interface design and process for parents to recognize and correct errors in tracking were rated low. This study also found that the gamified intervention was more effective in reducing child plaque than the nongamified approach. The remaining mobile apps published in a health informatics field reported a high ease of use of the interface and camera although parents had problems navigating the mobile app and expressed dissatisfaction with features that did not work (Jacques et al., 2020; van Rooy & Bus, 2010). However, the content, information, and reminders provided were rated as positive features in this app.

3.1.2.7.3 Medical Fields

Overall, 25% (2/8) of studies published in medical fields did not measure child-centered health outcomes (Khademian et al., 2020; Olson et al., 2016). These studies focused on changes in parenting behaviors or knowledge after the onset of the intervention or the feasibility of the intervention for evaluations in larger populations. In all, 12% (1/8) of studies found that maternal knowledge about pediatric oral health and related practices improved after the onset of the intervention and that high participation rates in the intervention indicated positive parent experiences with the technology (Khademian et al., 2020). In this intervention, parents specifically referenced that they liked the reminders and guided brushing videos the app provided. The other study reported that parents had increased awareness of language-promoting activities and local resources for child development support (Olson et al., 2016). This same study reported that parenting behaviors that promote language development increased, and parents reported that the number of texts and content of the messages were accessible and easier to navigate than when searching the internet. Of 8 studies, 1 (12%) study did not evaluate interventions related to child outcomes or parent knowledge (Huang & Li, 2017).

The remaining (4/8, 50%) studies published in medical fields measured child health outcomes after the onset of the intervention. Several studies have indicated that mobile-based interventions lead to significant child outcomes. Of the 8 studies, 1 (12%) study found that although BMI measurements of the intervention group did not differ significantly from those of the control group, physical activity levels did improve (Nyström et al., 2017) and 2 (25%) interventions targeting nutrition-related outcomes, including reduced sugary beverage consumption (Nezami et al., 2018) and improved child weight (Seyyedi et al., 2020), found that children met the goals set during the intervention evaluation. Another study found a significant improvement in child toothbrushing frequency, and the gamified version of the intervention was more successful in controlling plaque than the control group (Zolfaghari et al., 2021). However, 12% (1/8) of studies reported that the intervention had no significant impact on quantified child outcomes (Lozoya et al., 2019), despite positive experiences reported by parents.

3.1.3 Discussion

3.1.3.1 Principal Findings

We completed a systematic literature review of mobile-based health interventions for early childhood health promotion published within the past 10 years. Of the 15 articles we reviewed, we found that using mobile-based systems to deliver health interventions was generally well accepted by parents of children <5 years of age. We also found that, when measured, parenting knowledge of early childhood health topics and confidence to engage in health-promoting behaviors improved. For child health outcomes, several studies reported that the intervention did lead to targeted outcomes in child health, which indicates the potential for population-level improvements. In this section, we describe the opportunities for intervention designers and evaluators to critically engage with concepts in design practice, risk of technology-generated disparities, and reporting standardization.

3.1.3.2 Progression of Research Studies

The Obesity-Related Behavioral Intervention Trials model establishes a pathway of phases that supports the translation of information in behavioral and social science research into health interventions (Czajkowski et al., 2015). Using the Obesity-Related Behavioral Intervention Trials model, we documented the preparedness of the systems evaluated in the studies for large-scale phase 3 efficacy testing. In phase 3 efficacy testing or clinical research, researchers examine the efficacy of interventions and monitor outcomes in larger, more diverse populations, and over longer periods. We identified that 53% (8/15) of the studies evaluated their systems using nonexperimental methods and established the feasibility of the systems for target populations without documenting child health outcomes (Armenta et al., 2019; Hayes et al., 2014; Huang & Li, 2017; Jacques et al., 2020; Khademian et al., 2020; Nolen et al., 2018; Olson et al., 2016; Suh et al., 2014). The remaining (7/15, 46%) studies conducted early experimental evaluations of the systems in larger populations and evaluated related child outcomes (Domek et al., 2016; Jiang et al., 2019; Lozoya et al., 2019; Nezami et al., 2018; Nyström et al., 2017; Seyyedi et al., 2020; Zolfaghari et al., 2021). However, it is important to note that of the 6 studies that completed large-scale evaluations, 83% (5/6) of studies were published in medical fields (Domek et al., 2016; Khademian et al., 2020; Nezami et al., 2018; Nyström et al., 2017; Seyyedi et al., 2020), and the other was published in a health informatics field (Jiang et al., 2019). This indicates a lack of large-scale efficacy evaluations of early childhood health technologies in computing and health informatics fields.

Large-scale testing is crucial in determining the effectiveness of an intervention in real-world settings with diverse populations. Medical researchers may be more familiar with and have better access to resources for conducting these rigorous trials. However, insights from other fields are equally relevant in comprehensively understanding how interventions perform in the real world. For example, insights from computing research could ensure that technology is user-friendly, engaging, and accessible for diverse populations. Insights from health informatics research could ensure, for example, that the data collected by technology is secure, analyzed effectively, and used to improve the intervention over time. Without large-scale evaluations and collaboration between these disciplines, it is unlikely that each field individual will produce technologies that have proven effectiveness with diverse communities, through measurable improvements in child health, adhering to human-centered design principles, or having data-driven improvements to interventions over time.

Computing researchers have identified that novel technology designs often do not reach larger-scale testing and deployment in larger populations owing to funding constraints, lack of organizational support to maintain systems, retention of designers at original organizations, and incompatibility between early-stage designs and large-scale clinical evaluation processes (Klasnja et al., 2011). Multidisciplinary collaboration across computing, medicine, and health informatics can lead to larger-scale evaluations, as medical trials are more likely to be funded in the long-term (Psihogios et al., 2020). Partnerships between these disciplines can also support higher-quality designs and evaluations as researchers can be dedicated to 1 area of a project. For example, the Text4Baby program included a multiyear collaboration between computing and medical researchers. This project led to evaluations specifically for low-income parents and was evaluated at multiple stages, including a pilot evaluation (Evans et al., 2012) and a randomized controlled trial (Evans et al., 2015). The Text4Baby program was also evaluated across diverse contexts, including Spanish-speaking parents (Evans et al., 2012), pregnant people who smoke, and pregnant and postpartum people from underserved areas (Gazmararian et al., 2014). Chandler et al (Chandler et al., 2021) documented the cultural tailoring practices for mHealth tools aimed at addressing sexual and reproductive health outcomes for Black and Latina women and identified opportunities to improve long-term outcomes and address health disparities. In domains other than child development support, researchers have called for more impactful collaborations between computing and medical researchers. Calvo et al (Calvo et al., 2018) documented an initiative to bridge researchers in computing, medicine, and health informatics around the global mental health epidemic and identified challenges and solutions related to interdisciplinary collaboration. As the applications of technology-based interventions for child development are often novel, there is an opportunity to recognize the success of interdisciplinary collaboration in other domains and set standards for future work in this area. With support across these disciplines, the early stages of the design and evaluation process can include larger and more diverse populations and introduce multiple dimensions of evaluation that address interface design, population relevance, and clinical objectives.

3.1.3.3 Reporting Guidelines

We identified that there is inconsistency in the reporting of race or ethnicity data and socioeconomic backgrounds in the samples. Several studies in this review did not report the racial or ethnic backgrounds of the participants in their samples. In all, 33% (5/15) of studies did not report socioeconomic data for their participant samples (Huang & Li, 2017; Jacques et al., 2020; Lozoya et al., 2019; Nyström et al., 2017; Suh et al., 2014). Researchers have found that reporting the demographic makeup of research samples helps illuminate potential disparities in the effectiveness of novel systems (Van Veen et al., 2019). To address the potential of interventions to contribute to intervention-generated inequality, Veinot et al (Veinot et al., 2019) recommended setting recruiting objectives that lead to testing in more diverse samples by targeting members of both disadvantaged and advantaged groups in early evaluations. We also identified that there is consistency in demographic reporting formats within fields but not across them. To improve the generalizability of results across fields, researchers might rely on national guidelines for reporting demographics (Health, 2001). In addition, Siek et al (Siek et al., 2019) documented that certain racial disparities within technology use can sometimes be flattened when differences between groups are not reported or analyzed. Therefore, consistency in the reporting formats for racial demographics is necessary. Reporting demographics can also support broader research objectives to identify trends in technology use among specific populations (Veinot et al., 2019). As such, there is a need for researchers to both report their participant demographics with more granularity consistency and document the effectiveness of systems with attention to the unique experiences of different racial groups. Improvements in reporting have the potential to support more accurate and granular identification of those affected most by health disparities. For example, researchers have identified standards for demographic reporting that support the accurate identification of health disparities within public policy (Dorsey et al., 2014).

3.1.3.4 Research Across Fields

The research objectives, methods, and paper formats tended to be consistent within fields. Among studies from medical fields, papers tended to be shorter in page length, focused on evaluating child health outcomes, and used quantitative methods to experimentally evaluate the effectiveness of the systems. Computing fields focused on using qualitative research methods to identify whether the design of systems was feasible for target populations and documented the opinions of participants on interface and interaction experiences. As expected, studies published in health informatics fields use a hybrid of methods from both computing and medical traditions, experimentally documenting child health outcomes and the feasibility of systems for deployment in larger populations. Researchers in computing, health informatics, and medical fields have all focused on the impact of usability and feasibility on the long-term effectiveness of interventions (Fedele et al., 2019; Stowell et al., 2018). Researchers at the individual level might adopt a mix of qualitative and quantitative methods to complete more comprehensive evaluations of systems; however, interdisciplinary collaboration is needed to develop comprehensive and large-scale evaluations (Siek et al., 2019). The research methods favored by different fields could have implications for how user voices are centered into the design process. For example, studies in the computing fields often relied on qualitative methods like user interviews, which are useful in gathering in-depth perspectives. However, if these interviews are not conducted with a diverse range of people, they might not capture the needs of people from diverse backgrounds. While the field of publication itself may not directly address the inclusiveness of user input, the specific research methods employed within each field can impact how user voices are included in the design process. Partnerships between computing, medical, and health informatics researchers could lead to funding for large and long-term evaluations, a more comprehensive design process, and resources designated to developing content that addresses >1 need in the target population.

3.1.3.5 Content Development Process Reporting

Reporting content sources support the decision-making process in uptake for both parents and pediatricians (Liljenquist & Coker, 2021). For pediatricians to recommend mHealth systems such that their guidance is aligned with the guidance from the systems, interventions should report their content sources and refer to national guidelines for content (Garg et al., 2016). As mentioned in the studies from this review, an expert review of the content can be helpful in the design process. Although each study contributed a technology on a different topic area in child health (e.g., some addressed nutrition, others addressed physical activity), none of the studies in this review developed a technology that comprehensively addressed anticipatory guidance, development and behavior screening, or social determinants of health topics.

The social determinants of health topics are of particular importance, as they have the potential to support communities affected by racial disparities. The impact of social determinants on health content is 2-fold. First, screening for social determinants of health can illuminate the health risk factors that are directly influenced by social contexts. Garg, Boynton-Jarrett, and Dworkin maintain that social determinants of health screening are imperative for identifying how race influences health outcomes (Garg et al., 2016). Within child health promotion, social determinants of health screening can lead to tailored recommendations (Schickedanz & Coker, 2016). Second, the social determinants of health frameworks can be useful for informing the content of health technologies through features that are adjacent to core health guidance. For example, researchers have evaluated consumer health apps and have identified that the technology literacy, price, and system demands of mobile apps influence the user experience (Biviji et al., 2021), which are all related to the social contexts in which people interact with systems. Thus, social determinants of health content can be relevant to both the content and implementation formats of technology systems.

3.1.3.6 Design and Implementation Recommendations

There are several design, evaluation, and implementation recommendations that arise from the findings of this review and align with guidance in avoiding potential intervention-generated inequalities. Researchers might engage more diverse populations in the early design phases of systems to identify potential barriers to adherence in later testing phases and access them in later implementation phases. Computing researchers have identified that using human-centered methodologies in the early design and evaluation phases of system development leads to more effective and sustainable outcomes (Harrington et al., 2019; Primiero et al., 2020). Including and reporting both the experiences of diverse populations and demographic sample makeup can illuminate potential disparities in health interventions. In this review, most studies focused on the evaluation of developed prototypes and sought to understand how to improve these designs for later iterations in the target populations. Although usability and feasibility evaluations are beneficial for determining goals for future designs, understanding the broader contexts in which people use systems requires further specificity (Stowell et al., 2018). Evaluating systems, including specific objectives to address the effectiveness of racially diverse communities, can promote the recognition of racial disparities. For example, Brewer et al (Brewer et al., 2020) presented several case studies documenting the impact of context-specific considerations in health informatics interventions related to race and community. The case studies included in this work highlight strategies for implementation and design that directly respond to the experiences marginalized communities have with their health and related technologies. Unless there are specific objectives for late-stage evaluations to capture the experiences of underserved populations, these evaluations cannot respond to technology-generated disparities.

Involving underserved populations in early-stage design processes can illuminate the influence of racial disparities and the potential for technology-generated disparities. There is an opportunity to document the earlier stages of design and use methods in early-stage processes that promote meaningful engagement with the target populations. For example, researchers have relied on design methods that enable target populations to become cocreators of systems, including co-design (Primiero et al., 2020) and participatory design (Light & Akama, 2012). There is a broad spectrum of participation in target populations, extending from the community level to individualized participation (Berge et al., 2009). Early-stage involvement in design processes is crucial to meaningfully address the risk of technology-generated disparities, as design specifications born out of conversations with target populations can respond directly to their unique needs (Van Veen et al., 2019).

Meaningful engagement with communities also extends to contexts in which they are likely to interact with health interventions and environmental factors that contribute to the effectiveness of these systems. Developing interventions within the community context can foster awareness of the reality of how communities experience and interact with technology. For example, Muñoz and Arriaga (Muñoz & Arriaga, 2015) documented the preferences of low-income parents when tracking child development by using technology. In this work, the researchers met parents at centers for women, infants, and children and identified context-driven guidelines for technologies, including sharing information between multiple caregivers and across generations. Modifying studies to be culturally aware can foster greater participation from communities. From the same work by Muñoz and Arriaga (Muñoz & Arriaga, 2015), 1 member of this research team spoke Spanish, the dominant language in this community, and the researchers included Spanish materials. This led to a substantial increase in the recruitment of Spanish-speaking parents (nearly doubled). Researchers have also demonstrated that deploying interventions in diverse contexts requires attention to the unique community contexts. Escobedo and Arriaga (Escobedo & Arriaga, 2022) engaged with parents in a neighborhood childcare center, where they evaluated a milestone-tracking application. In this study, the researchers collaborated with Spanish-speaking parents and identified that official translations of developmental milestones from the Centers for Disease Control did not reflect the Spanish variant (Mexican Spanish), which is primarily spoken in the United States. Through careful engagement with communities, both design and evaluation processes can be responsive to the unique experiences of diverse communities.

Researchers might also engage families as designers of technologies to identify well-suited delivery methods and feature specifications. Studies have engaged families in design practice and have found that systems are better aligned with family experience (Yuwen et al., 2021). The user interface and experience can also be honed through this type of research engagement (Ogbonnaya-Ogburu et al., 2020). Although this systematic review did not specifically focus on the design and evaluation of features in these technologies, researchers have demonstrated the influence of features on outcomes (Klasnja et al., 2011). Although none of the articles included in this review included feature-level analyses, including the evaluation of features may lead to an understanding of what features affect proximal outcomes.

3.1.3.7 Limitations

There are limitations to our findings. We did not include articles that described the components of an mHealth technology or a study to evaluate it but did not have participant groups using the technology (e.g., study protocols). We also did not include studies where mHealth technology was a part of a larger intervention or studies of technologies developed for parents of children with specific health conditions, such as autism. This may exclude technologies that address areas of early childhood health promotion, specifically those covering developmental delays. Finally, our analysis of this work was heavily informed by Bright Futures Guidelines for Health Supervision of Infants, Children, and Adolescents, which was developed in the United States and thus could include content that is culturally different from developmental screening content in other countries. The Bright Futures guidelines are unique to the developmental screening processes in the United States, which may frame child health needs differently than other countries. As such, our analysis may not reflect each unique context in which these child health technologies have been developed.

3.2 Quality of Mobile Apps for Child Development Support: Search in App Stores and Content Analysis

This content analysis aimed to document the landscape, design, and content of apps in the United States available to parents as they promote their child's developmental health. We explored two major app stores in the US (Google Play and Apple App stores). To our knowledge, there has not been any assessment of the quality of these apps to identify how many developers follow evidence-based guidelines in the creation of these mobile apps. To assess the current state of mobile apps for early childhood development and health promotion, we have the following research objectives:

1. What is the landscape of apps that support parents promoting their child's developmental health, for children aged 0 to 5 years?
2. What aspects of child development support do specific features or design choices address?
3. What burdens are these apps potentially placing on parents or caregivers as they use them?
4. What is the cultural competency of these apps?

3.2.1 Methods

3.2.1.1 App Search and Selection Strategy

We used a content analysis approach based on methodological guidance from Downe-Wamboldt (Downe-Wamboldt, 1992) and Mendiola et al (Mendiola et al., 2015) to guide the collection and coding of early childhood wellness apps. In January 2022, we searched across Apple (iTunes or App Store) and Android (Google Play) app stores, as identified by Statista (Statista, 2022) as the top 2 most popular app stores in the United States. Our search strings included terms describing child development in simple words (e.g., *baby health* and *baby app*). We developed our search terms by combining different strings of terms that are synonymous with the term "*child development app"*. The full search strings used in each app store are presented in Appendix C. We limited our search to apps that were available in English and were free to download, as it is recommended that mobile apps for lower-income or disadvantaged communities should be freely accessible (Christodoulakis et al., 2017).

We completed a unique search for each search string in the app stores. We searched for Android apps using the mobile version of the Google Play store, accessed through a web-based smartphone interface. We accessed the Apple apps by searching in the mobile version of the Apple App store. For each of the search result lists, we recorded app titles, respective app stores, and search terms used for all apps yielded from the search. We downloaded all Apple apps to an Apple device running iOS 14 and Android apps to an Android emulator running Android 7.2 on a desktop computer. To mitigate potential biases based on tailored search results, we completed all searches without being logged in to an account on the app stores.

3.2.1.2 Selection Criteria

The 3 members of the research team collaborated to develop the inclusion and exclusion criteria for the mobile apps. We included apps if they (1) supported screening or tracking of developmental milestones up to at least the age of 5 years, (2) supported tracking of health promotion behaviors for children up to the age of 5 years (e.g., feeding or sleeping), (3) supported English (as the primary language or translations), and (4) were free to download. We excluded apps from the analysis that (1) did not involve baby or child information tracking in some capacity (e.g., pregnancy tracking, fertility tracking, or period tracking); (2) only allowed tracking of sentimental mementos; (3) did not offer English translations; (4) were paid apps; or (5) were not downloadable or had restrictions (e.g., requiring an early access password).

3.2.1.3 Selection Process

We documented the search results on a spreadsheet and flagged duplicates for follow-up across stores. Several apps were present in both app stores but used different names in each app store. A researcher screened the search results in 2 phases by using the inclusion and exclusion criteria. The first phase involved screening the titles of the apps for duplicates between Android and Apple stores and marking apps as potentially relevant. For duplicate apps, we downloaded each and first compared for differences in functionality before excluding a version of the app. In the second phase, we applied the inclusion and exclusion criteria to the app's descriptions in the app store and confirmed the availability for download. A flow diagram detailing the number of apps present in and after each phase is presented in the Appendix C Figure.

3.2.1.4 Data Extraction

A researcher downloaded and reviewed the included apps, documented content into a web-based survey form, and reviewed the data generated on a spreadsheet. This content included (1) the name of the app, app store downloaded from, category in the app store, size in megabytes, highest operating system supported, and latest date of update; (2) the developer name or company, developer's classification (e.g., individual or company), and developer's self-reported credentials related to early childhood health (if provided in the app posting); (3) privacy permissions that the app requests; (4) in-app purchase content and prices (if offered) and if advertisements are present in the app; (5) other languages offered by apps where English was set as the primary language; and (6) content and delivery structures of the apps, meaning what features each app used (e.g., tracking functions or reminders) and what topics were addressed in the apps. We also documented other barriers to accessing mobile apps guided by the literature in health informatics related to mobile health app efficacy for diverse populations, including technical requirements such as internet access, size and data demands of the app, 1-time or subscription costs, and language availability (Murray et al., 2016).

3.2.1.5 Data Analysis

The authors developed codes for the app's features and content by referencing the national Bright Futures Guidelines for early childhood health promotion (Hagan et al., 2017) and User Burden Scale (Kientz & Suh, 2018). With guidance from an author, who is an academic researcher in developmental screening and pediatric health promotion, we reviewed Bright Futures Guidelines and categorized contents by topics covered in well-child visits with pediatricians. From User Burden Scale, we included topics present in the user experience of mobile apps. We have categorized our coding scheme and the peer-reviewed content that informed the coding scheme in Table C1 in Appendix C. We also completed a search of all included apps in January 2022 on Google Scholar to identify if the apps had evaluations published in peer-reviewed venues. An overview of the app characteristics is available in Table C2 in Appendix C.

3.2.2 Results

3.2.2.1 Selection and Inclusion of Mobile Apps

Our initial searches yielded 1348 apps between the Apple App store (574 apps) and Google Play store (774 apps). We excluded 1199 apps during the screening process. We removed 324 (24.1%) duplicates that appeared in both the Apple App and Google Play stores' search results after comparing functionalities among apps and prioritized including Google Play store versions over the Apple App store versions for the convenience of app review in a web-based emulator. Of the remaining 1024 apps, we excluded 560 (54.7%) apps by title, 400 (39.1%) apps by relevance, and 64 (6.3%) by cost or password-protected download, leaving 149 (39.1%) apps that met the inclusion criteria and were coded. The figure in Appendix C illustrates the number of apps excluded from the search at each stage of the screening process.

3.2.2.2 App Store Characteristics

Table C2 in Appendix C summarizes the coded app characteristics. In the sample of coded apps, 52 (34.8%) came from the Apple App store and 97 (65.1%) came from the Google Play store. In the Apple App store, 52 apps were distributed across the following categories developed by the Apple App store: Medical (n=28, 54%), Health & Fitness (n=16, 31%), Education (n=5, 10%), Utilities (n=2, 4%), and Lifestyle (n=1, 2%). In the Google Play store, 97 apps were distributed across the following categories developed by the Google Play store: Parenting (n=68, 45%), Medical (n=10, 6%), Health & Fitness (n=8, 5%), Education (n=7, 4%), Books & Reference (n=2, 1%), Lifestyle (n=1, 0.7%), and Tools (n=1, 0.7%).

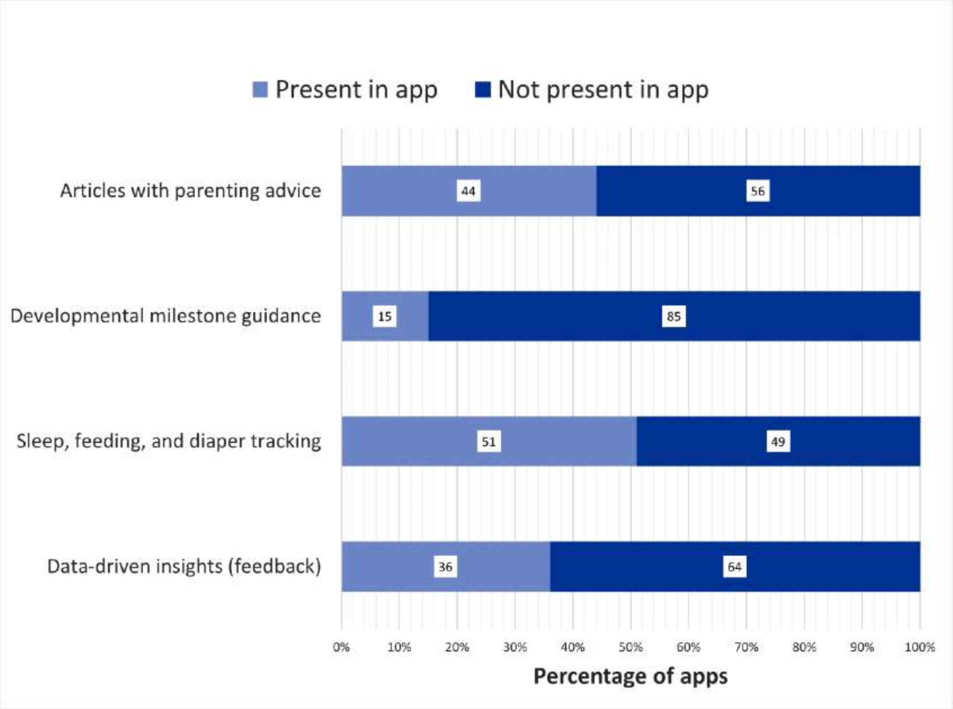
The earliest operating systems supported ranged from 2010 to 2016 (Google Play store) and from 2014 to 2017 (Apple App store). On average, apps supporting operating systems have been released in the last 7 years. The oldest operating systems were supported by apps from the Google Play store: an app supported phones running operating systems released in 2010. Approximately 38% (37/97) of the apps from the Google Play store supported phones running operating systems released in 2013 or older.

Across both the Google Play and Apple App stores, the dates of the app’s last update ranged from 2014 to 2022. In the Google Play store, the oldest date of the last update was 2015. On average, apps have had at least one update in the last 2 years. Approximately 45.6% (68/149) of the apps were updated in 2022. An app from the Apple App store had not been updated since July 11, 2014, but at the time of writing, it was still available for download from the app store. Unless specified otherwise, the remaining findings are generalized across both the Apple App and Google Play stores.

3.2.2.3 App Features

We also categorized apps based on those that provided feedback to guide parent action and those that did not provide feedback. This categorization was based on the functionalities related to the user experience for data entry that emerged from the apps during the data-gathering stage. The figure below depicts the features present or absent in the mobile apps used in this study (Figure 4).

Figure 4: Features present in mobile apps



Apps that provided feedback supported parents in tracking their child's health data and analyzed the data to recommend that parents pursue specific actions. For example, a parent might use an app to track their child's milestones, and the app consolidates information (e.g., in a summary for parents to review), determines if there is a delay, and recommends the parent contact a pediatrician for a more detailed assessment of their child's milestone progress. Apps that did not provide feedback allowed parents to track data such as milestones but did not generate personalized feedback on milestones or recommend that parents seek consultation from a pediatrician if their child was delayed in certain milestones. We classified the apps as providing feedback based on their primary and secondary functions offered in the app. Of the 149 apps included in this study, 54 (36.2%) provided feedback to parents. The remaining 63.7% (95/149) of the apps included in this study were classified into the nonfeedback category, as neither their primary nor secondary functions provided feedback informed by personalized information entered by the parent. The textbox below highlights some of the main features present across apps that provided feedback to parents and those that did not (Textbox 2).

Textbox 2: List of features in included apps

Features that provide feedback to parents (in no specific order)

- Data visualizations or summaries of user-generated data
- Dynamic checklist of developmental milestones by age (highlighting on track or off track)
- List of development-promoting activities that parents can try

- Screening checklist for specific child health conditions
- Trivia or quiz questions about child health and parenting topics
- Weight, head, and height centile calculator
- Data entry (eg, diapers, feeding or sleep times, words, vaccines, or new teeth) paired with insights and analysis of data
- Growth chart for weight, height, and head circumference that maps and provides guidance about the child’s measurements

Features that do not provide feedback to parents (in no specific order)

- In-app articles with parenting guidance
- Sentence-long parenting tips
- Sentimental milestone diary
- Social media forum to connect with other parents
- Videos demonstrating activities
- In-app shopping for baby and parents
- Data entry (eg, diapers, feeding or sleep times, words, vaccines, or new teeth) without insights or analysis of data
- Growth chart for weight, height, and head circumference that does not map or provide guidance about the child’s measurements

3.2.2.4 Content and Delivery Methods of Apps

We classified the apps into 2 primary categories, acknowledging that the age range for these apps may extend beyond the functionalities offered within each category. The first category included apps that tracked feeding, sleep, and diaper tracking similar to the tracking recommended for parents immediately following birth (from birth to approximately 18 months). The second category of apps included those that proctored developmental milestone screenings through dynamic questionnaires (from birth to age 5). In all, 6.7% (10/149) of the apps reviewed in this analysis supported feeding, sleep, diaper tracking, and developmental milestone tracking.

Half (76/149, 51%) of the apps reviewed in this study had a primary function related to feeding, sleep, and diaper tracking. In these apps, parents create a data entry of (1) when their infants fall asleep and for how long; (2) how many diaper changes they have in a day and the quality of the infant’s excretion; and (3) when the infant was fed, for how long, what they were fed with (e.g., breastfeeding or bottle), and which breast the breastfeeding parent used during their feeding session. Some apps include advanced features, such as generating charts detailing average sleep duration, feeding duration, or feeding patterns, if multiple methods are used. However, none of the apps in this category offered feedback based on the data entered by parents. For example, to test the functionalities, a researcher made multiple entries in the apps, demonstrating that the infant had not excreted in over 3 days, as national guidelines for infant health recommend contacting a pediatrician if the infant does not excrete for >3 days. None of the apps flagged this pattern as an issue or recommended the parent contact a healthcare professional. It is important to note that while half of the apps offered these features, tracking feeding, sleep, and diaper changes might not be relevant for the entire age range of the apps (up to 5 years).

Of these 149 apps, 66 (44.3%) provided secondary functions, such as access to articles with generic information, which were not personalized to the parent or infant's unique characteristics. These articles included nonspecific parenting advice, information about child developmental milestones, activities to promote children meeting milestones, or photos and video trackers for sentimental child milestones.

Of the 149 apps in total, 23 (15.4%) in this analysis had primary functions related to developmental health promotion and developmental milestone screening. In these apps, parents complete question sets to check their child's progress toward milestones in the 5 key skills outlined by Bright Futures: gross motor, fine motor, speech and language, cognitive, and social and emotional skills. After completing question sets, the apps generated a summary of milestone progress, sharing if the child was on track to meet milestones, required extra support to meet a milestone, was ahead in their milestones, or was behind on a milestone. On average, these apps supported milestone tracking from birth to the age of 5 years, and apps ranged in support across health promotion themes from birth to the age of 8 years. All apps in this category recommended that parents connect with a pediatrician to follow up on their child's developmental progress. In all, 4% (2/53) of the apps in this category shared milestone-dependent activities that parents could follow to promote their child's progress toward milestones; however, these activities were not tailored to unique constraints that families had (e.g., safe environment or resources).

Of the 149 apps, 50 (33.6%) offered content related to early childhood health through articles, web-based forums, or growth charts. Apps in this category typically provide information about child health in a noninteractive way, either through lengthy articles or sentence-long trivia facts. An app in this category allowed users to engage with content in a semitailored way, using a chatbot with predetermined chat options, enabling the user to filter information through interactive means.

3.2.2.5 User Burden

We coded apps for their perceived user burden based on 6 user burden constructs (Kientz & Suh, 2018), including the difficulty of use burden, privacy burden, and financial burden. Using these constructs, we coded for user burdens that might deter users from continuing to use the app in a meaningful way. To address time-based burdens, defined by Suh et al (Suh, Shahriaree, et al., 2016) as "requires frequent use or a significant amount of time to use," we documented the time that it took the researchers to complete onboarding tutorials and develop an understanding of how to use the app. We identified that of the 149 apps, 62 (41.6%) required less than a minute to complete onboarding tutorials. In total, 80 (53.6%) apps required <5 minutes to complete onboarding tutorials, whereas 7 (4.7%) apps required >5 minutes to complete the tutorials. In total, 24 (16.1%) apps required >10 minutes for researchers to understand how to use them. However, it is important to note that the research team is not representative of the target population, and as such, these estimates cannot be extended beyond this context.

To address the difficulty of use burdens, we coded for the amount of information presented all at once and whether that information was overwhelming (i.e., identifying learning curves). Suh et al (Suh, Shahriaree, et al., 2016) define difficulty of use burdens as “The system does not fit with the abilities of the user and is difficult to use. Example systems: i) A photo editing soft-ware package with a steep learning curve; ii) A website that is not compatible with a blind user’s preferred screen reader.” Following this guideline, we documented the presentation of information in the app, and important information about the app’s user experience (eg, key functions or menus) were readily surfaced to the user. A total of 23 (15.4%) apps presented high amounts of information to the user right away, such as long, text-heavy articles about parenting that required long durations of scrolling in the app, highly detailed charts without clear labels, or cluttered home screen or menu items that required the user to click through all of them to understand what they were for. We coded 78 (52.3%) apps that presented large amounts of text without audio or video alternatives, which could present accessibility issues for users with low literacy or vision challenges. We did not directly try out the smartphone’s system accessibility tools in these apps.

More than half of the apps did not require the user to remember extensive information on their own, including the cadence for data entry in apps that require data tracking, key takeaways from guidance on child behaviors and related parenting actions, and returnability for content that may be relevant for the parent later. A total of 136 (91.3%) apps offered functionality within the app that remembered and surfaced information for the user, such as including reminders to track a child’s health metrics or allowing the user to pin relevant pages to access later. We also tracked potential usability concerns related to the mobile app’s system responsiveness, within reliability and user experience. A total of 33 (22.1%) apps posed usability and reliability concerns, including delays in functioning or frequent crashes. These apps also posed additional concerns within the user experience, including requiring repetitive actions to track information (not providing a seamless data-entry experience) or not labeling icons with text descriptions that would require the user to interpret imagery on their own to discern functionality. A total of 6 (4%) apps had color schemes with low contrast between the text and backgrounds. Furthermore, 32 (21.5%) apps had text sizes smaller than 16- to 17-point font, which is not recommended by Google in its Material Design guidelines for developers and Apple’s Human Interface Guidelines.

3.2.2.6 Financial Burdens

We also tracked potential financial burdens on the user. Almost half of the mobile apps required in-app purchases to access the full extent of the app’s capabilities or to remove advertisements from the app. Liu et al (Liu et al., 2012) described the business strategy of these apps as *Freemium*, where apps are free to download but have highly limited functionality without the user paying for premium content. A total of 45 (30.2%) apps required an average 1-time payment of US $8 (SD 11.89), ranging from US $1 to US $60. Furthermore, 25 (16.8%) apps required subscription fees to access the full functionality of the mobile app or remove in-app advertisements. Of those apps, subscriptions averaged to US $57 (SD 48.75) per year, ranging from US $3 to US $225 per year, with an average subscription price of US $23.99 per month. A total of 6 (4%) apps in this analysis included companion tools to supplement app features, which parents would need to purchase to take advantage of the full functionality of the app.

We identified that advertisements were another potentially burdensome feature of some apps. Some advertisements could be bypassed by paying for premium features in the app; as such, advertisements frequently interrupted the user's experience with the functions of the mobile apps. In total, 3 (2%) apps had advertisement pop-ups that blocked features in the app for at least 20 seconds. Furthermore, 4 (2.7%) apps had advertisements that presented adult content, such as weapons, drugstores, or adult games.

3.2.2.7 Privacy and Permissions

The Google Play and Apple App stores have unique systems for tracking the privacy policies of apps, although each store includes information about data-use permissions. Between Apple and Android apps, 30.9% (46/149) of apps listed that data collected from the app would not be linked to the primary user. Among those, 13% (6/46) of apps requested access to potentially sensitive data, such as location, contacts, photos, camera, network connection information (access to internet connection information or Bluetooth devices connected), or existing data on the device. A total of 75 (50.3%) apps requested access to potentially sensitive data such as those outlined earlier but did not provide information on how the data would be used on the download page. For these apps, data-use policies were located directly in the app. Furthermore, of the 149 apps, 40 (26.9%) apps did not provide any information related to privacy policies or data-use permissions and only 12 (8%) apps allowed users to delete their profiles or data collected in the app. All apps requested potentially identifying information, such as the parent's name and age, child's name and age, and zip code or approximate location.

3.2.2.8 Developers and Credentials

Using information from individual app pages in the app store and external web-based resources (linked from app pages or within the app), broadly, apps were developed by companies; 125 (83.9%) apps were developed by individual associations. Of these apps, 2 (1.6%) were developed by companies in partnership with researchers at a university. We reviewed the company websites posted on app store pages where the app development teams and credentials were listed. Of these associations, only 12 (9.6%) listed subject-matter experts on their app development teams. A total of 7 (5.6%) apps were developed by parents or people who had parented previously. In total, 106 associations did not mention that they included subject-matter experts or parents or caregivers in their development teams. In all, 3 (2.4%) apps were developed by teams from hospitals or medical centers, 2 (1.6%) apps were developed by government agencies, and 1 (0.8%) app was developed by a nonprofit organization. In total, 14 (9.4%) apps were developed by individuals who did not specify their subject-matter expertise or lived parenting experience. An app was developed by 2 parents with an education in sports science. Among the 149 apps, only 13 (8.7%) apps referenced building content in the app following guidelines from government standards (eg, CDC or World Health Organization guidelines) or by citing relevant literature on early childhood health milestones.

3.2.2.9 Technical Requirements

We coded technical requirements that may prevent users from continuing to use the mobile app after download. Of the 149 apps, 60 (40.3%) required Wi-Fi or paid cellular data plans to function. In total, 11 (7.4%) apps required more space than specified on the app download page for the downloaded content. Furthermore, 48 (32.2%) apps required an email address to use the full functionality of the app, and 2 (1.3%) apps required a Google account. Of these apps, 4 (8.3%) required a phone number that could receive text messages to sign up for the app.

On average, smartphones made since 2016 hold between 64 and 128 GB of memory storage (Li et al., 2013; Wang, 2021). On average, operating systems released in 2016 and later require 20 GB of memory to run, leaving between 44 and 108 GB for the smartphone owner's personal data, including app downloads. For the apps included in this analysis, the average size of the apps across both the Apple App and Google Play stores was 0.0314 GB or approximately 0.07% of the space for a smartphone with only 44 GB of space available. The sizes of the apps ranged from 0.0016 GB (approximately 0.004% of space) to 0.3455 GB (approximately 0.8% of space). For the Apple App store specifically, the average app size was 0.06 GB, while the apps from the Google Play store had a lower average size of 0.02 GB.

3.2.2.10 Health Literacy Requirements

We tracked the health and reading literacy (Ancker et al., 2020) levels required by the apps. We also tracked if the app had substantial grammatical problems that hindered the reader's understanding of the content. We also documented the reading levels required for the content in the apps by selecting samples of reading required for all features in the app. Using the Flesch Reading Ease method, we entered text samples from the apps into a web-based resource that calculated the reading level. In sum, 42.9% (64/149) of the apps in this review presented content below the 7th or 8th grade reading level (Farr et al., 1951). Of the 149 apps, 3 (2%) used languages categorized at the college reading level. Of the 113 apps that offered explanations of health topics, 108 (95.8%) apps used simple language (below the 7th or 8th grade reading level) to explain health terms.

3.2.2.11 Cultural Competence and Personalization

We also included a dimension of evaluation that focused on cultural competency and tailoring of the apps for diverse groups. A limitation of this work is that we did not include apps developed and presented in primary language aside from English. Mobile apps published in app stores require additional steps to optimize them for globalization or availability across >1 language version of the app store (El-Kassas et al., 2017). To access apps with primary languages other than English, a user is required to complete additional steps, including modifying their country or region for their settings across their device, obtaining a virtual private network, or having access to a payment card authorized for use in another country (Apple, 2022). To represent the search experience of people with limited technology literacy, we retained the default search experience for users operating their devices in the United States.

In this study, only 20.1% (30/149) of the apps offered languages other than English, including Spanish, Mandarin (Chinese), and German. Although we did not include mobile apps developed in a primary language other than English, we did intend to document other aspects of cultural competency that could be present in the design of mobile apps. In this area, we examined the perceived support of multiple cultural experiences following guidance from the theories of cultural competence, an approach to patient care (Curtis et al., 2019). We documented the diversity of visual aids in apps that included pictures and videos. Only 12.1% (18/149) of the apps in this study offered images, videos, or icons that depicted people of color. In addition, 24.2% (36/149) of the apps did not offer any personalization features. Of the 75.8% (113/149) of apps that did offer personalization features, those features included changing the name of the child or parent profiles in the app, adding images of a child or family, and changing the colors or themes of the user interface. It is also important to note that several of the apps in this study used gendered language when referring to family configurations (eg, referencing mom and dad, offering only male or female choice for child and parent). An app included in the study, *Baby Sparks—Development App*, offers personalization features that address diverse configurations of families. When getting started in the app, users have the option to self-identify with a broad set of titles, including grandparents, aunt or uncle, development professional, or babysitter. However, similar to the other 12.1% (18/149) of the apps in this study that included diverse imagery, this only includes pictures of families from different races and ethnicities. None of the apps in this study included imagery that presented queer families; caregivers of different ages; or family members with disabilities, different weight ranges, or different religions.

3.2.3 Discussion

This content analysis found that early childhood health apps support 3 categories of child health monitoring: tracking feeding, development tracking, and learning new information about parenting behaviors. By classifying apps, we documented some of the available apps that can support parents in promoting their child’s healthy growth.

3.2.3.1 Searching for Quality Apps

Assessing the quality of mobile apps is an extremely difficult process if the end user is not informed about what qualities they should examine. Parents sometimes seek guidance from trusted sources to navigate the breadth of parenting knowledge available to them, relying on friends and family, curated content from web-based sources, and discussions with web-based communities. Conversations with healthcare providers also inform the decisions that parents make about their parenting practice. Currently, other parents and medical professionals contribute their reviews of mobile apps for child development support on the web. However, reviewing these resources and making an informed decision requires more time and effort from the parents. For this reason, parents generally rely on the content present in the app store to make decisions about which apps are most appropriate for their family’s needs (Virani et al., 2021).

There is an ongoing discussion on the role of the regulation of mobile apps for health promotion, particularly among apps promoting weight loss and dieting, mental health support, and chronic disease management (Shuren et al., 2018). Within these areas, it is unclear which groups are responsible for the regulation of content and format for mobile apps (Hassanaly & Dufour, 2021) and at what level in the app development and publishing process. Mobile apps are positioned to spread information widely and directly impact family actions. For this reason, it is important that mobile apps do not promote inaccurate and potentially harmful information. As mentioned earlier, there are some regulations of mobile apps offered by federal organizations, but the provisions of those regulations can be difficult to interpret for people who are not app developers. However, because the question of regulation in mobile apps is ongoing across business, economics, government, medicine, and design, there is a need to support parents who are actively seeking support from mobile apps and prevent the spread of inaccurate and potentially harmful information to families. As mentioned, mobile app users look toward reviews in the app store for more information about the quality of apps before downloading, but these can sometimes be untrustworthy (Biviji et al., 2021). As parents seek guidance from trusted sources, there is an opportunity to both develop a framework for the evaluation of mobile apps that parents and pediatricians might rely on when comparing apps in the app store and for designers as they develop child health promotion apps. For example, in both the Google Play and Apple App stores, there are categories (eg, device compatibility, languages offered, and images) that communicate high-level information to users before download. There is an opportunity to leverage how information about apps is presented in the app store (eg, screenshots of app content and descriptions of functionality available in the app), with potential to support end users and people who recommend apps (ie, healthcare providers) as they navigate the available apps in the app store.

Finally, for designers, an evaluation framework can act both as a guide for ethical design outcomes and as a method for evaluating the ethics of apps. In this study, some of the content of our coding framework is directly related to digital ethics (ie, user burden). There is ongoing discussion in computing that references digital ethics and opportunities for digital ethics to act as a guide for design decisions, especially among mobile apps (Sharp & O'Sullivan, 2017). The Associated Computing Machinery provides a code of ethics (Gotterbarn et al., 2018; McNamara et al., 2018) that designers have previously referenced in their work, to develop useful systems without harming users. Although a review of ethical and unethical practices in mobile app design is beyond the scope of this paper, future work in this area might extend the criteria for the evaluation of mobile apps explored in this paper, supporting designers as they make ethical decisions. For example, the criteria for evaluation might include user burden ratings, technical requirements, areas of child development addressed, cultural competency, health literacy required, and content supported by scientific guidelines. The findings of this study can be used as a foundation for researchers to develop an evaluation framework. Designers and researchers might collaborate in this area to develop a set of criteria that represents both the research and design perspectives and requirements for useful and practical guidelines. In Table 2 below, we share a few examples of evaluation criteria that researchers and designers might develop for the evaluation of mobile health apps for child health promotion.

Table 2: Examples of criteria for the evaluation of mobile apps for child health promotion.

Criteria	Definition	Professionals involved in refining the criteria
Scientific evidence foundation	What are the sources used for health information in the mobile app? Are these sources based on well-founded scientific claims?	Child health researchers, pediatricians, and public health organizations
Areas of child development covered	Does the mobile app address all the areas of child development based on guidance from health authorities?	Child health researchers, pediatricians, and public health organizations
Information communication format	Does the app offer multiple modes of communication (eg, video, audio, text, or pictures)?	Mobile app designers, human-centered computing researchers, and accessibility and inclusion researchers and practitioners
Technical requirements	Does the app require Wi-Fi or data services? Is the app inclusive of devices that are older or have fewer functionalities?	Mobile app designers and human-centered computing researchers
User burdens of the interface	Does the app prevent user burdens on the user as they interact with the app?	Mobile app designers, human-centered computing researchers, and mobile app designers
User burden of access	Does the app prevent cost, health literacy, reading literacy, or security burdens for the user?	Families, public health professionals, health providers, community health workers, and community organizations
Cultural competence	Does the app support a diversity of family experiences by including languages other than English, using nongendered language, presenting diverse family imagery, and offering inclusive health guidance?	Community health workers, community organizations, health providers following culturally informed practices, and diverse families

There is also an opportunity to improve the search experience in the app store. For example, compatibility with accessibility features in smartphones can be listed directly in the app store such that the user knows what to expect when downloading an app. The search experience can also be improved by providing search filters; for example, which apps are free and which have advertisements. This information is already available in the app store but cannot be reviewed across multiple apps simplistically (eg, when comparing multiple apps). Another potential barrier in the app store search experience is the prevalence of promoted apps, which are prioritized in the search before other apps, regardless of their quality. This is potentially harmful, as it may mislead users to believing that these apps are of higher quality. Radesky and Hiniker (Radesky & Hiniker, 2022) broadly promote platforms (which include app stores) being redesigned to be more child-friendly and suggest that through these design changes, systems will widely be less predatory. Finally, there is a need for future work to examine the readability of privacy statements present in both app stores and mobile apps themselves. Currently, the Google Play and Apple App stores offer high-level summaries of privacy and data-use information, and future work might examine the potential for these summaries to support communicating information related to health data and privacy specifically.

Another adjacent finding worth mentioning is the volume of apps in this study that used a *freemium* business model. App managers have referenced using the *freemium* model to improve the likelihood of users purchasing a premium app after a free trial (Appel et al., 2020; Liu et al., 2012), despite lower reviews in the app store. Other researchers have identified that users are willing to pay for apps if they offer more advanced features and improved quality compared with free apps (Biviji et al., 2021). In this study, the costs of apps ranged significantly, and some app subscriptions were expensive. It is worth considering how lower-income users may be excluded from benefiting from higher-quality apps because of the price burden (Kientz & Suh, 2018). Although the use of this business model is at the discretion of companies developing apps and their priorities for app use, there is a need for future work that examines the broad impacts of the *freemium* model for low-income communities and further discussion in industry spaces of the ethics of using *freemium* models for health-promoting mobile apps.

Although beyond the scope of this paper, it is worth noting that several apps included in this analysis were rated as family-friendly but included adult-only content in their advertisements. Other studies have mentioned advertisements in apps that are inappropriate; for example, showing inappropriate advertisement content to children (Chen et al., 2013). Although parents are the primary users of the apps examined in this study, future work might address the effectiveness and accuracy of current rating systems for *family friendliness* among mobile apps.

3.2.3.2 Relevancy of Apps for Underserved Groups

Considering the experience of underserved and marginalized people in this space is crucial. Smartphones are widely owned and have the potential to provide new access to information for people without access to care providers or health resources in health networks. We reported space requirements for mobile apps and found that, on average, the size of apps in this category is feasible for the average space available on smartphones. We want to highlight the potential financial burden of these apps. Of the apps reviewed, subscriptions averaged US $57 per year, ranging from US $3 per year to US $225 per year, with an average subscription price of US $23.99 per month. There is a need to further examine the role of financial burdens from apps as a barrier to use by people from lower-income backgrounds in space, as researchers have done for other health apps (Vangeepuram et al., 2018). Another key finding in this review was related to the lack of culturally diverse visual aids in apps and personalization features. Apps are demonstrated to be more effective when highly tailored to the user's unique experience (Prasad et al., 2012), and culturally informed approaches to health care discourage using one-size-fits-all approaches to patient care and communication (Curtis et al., 2019). Finally, the apps included in this review have ≤3 primary features at a time. There is potential for more features in a singular app to burden the user and reduce the likelihood that they will learn all the features present in the app or continue to use the app over a longer period. As such, there is a need for future work that documents the use patterns of parents in this area. To specify, what apps do parents use at different stages of their child’s growth? What is their experience with managing information across multiple apps at a time? Answering these questions may illuminate opportunities for growth in the field when designing new apps for parent support.

3.2.3.3 Limitations of This Work

There are several limitations to this work. First, the app market is constantly changing. Since we began this review, it is likely that nearly all of the apps in the study have been updated and improved on. As such, the findings of this study may become obsolete for this domain as apps improve in the future. Another limitation is that we did not assess the compatibility of the built-in accessibility features of these apps. There is a need for future work that examines how these apps respond when features such as screen readers or text magnification are enabled to capture the diversity of experiences for people using smartphones.

Another limitation is that we did not analyze the distribution of apps across different age ranges. While we categorized apps based on their primary functions (infant tracking or developmental health promotion), a deeper analysis of the age ranges these apps targeted would have provided a more nuanced understanding of how the functionalities are distributed across the early childhood development spectrum (birth to 5 years). This information could be valuable for developers and researchers who are tailoring information for specific age groups.

Future work may also address the personalization and cultural relevance of experiences in these apps. Tailoring and personalization of care approaches are extremely important in clinical practice, and for apps to be compatible with care happening in clinical contexts, apps should address this need as well. Finally, unlike other content analyses in this field, we did not include app reviews from the app store in the analysis process. This leaves out a key component of information that is usually relevant as users decide what apps to use and engage with other users in the community (Alqahtani & Orji, 2020). Overall, there is a need for more assessments of mobile apps in this area to continue to capture how mobile health apps for child health promotion are changing over time and how they continue to support families.

3.3 Chapter Conclusion

Early childhood health promotion technologies promise to have a meaningful and sustained impact on the health and well-being of children. In studying two areas of innovation for these technologies (academic research and industry design), I found that these technologies are promising, as parents of young children find them feasible, these technologies make meaningful improvements in parent’s confidence and knowledge, and show promise in improving child health outcomes (which also suggests potential for population-level improvements). However, these technologies are likely to fail to improve outcomes if they do not adequately address the greater social, political, economic, and historical contexts that shape the lives of children and their families. Existing design and research frameworks frequently overlook the influence of culture on parents’ and families’ health perceptions and experiences. As a result, these technologies may inadvertently perpetuate stereotypes or provide experiences that exclude families with diverse perspectives and values.

I conducted a systematic review and content analysis of mobile-based technologies for early childhood health, which revealed a lack of technologies that comprehensively address all aspects of child health, including anticipatory guidance, developmental and behavioral screening, and the social determinants of health. This fragmented approach reduces the potential effectiveness of technologies, particularly for marginalized communities, as they fail to consider the broader contexts where children develop and grow. Further, I found that while many apps exist to support parents in learning about developmental milestones, the high volume of low-quality apps and the difficulty of identifying evidence-based, inclusive, and accessible resources may make it challenging for parents (and healthcare professionals that seek to recommend these tools) to find effective tools.

I highlighted the challenges and suggested opportunities of academic research in this space. The current landscape of academic research in early childhood health promotion has many obstacles that hinder progress and limit the impact of innovative technologies. Many technologies do not progress beyond initial feasibility testing in small populations, which indicates the urgent need for more extensive and rigorous evaluation to understand how technologies perform in highly diverse populations. More collaboration between fields can enable these larger-scale evaluations, and further foster a multidisciplinary approach that brings together more diverse and comprehensive knowledge to this complex health technology space. Within these studies, there has been limited engagement with diverse populations in the early design stages, which risks creating more technologies that fail to meet the specific needs and preferences of those families. This lack of inclusivity could lead to technologies that are poorly aligned with the realities of marginalized communities, widening disparities if they are deployed in larger populations.

Studies are also inconsistent in their reporting of participant demographics, making it difficult to fully assess the potential of interventions in reducing or widening disparities. Greater standardization in reporting formats and transparency in research methods would enhance the reliability and generalizability of the research findings. Further, many technologies only address single aspects of child health, neglecting to address the broader social determinants of health. This oversight risks creating solutions that fail to address the root cause of disparities. Technologies that offer more comprehensive content may be more effective, offering a more holistic approach that supports childrens’ and families’ well-being within their context. Relatedly, community-level technologies may provide more awareness of the context and preferences that lead to more appropriate technologies, harnessing the collective wisdom and diverse experiences of communities to inform the design and implementation of technologies. By adopting the cultural safety approach in this space, we can better value and prioritize the perspectives of marginalized communities in how we design these technologies.

I also provide a snapshot of the technologies readily available to parents through the Apple App Store and Google Play Store. While these platforms host an extensive library of potential resources, the current landscape has several challenges that hinder the dissemination of high-quality, equitable apps. I recognized the availability of potentially valuable apps for child development support, but I identified that there are difficulties in finding high quality apps due to limitations in the types of apps offered, and the support that the app store provides in evaluating their quality. The lack of rigorous quality control and prevalence of marketing-driven listings make it difficult for parents to discern beneficial tools from unproductive tools. Additionally, I raise concerns about the prevalence of apps that may exclude marginalized groups, including apps that promote the “freemium” model that are likely to exclude low-income families, and the lack of inclusive content that is likely to exclude diverse families. These barriers limit access to essential support for families, especially those in marginalized communities. I call for more research and design on apps and the app stores that consider the importance of health equity. A greater focus on inclusivity, transparency, and equitable access in this space is needed to ensure that these technologies have impact for communities, regardless of their backgrounds or circumstances.

This chapter has laid the groundwork for the rest of this dissertation by highlighting the role of cultural safety, health equity, and community engagement in the design and research of early childhood health promotion technologies. It has outlined the key challenges and opportunities in the field, indicating the urgent need for a more equitable and comprehensive approach to early childhood health promotion technologies. By establishing these foundational principles, this chapter indicates the need for a more equitable and effective approach to using technology to support the health and development of all children. The following chapters will further explore the challenges of implementing these principles and offer concrete strategies for creating technologies that are more likely to improve outcomes for children in marginalized communities.

The remainder of this dissertation builds on this foundation, specifically focusing on health equity within the design and research of early childhood health promotion technologies. Through the chapters, I further explore the complexities of implementing cultural safety into practice, offering practical strategies and insights for navigating the nuanced and multifaceted challenges of this field. Key themes emerging from this chapter, such as the need to consider the social determinants of health, the necessity of community-based approaches, and prioritizing health equity in mobile app content and delivery, will be revisited throughout the dissertation. These themes will serve as a guiding framework for the upcoming analysis and discussion, particularly in ensuring a coherent and cumulative approach to advancing health equity in early childhood health technologies. Chapters 7 and 8 will specifically delve deeper into the challenges associated with implementing these suggestions, providing a nuanced exploration of these barriers and facilitators to achieving cultural safety in early childhood health promotion technologies.

Chapter 4: Focus Groups to Identify Context-based Parent Needs

Immigrant and refugee families make up a significant part of Seattle's population, yet they still face challenges in accessing preventative healthcare (Seattle.gov, 2023). The Seattle Office of Immigrant and Refugee affairs, and the King County Community Health Needs Assessment both highlight trends in healthcare access and child and family health outcomes for these communities (Community, 2024). While numerous services exist to support these families, research demonstrates that awareness and accessibility, cultural and linguistic barriers, and challenges in service delivery contribute to disparities in care for immigrant and refugee communities (Asgary & Segar, 2011; Morrison et al., 2012). These findings underscore the urgent need for innovative approaches that address these barriers and improve healthcare access for families in marginalized communities.

Given the lack of engagement with immigrant and refugee communities in the development of child development support technologies, I aimed to gain a deeper understanding of the experiences and needs of these families. I collaborated with First Five Years and Beyond (FFYB), a non-profit organization supporting families with young children in South King County, Washington, who primarily assist families recently immigrated from West Africa. Through focus groups with parents and conversations with FFYB leadership, I gained valuable insights into their engagement with child health guidance and their perceptions of technology. This collaboration took place in December 2021. I conducted two focus groups (one virtual and one in-person) with parents, and the content of the focus groups were informed and refined through collaboration with the FFYB leadership. By engaging with them, I learned more about the services they offered families, saw where they operate, and learned how they built social support networks between families.

Given the specific needs of this community and the importance of building trust and rapport, we adopted a Community-Based Research (CBR) approach for this study. CBR goes beyond simply conducting research in a community. It emphasizes collaboration with community partners, who play a critical role in the research process and outcomes, but the level of community member involvement can vary. In contrast, CBPR emphasizes a more egaliatarian partnership between researchers and community members. Community members are not just participants, but active co-creators throughour the entire research process. This includes defining research questions, designing the data collection methods, analyzing data, and disseminating findings. While our community partners were involved in several of these stages, they were not involved as co-creators in all and instead provided feedback. As mentioned, we partnered with FFYB, who has a strong presence in the West African immigrant community of South King County. Through ongoing dialogue with FFYB leadership, we were able to 1) refine our research questions to ensure that they were relevant and culturally appropriate for the community, 2) gain valuable insights into the lived experiences of immigrant families through focus group discussions, and 2) develop a more culturally sensitive approach to data collection and analysis. This collaborative approach enabled the research process and findings to be more meaningful and actionable. While adopting a more robust Community-Based Participatory Research (CBPR) approach, where community members are directly involved in all stages of the research, may be ideal for most community projects, the CBR approach in our study was still effective in building trust, gathering rich data, and contributing to positive change for this specific community. For this study, initiating the full CBPR model, which often requires a longer timeframe for relationship and capacity building within the community, was not feasible within the project timeline. However, adopting the CBR approach enabled us to ensure the relationship between the research team and the community was more meaningful than an extractive research approach.

The key findings from the focus group sessions provide a clear picture of how parents from a West African immigrant background navigate and understand guidance about their child's health. The findings highlight both the successes and challenges these parents face in implementing child health guidance into their daily routines. Further, the research reveals the resources and support networks that these parents rely on as they strive to provide the best care for their children. By providing a deeper understanding of their experience, I aim to inform and inspire the development of future technology interventions that target the broader contexts impacting parent's capacity to promote their children's development. This includes addressing basic needs, building support networks, and integrating technology into existing community resources and services. I contextualize the findings of this study by drawing on ongoing research in the modern and historical factors contributing to mistrust in healthcare systems and technology among marginalized communities, the implications for leveraging social networks as a source of health information, and the importance of addressing basic needs for child development. Overall, my work contributes to the body of knowledge about parent's and family's experiences, while reaffirming the need to center community experiences and understand the limits of technology for certain communities.

The daily realities of parents are full of constant challenges, and for parents in marginalized communities, these challenges are compounded by the broader context of social and economic marginalization. Research has consistently shown a link between social and economic inequity and children's health outcomes (Cabieses et al., 2016). Parents facing additional barriers to meeting their family's basic needs are likely to experience additional stress and less capacity to meet more specific child development needs (Pearce et al., 2019). For these parents, they may be aware of the needs their children have, but are unable to meet those needs in the ways that are recommended to them. Early childhood health promotion technologies (ecHPTs) are designed to support children's development through a variety of ways. Often, these technologies aim to increase parent's awareness of child development information and equip them to follow-up on developmental concerns sooner, or provide them with guidance on things they can do to promote their children's development (DeWitt, Kientz, Coker, et al., 2022). While these technologies are promising for low-income communities and people from marginalized backgrounds, they may be missing a significant opportunity to produce meaningful change in children's health outcomes. Technology interventions that solely target their individual behaviors in this way, i.e., by recommending activities or behaviors that are unaware of their broader parenting context, are unlikely to lead to meaningful changes in the health outcomes of those children. For this reason, technology interventions may be more beneficial that target the broader contexts that impact parent's capacity to engage in development-promoting activities.

In King County, Washington, disparities in child health outcomes persist (Community, 2024). Higher costs of living, income inequality, and limited access to health services put strain on families to afford basic needs and find resources for child development support (Seattle.gov, 2023). In some areas of King County, these issues are more pertinent. South King County is home to a highly diverse population, which includes a significant number of immigrant and refugee families (Seattle.gov, 2023). They may have additional difficulty navigating services and establishing a strong support network. To understand the opportunities and limitations of child development support technologies for parents from West Africa who immigrated to the United States, we completed a focus group study to hear their lived experiences. In this work, we (myself and my collaborators) had three guiding research questions:

1. How do parents from a West African immigrant background describe their experiences navigating and understanding guidance about their child's health?
2. What are the successes and challenges faced by these parents when implementing child health guidance in their daily routines?
3. In their efforts to provide effective care for their children, what resources and support networks do these parents rely on?

By providing a deeper understanding of their experiences, we aim to inform and inspire the development of future technology interventions that target the broader contexts impacting parent's capacity to promote their children's development. Throughout the rest of the chapter, I write from a first-person plural perspective to represent the collaborative efforts between me, FFYB, Leslie Coney, Kendra Liljenquist, and Julie Kientz.

4.1 Methods

We have completed two focus group sessions with parents who identified as West African, low-income, first-generation immigrants, and members of the community organization, First Five Years and Beyond (FFYB), we partnered with for recruitment and guidance on the content of the research sessions. All the parent participants were the primary parent of at least one child under age 5. In these sessions, we aimed to 1) hear parents' lived experience with navigating guidance about their child's health, 2) identify successes and challenges when acting on child health guidance in their daily life, and 3) document who or what (e.g., resources) they rely on for support to be successful in their parenting practice. During the sessions, two researchers (with support from community partners), proctored a semi-structured group interview. Parents engaged in open-ended storytelling and conversations with other parents about their experiences. We asked parents to share experiences about how they handled different challenges in their parenting practice. For example, we asked parents to share what they did when their child had a cold or how they handled recommendations from their child's doctor regarding their health.

The involvement of community partners significantly enhanced the participation of parents in the sessions. Leadership partners from FFYB clarified questions, shared insights about the specific programs parents had participated in, and suggested ways to make the sessions more convenient and engaging. We also held our in-person sessions in the FFYB office and paid a community member to cook food. In later conversations with FFYB, they shared that these steps made parents more comfortable with sharing information about their families, more likely to participate in the activities, and felt more trust in the research team to assure their safety and privacy of their information.

We also outlined a community partnership agreement (memorandum of understanding) between the University of Washington research team and FFYB. In this document, we worked together with FFYB leadership to document the purpose of the research engagement, document the strengths and opportunity for growth of each partner, describe the benefits of collaboration for each partner, and document the key roles and responsibilities of each partner. The key roles and responsibilities outlined in the document are as follows: “UW HCDE will manage research activities, recruit participants, and compensate all parties involved. FFYB will advise on content and logistics, secure research spaces, and receive priority access to research findings and tools”. The document also outlined the process for decision making, financial agreements, ownership of the research produced in the study, and process for terminating the partnership.

The research team used sticky notes and a paper easel board (in the in-person session), and a virtual whiteboarding tool with virtual sticky notes (in the virtual session) to visually document and organize ideas. Parents also completed a survey before the session to capture additional details about their family structures and experiences. To analyze the content of the sticky notes, we used a thematic analysis and affinity diagramming approach to identify recurring themes and patterns in the parent stories (Vaismoradi et al., 2016). This bottom-up approach allowed us to capture the full complexity of parents’ experiences and derive meaningful, actionable conclusions.

4.2 Findings

4.2.1 Parent Demographics

To maintain parent’s privacy (at the request of parents in the study), we did not collect individualized demographic data from the parents in this study. Instead, we provide a high-level overview of the parents in this study. All the parents were primary caregivers to young children under 5, belonged to a group called FFYB, came from low-income backgrounds, identified as West African, were first-generation immigrants, owned smartphones, and had jobs (part-time or full-time).

4.2.2 Primary Findings

From these two sessions, we had three key findings. Overall, we documented another case study indicating the significance of meeting basic needs to enable parents to engage in conscious efforts to support their children's development. We also identified that families in this particular community relied heavily on the social support networks they had developed in Washington, as well as maintaining connections with family members at home, to receive guidance and support for non-urgent health and child development concerns. Further, we identified that there are some similarities and differences in how parents use technology in this community.

Meeting basic needs has a crucial role in enabling parental engagement for children's development. Our discussions with parents primarily focused on the profound impact of financial, food, and housing insecurity on their ability to actively support their children's growth and learning. Parents expressed that while information about their child's developmental progress is essential, they felt limited in the action they could take due to stressors from their environment. While discussing their priorities in promoting their child development, all parents in the study started by emphasizing their effort toward meeting basic needs for their family. One parent said, "[You] gotta be responsible to live in America" (parent from in-person session, who worked night shifts). Basic needs, including time, money, and energy were mentioned as barriers to planning and carrying out additional activities related to their child's health and development. One parent shared that "You cannot forget because it is a part of your life" (parent from in-person session). Parents expressed that meeting basic needs was generally the top priority in their parenting practice. In our discussion about the stress associated with basic needs, one parent shared, "The constant worry about bills…it makes it hard to focus on anything else". They spoke on the difficulty in paying bills, sometimes having to reprioritize their budget to pay off high-risk bills (like food and rent) first. Parents referenced using their phones to collaboratively budget with their partners and keep track of due dates. This finding aligns with existing research that emphasizes the importance of addressing financial and social hardships for effective parenting (Trentacosta et al., 2018).

In some cases, both parents worked to meet their family's basic needs. Despite the challenges of work schedules, parents found ways to be present and involved. More than half of the parents in the study worked night shifts, yet they still ensured their children were ready for school, had meals prepared, and received help with homework when they came back. One parent succinctly captured the sentiment: "I don't get sleep" (parent from in-person session who works night shifts often). Another parent in the in-person session related to this, sharing, "After working all night, I have no energy for playing with my kids, let alone help them with homework". However, once basic needs were addressed, parents made time for planned activities with their children. They took their children to the park, participated in community organization events, and visited the library. These outings had a positive impact, with parents sharing stories of how their child's reading skills improved and how parents and children both benefited from socialization opportunities. For example, one parent was happy to see their child's reading ability improve, so they made a point to read together as often as possible. Another parent appreciated the community organization events, which provided childcare for the parents while they socialized with other caregivers.

Parents shared that they tend to repeat the same activities, like reading, taking their children to the park, or taking their family to community organization events, because they know how much energy, time, or money is needed to engage in those activities. From this, it is evident that parents are overwhelmed by basic needs but want to engage in activities that support their children. While we agree that more basic needs support programs could help these families, there are barriers to utilizing those programs. From conversations with our community partner, we heard that the community organization tries to supplement basic needs (like food, diapers, and wipes) through programming, but struggles to meet demand due to funding. Because the community organization is a trusted space in their community, and does not require income disclosure, the program is highly successful.

Despite the availability of online information about free and low-cost activities for families and basic needs, parents did not mention using specific online resources that documented those activities that could support their child's development and growth within the parent's means. However, many families in this study are reluctant to share personal, private information about themselves and their family due to concerns about immigration status, which can prevent them from accessing basic needs programs that could help. Basic needs programs often require sensitive information about income status (Garg et al., 2016), and while families might be eligible for them, they may be reluctant to sign up or even check their eligibility for these services.

Heavy reliance on social support networks and community resources was a common theme among parents. When faced with stress related to their child's health, they sought guidance and support from family, friends, community organizations, and healthcare professionals. One parent in the virtual session, who had immigrated to the US last year, expressed that "My mom and my sisters are my lifesavers… and they just remind me I am not alone in this". For example, families in the study often turned to established social networks in Washington and familiar connections at home for advice on non-urgent health and development concerns. During our discussion, on parent expressed that "FFYB is like a second home for us…they provide the meals and activities for the kids", which many other parents expressed agreement with. Community organizations played a crucial role by providing essential resources like food, diapers, and wipes. However, as mentioned, the demand for these resources consistently outpaced the availability due to funding limitations. It is important to note that these community resources often have less stringent requirements compared to basic needs programs mentioned earlier. While programs might offer more substantial assistance, they often require documentation of income status or other sensitive information, which discourages some immigrant families from applying due to fear of jeopardizing their immigration status. This creates a trade-off between comprehensiveness of aid and ease of access.

When their child was sick, parents first assessed the severity of the illness. If it was serious, they sought support from a healthcare provider. In many African communities, parents sometimes turn to cultural or familial knowledge for guidance (Adekeye et al., 2014). This was evident in the study sessions, where parents shared advice and experiences. For example, one parent brought medicine for relieving cold symptoms and passed it around the group for recommendations. One parent shared that "We share everything here". Another parent said, "When my child is sick, I call my mother in [their home country]. She knows what works best". Parents in this community also often looked to others with more experience for wisdom, especially when seeking advice from family or friends. They also observed other children in their community to gauge how knowledgeable or experienced other parents are. One parent who regularly attended FFYB events shared “I look to see how their kids are doing.. this way I can know if I can trust them”. Synergy in cultural backgrounds could also play a role, with parents sharing that they relied on the advice of family members specifically because they shared the same cultural heritage. One parent shared that she and her mother had a shared cultural background, so she expected that her mother’s advice would be well-aligned with her parenting philosophy.

To gain a well-rounded understanding of their child’s health, parents gathered information from various sources. They relied on healthcare professionals for mainstream medical advice, but they also considered feedback from teachers and caretakers in the community. One parent shared that through checking in with their child’s teacher, they could understand if their child was doing well in reading and math. These individuals provided insights into how the child was doing relative to their peers. Parents also observed their own children closely during activities to gauge their progress and well-being. One parent shared that when they are talking, reading, or doing other activities with their child, they can tell if they are “struggling or doing well”. In the virtual study sessions, parents shared that they used resources like parenting books, social media pages, and online research to learn about developmental milestones and health promotion activities.

The use of technology in parenting practices varied among the focus group participants. We learned that parents use their smartphones to budget, keep track of appointments, and communicate with friends and family. While technology was primarily used for organization, planning, and communication, some parents expressed mistrust of using the internet as a source of parenting and child development information. One parent said, “I do not trust Google” (Parent who immigrated within the last six months). They preferred to rely on trusted individuals and resources they had already established relationships with. However, when information came from a source that they trusted, like communicating with health professionals through MyChart (an online patient portal) or specific online communities, information delivered through technology was accepted and even found useful. For example, one parent of twins expressed that she had membership in a “Parents of Twins” Facebook group, to see how other parents handle twin-specific parenting. They shared, “They just understand what is happening, I don’t have to explain it”. These anecdotes highlight the importance of trust in the credibility of information sources. Parents in this community carefully vetted people that could potentially give them parenting and child development advice. Further, the autonomy and control that technology provides in accessing information when needed also seems to be valued by parents.

4.3 Discussion

We completed focus groups with parents from West Africa in partnership with a non-profit organization. From our findings, we identified key opportunities to change directions in what ecHPTs offer for parents and families. These findings underscore the importance of addressing basic needs to empower parents. By acknowledging these challenges and collaborating with community partners, we can create a more supportive environment where all parents can effectively nurture their children's development.

4.3.1 Addressing Parents' Priorities through Technology

Ecological factors significantly impact a parent's capacity to engage in behaviors that promote their children's development. While parents in the community we connected with were aware of their children's development needs, they often felt unable to address them due to environmental stressors like limited financial resources and food and housing insecurity. Current early childhood health and parenting technologies focus primarily on educating parents about child development (DeWitt, Kientz, Coker, et al., 2022; DeWitt, Kientz, & Liljenquist, 2022). Though helpful, these systems often lack the ability to tailor recommendations for parents facing additional environmental stressors. To be truly beneficial, these technologies must take into account a parent's basic needs and resources, and find ways to support parents with addressing those basic needs. One direction for future technologies could include sharing information about basic needs support programs based on parents' eligibility. However, this could be challenging given parent's concerns about privacy regarding their personal information.

Some potential solutions could include using aggregated data matching to match parents with relevant programs based on anonymized data like zip code or income brackets. This would allow for parents to connect with resources without the collection of personal data. Another approach could use data encryption techniques to ensure the privacy of data. However, these practices should be transparent and understandable so parents can make informed decisions about data use. When using data, only the minimal amount required for the technology to function should be collected, and clear explanations of how data is being used should be provided. Early childhood health technologies could also provide clear explanations about the types of support programs available and how to find them independently, without requiring personal information. They could integrate directories of trusted community organizations that offer basic needs support, allowing parents to choose how they connect. Partnering with community organizations to deliver this information will build trust (Bogart & Uyeda, 2009). Emphasizing strong data security practices and anonymization will further enhance trust (Ostherr et al., 2017), especially if data privacy information is delivered in an understandable way (i.e., clear and concise information). However, unless there is trust from the community to engage with the technology, including trust-building features will have insignificant impact. Collaborating with community organizations that parents already trust to deliver information about basic needs support is essential. Parents should understand the benefits of data privacy, the importance of transparency, and how their data will be used to connect them with valuable resources.

From parents' understanding of time, energy, and money as limited resources, it is clear that they need accessible and feasible activities to promote their child's development. During the study, parents prioritized activities that aligned with their social and economic barriers. This highlights an opportunity to create and share activities that are truly within reach for parents addressing basic needs. Providing development-promoting activities that require minimal resources can help give all families opportunities to engage in beneficial behaviors. With the proliferation of data-driven health recommendations, researchers and practitioners should prioritize technologies that consider the impact of basic needs on a parent's ability to engage in development-promoting activities. Technologies in this space could move from focusing on changing parent’s knowledge and awareness of child development milestones, and instead move toward providing feasible ways for parents to engage in activities that they know are important for their children.

4.3.2 Addressing child health guidance shared in social networks

Families in this group generally do not seek developmental guidance from providers unless there are serious concerns that cannot be addressed within their trusted family networks. This reluctance likely stems from historical mistrust in the medical field, lower expectations for positive outcomes, discriminatory experiences, and a preference for a more holistic approach to health in some African and African-American communities (Betancourt et al., 2016; Nuriddin et al., 2020). Parents in this study reported relying heavily on trusted family and friends for guidance on non-urgent health and child development concerns. This aligns with research suggesting such advice is often seen as more effective and requires less effort to obtain compared to contacting healthcare providers (Poretski et al., 2021). Current healthcare systems may not always provide the on-demand access to information parents seek (Nuriddin et al., 2020). As a result, parents turn to their social networks for faster and more responsive guidance.

There are several advantages to receiving health guidance from personal networks (Ramírez et al., 2013). First, pre-existing personal knowledge and experiences with health conditions reduce the effort required to provide relevant background information. Second, these networks are more likely to be available and accessible than healthcare professionals, especially in non-urgent situations (Gray et al., 2005). Lastly, the pre-existing relationships built on trust and respect are likely to be more supportive overall. However, personal networks may not have the same level of quality and comprehensiveness as health professionals, which could potentially lead to inaccurate health guidance. Despite the push for solutions to healthcare access, like community programs, telehealth, and online resources, marginalized communities still experience barriers to accessing healthcare.

Early childhood health promotion technologies could shift focus from encouraging parents to seek guidance from medical professionals and instead engage with extended family members. New technologies could facilitate learning about child development alongside parents within these extended networks. Families in our study also discussed engaging with online social networks, where child development experts could offer personalized advice through online forums. Experts could also join these groups to guide conversations and impact the content being shared. Automated content moderation techniques could present opportunities for learning in the content being shared on social media (Morrow et al., 2022). Technologies could target people (family and friends) and services (community organizations) actively providing parents with guidance, such as engaging extended family members or joining online social networks. This shift could change the landscape of information and support available to parents.

4.3.3 How technology works to support development indirectly

Parents in this community primarily used technology to stay organized and plan around basic needs, and communicate with their trusted support networks, sometimes due to a lack of trust in the information they can access through technology. This lack of trust likely stems from concerns about the credibility and reliability of information found online. Parents might be skeptical of websites, social media, or even apps due to the prevalence of misinformation or scams. This finding aligns with ongoing research about distrust in technology among certain communities, especially those with limited access to the internet or diverse devices, and concerns about privacy, misinformation, or scams (van Rooy & Bus, 2010). Specifically, parents might lack the skills to critically evaluate online information sources, leading to them relying on trusted social networks for sharing information, which bypasses online sources altogether. While parents did not use technology as an informational source, they felt comfortable using it for communication and planning.

To support child development, technologies could focus on connecting families with resources and people who can address basic needs. Research has shown the challenges of assessing needs related to food, housing, and childcare, especially for immigrant or refugee families (Asgary & Segar, 2011). Technologies could streamline the process of connecting families with relevant community resources and guide them through complex application processes for government benefits. Crowdfunding or resource-sharing platforms and social media sites for resource exchange could also be connected to help families cover specific costs or share items like clothing or toys (Zhu, 2024). Some existing technologies, like virtual food pantries and meal delivery programs, could be leveraged to reduce parent effort in ensuring their children have nutritious meals. Additionally, ecHPTs could connect families to skill-building courses or job training programs to empower parents and increase their capacity to engage in child development.

Lastly, during the study we unofficially observed children using their parent’s devices to play games or access entertainment. There is extensive research on games that promote child development (Media et al., 2016), and some indicating parent’s perceptions and expectations for these technologies (Sălceanu, 2014). However, there is still an opportunity to incentivize parents to download child development-promoting apps. For example, those apps could offer a reward system where children earn points for completing activities, and parents could redeem those points for vouchers or discounts on basic needs items like diapers or groceries.

4.3.4 Discussion of Method and Approach

This study utilized focus groups to explore the experiences of parents from a vulnerable and marginalized community. Focus groups allowed for open discussions and shared perspectives on the challenges and strategies that parents engaged in. The group setting also supported parents in building off each other’s ideas and having group discussions about the topic. Using the focus groups also enabled us to capture rich data about parents’ lived experiences. However, social desirability might have contributed to bias in the responses that we received from parents (Johnson & Van de Vijver, 2003), and future research could incorporate in-depth interviews to gain a more nuanced understanding of individual experiences. Further, using a virtual session alongside an in-person session allowed for the inclusion of more people in the research study.

Partnering with a local community organization was especially beneficial for this project. In particular, there were advantages of collaborating with FFYB in recruitment, guidance of the research content, and comfort of the parents participating in the research study. Throughout the study, FFYB was a direct liaison between the research team and parents, which supported communication. Also, FFYB gave us feedback on the interview questions and helped us to word them in a way that had more meaning to the community and aligned better with their lived experiences. Based on discussions with FFYB leadership at the end of the study, the collaboration greatly improved trust and the participation of parents in the study. At the end of the research engagement, FFYB was enthusiastic about continuing the research collaboration and identifying ways to align the research team goals. This partnership would likely be strengthened by working together over a longer period of time, and we look forward to future opportunities for collaboration with them.

There are limitations to the generalizability of the research findings. While the focus groups provide rich data, we acknowledge that the two focus groups that we conducted may not represent the entire West African immigrant population. Social desirability bias is also a potential limitation. Future research could involve a larger sample size and incorporate practices like member-checking (Grieb et al., 2015), where community collaborators review the research findings to ensure accuracy and representation of their experiences.

4.4 Chapter Conclusion

So far, my dissertation argues that technology innovation for early childhood health technologies (ecHPTs) may be misdirected in meeting the needs of families from marginalized communities. ecHPTs often focus on individual parent behaviors and information delivery, which overlooks the broader social, political, economic, and historical contexts that affect children and their families. Overall, this chapter strengthens the argument for culturally safe ecHPTs by showcasing the real-world challenges faced by families and the limitations of existing technology approaches. By adopting cultural safety as an approach to research and design, we can better understand the diverse needs and perspectives of families, identify and mitigate bias in research and design, and strengthen the representation of communities in technology innovation.

To understand the potential for ecHPTs in these communities, I engaged parents in King County, Washington who had recently immigrated from West Africa in focus group discussions about their experiences supporting their child's development and using technology. From this work, I learned that the parents I talked to prioritized meeting basic needs for their families, and did not use technology to seek out information about their child’s development directly. They also primarily relied on their support networks of family and friends for more responsive child health advice. However, they did use technology as a communication tool, to engage with people that they trust for child development guidance, and to keep organized with their basic needs. These findings indicate the potential limitations of current ecHPTs that solely focus on individual parent behaviors (e.g., helping parents keep track of milestones) and information delivery (e.g., improving parent knowledge as a primary aim). The study also revealed that parents in this community are very different in their experiences and needs. Some are burdened by basic needs and work hard to find ways to engage in child development within their capacity. Other parents rely on support from trusted people in their support network, including friends, family, and people in their local community. Relatedly, some parents have no interest in technology providing them with information about their child's development directly, while others feel comfortable using technology to discuss child development with people they trust. This diversity underscores the need for ecHPTs to be flexible and adaptable to different family circumstances, and further demonstrates how context-unaware technologies can exclude parents.

From the systematic review and content analysis, I learned that most ecHPTs are focused very narrowly on teaching parents new information about their children's development screening or articles on parenting strategies. None of the parents I talked with in this study mentioned engaging with tools like this, and if they did mention seeking information about child development through technology, it was primarily by connecting with real people who may (or may not) have given them similar information. Further, current ecHPTS do not actually address the broader context where parents may implement the advice they are given. For example, an app may recommend that a parent limit screen time to no more than one hour a day, with an adult present. This recommendation could be potentially harmful if it does not consider a family's circumstances. For parents without childcare, screens can be a valuable tool to occupy children and allow them to get things done. Eliminating that tool entirely creates a burden for parents without offering alternatives. This approach makes assumptions about parents and does not give space for parents to share their experiences without judgment. This approach also does not express a commitment to equity, as it does not adapt care recommendations to the parent's needs and background. Instead, an app employing a culturally safe approach could ask about a family's situation first (e.g., work hours, childcare access) and tailor screen time suggestions. The app could also instead recommend high-quality educational screen time options or screen-free activities that require minimal supervision. Lastly, the app could connect parents with childcare resources depending on their needs, and support them with understanding their eligibility. By presenting options in a way that respects the parent's autonomy, adapting the recommendations to the parent's context, and avoiding making assumptions about the parent, the refined app employs a culturally safe approach that respects the knowledge and lived experiences of the parent and may better resonate with more people.

I discuss several opportunities for ecHPTs to impact child development by focusing on helping parents meet basic needs to improve their capacity to engage in child development promoting activities, and to improve the quality and relevance of the information that they receive from people they trust in their communities. Overall, the findings from the study presented in this chapter highlight the challenges faced by immigrant families due to basic needs insecurity and limited access to resources. I emphasize the importance of considering cultural background in health information seeking and decision-making as well. These points directly support my thesis that existing technologies fail to consider the social context and cultural needs of families.

We also demonstrate the value of Community-Based Research (CBR), which is a specific type of Community-Based Participatory Research (CBPR). Because CBR involves conducting research in a community setting, but the level of community participation can vary, the CBR approach was better suited for this research engagement, as our primary aim was to gather information about a community. For example, the research team was primarily responsible for designing the research study, although FFYB participated in providing feedback on the study activities. While adopting the CBR approach in our study still provided valuable insights into the community's needs and experiences, compared to the CBPR approach, it had a weaker emphasis on empowerment and co-ownership of the research process. By partnering with FFYB, the research team gained invaluable access to a specific community and could directly hear about their challenges and success navigating child health guidance. FFYB's involvement as a trusted community partner made parents feel more comfortable sharing their experiences. This provided a richer understanding of their lived experiences than the researchers may have heard on their own; parents were likely more forthcoming and honest about their lives compared to if we had tried to engage with them directly. FFYB's insights in the research helped tailor the methods (i.e., the questions we asked, setting the context for the research study) and logistics (i.e., food and location) to better suit the cultural context of the parents. The research also fostered a two-way knowledge exchange between the research team and the community. While we gained valuable insights into the community's experiences, FFYB also benefited from having priority access to the research findings and discussions that we had with parents. This empowered the community organization with knowledge they can use to better serve the parents in their community. Overall, the CBR approach deeply enhanced the research engagement and led to more specific insights that were more relevant and impactful.

By promoting cultural safety, which emphasizes respect for the knowledge and lived experiences of people, we can create ecHPTs that better resonate with families and improve health outcomes. Cultural safety would involve understanding the struggles associated with meeting basic needs and the influence of cultural factors on health information seeking and decision-making. The findings highlight how technology can perpetuate health disparities; by not considering the struggles associated with meeting basic needs, ecHPTs may exclude families who are most in need. The research presented in this chapter strengthens my argument for the production of culturally safe health promotion technologies, and the need for community-based approaches, by illustrating the real-world challenges faced by families and the limitations of existing approaches.

Chapter 5: Heuristics for Evaluating Mobile Health Apps for Parents of Young Children

Early childhood health interventions are promising in improving child health outcomes. However, marginalized families often lack access to these interventions due to financial, cultural, and systemic barriers. For example, the cost of services, language barriers, and the limited availability of services can prevent families from accessing early childhood health interventions

(Cavallera et al., 2019; Marra & Espinosa, 2020). These barriers contribute to disparities in child health outcomes in several ways. Families in marginalized communities who lack access to interventions miss out on preventive screenings, vaccinations, and early detection of potential health issues. This can lead to delayed diagnoses, more severe illness, and worse overall health outcomes for children in those communities.

Mobile health (mHealth) technologies offer a promising solution, due to their cost-effectiveness, scalability, convenience, and potentially tailored information and support (Ray et al., 2017). They can be translated into multiple languages, offer culturally relevant information, and connect families with healthcare professionals remotely. However, for mHealth apps to offer meaningful impact, they must prioritize the usability of these systems. By creating systems that are not human-centered, they risk widening the gap in health outcomes by not having a meaningful impact for the people that use them. Creating apps that are easy to navigate and understand can lead to more people using them more often and in more effective ways (Overdijkink et al., 2018).

Considering the criticality of mHealth technologies needing to have a meaningful impact for children and families, designers and researchers can use systematic methods to evaluate the quality of their tools. Heuristic evaluation is an approach to evaluating the design and usability of technology interfaces, using a set of guidelines to identify potential issues. Because the mHealth field is constantly evolving, using heuristic evaluation can guide the design of these apps in a more timely manner, ensuring that they are accessible and effective for people using them. Heuristic evaluation is a well-established method for proactively identifying usability issues in technology design (Nielsen & Molich, 1990*)*. This method uses a set of heuristics, or guidelines, to identify potential problems with the usability of a system. Designers and researchers can easily incorporate heuristic evaluation into their processes. They can use standard heuristics like Jakob Nielsen's or domain-specific ones. Experts can conduct heuristic evaluations by systematically applying the principles to the designs, identifying issues. Heuristic evaluation's benefits for early problem detection and usefulness in early and late stages of the design process make it a useful tool in improving the user experience of technologies.

Heuristic evaluation offers an approach to proactively identify usability issues in the design process. By applying established usability principles to technology interfaces, evaluators can catch potential problems early, preventing resource consuming redesigns later (Nielsen, 2005). Compared to other technology evaluation approaches, like user testing, heuristic evaluation generally requires fewer resources and is more time-efficient (e.g., not requiring recruitment of target users). However, heuristic evaluation should not replace user testing. Instead, it can serve as a valuable precursor to future user testing, by focusing the user testing efforts on more salient usability concerns. By proactively identifying issues and targeting specific design elements, heuristic evaluation streamlines the overall testing process.

Designers and researchers can incorporate heuristic evaluation into their design processes. Identifying the most relevant set of usability heuristics, for example, Nielsen’s heuristics for identifying common usability issues (Nielsen, 2005), can help focus the evaluation on a specific aspect of the design. Other heuristics exist that are more domain specific (Khowaja & Al-Thani, 2020; Langevin et al., 2021; Nishchyk et al., 2024; Samarakoon et al., 2021). Experts can also be engaged in this process to conduct heuristic evaluation, by systematically applying the heuristic principles to the designs, identifying issues. With its significant benefits for identifying usability issues early, heuristic evaluation holds substantial potential for improving the user experience of technologies.

There are many heuristics available for evaluating mHealth systems. For example, specialized heuristics exist for evaluating mHealth apps (Khowaja & Al-Thani, 2020), electronic medical records (Tarrell et al., 2015), patient safety (Zhang et al., 2003), eHealth (Baumel & Muench, 2016), persuasive health technologies (Kientz et al., 2010). Heuristics also exist for evaluating technologies for specific populations. For example, heuristics exist that provide considerations when designing technologies for older adults (Nishchyk et al., 2024; Silva et al., 2015), children (Alsumait & Al-Osaimi, 2009; Camargo et al., 2019), and people working together (Baker et al., 2002). However, a gap exists in heuristics specifically designed for people who manage health data or promote health behaviors for dependents. Considering this gap, researchers have employed existing heuristic evaluation methods to conduct evaluations of systems that parents use (Choi & Bakken, 2006; Joshi et al., 2009). Across these studies, limitations of using usability experts for heuristic evaluation were mentioned, because this method heavily relies on the specific knowledge and experience of the evaluators. While usability experts excel at identifying general usability issues, they may not have specialized knowledge in all domains. For instance, experts evaluating an mHealth app designed for parents managing children's health data might miss usability issues specific to this domain due to a lack of expertise in child health or parent needs.

As such, because involvement of domain experts in the design process can be challenging due to cost and resource constraints in projects (Chilana et al., 2010), heuristic evaluation is likely to continue being conducted by professionals who are not domain experts. To address this gap, this chapter explores the benefits and limitations of a new set of heuristics for specifically evaluating health technologies aimed to support parents in navigating their children’s developmental progress. To provide practical guidelines for evaluating new and existing technologies, and align the heuristics with the domain knowledge missing from existing heuristic methods, I developed the heuristics from content in literature on early childhood health promotion technologies. Throughout this chapter, I use the wording “we” to represent the joint collaboration of the research team, which consisted of several students from the University of Washington Human-Centered Design and Engineering department, and my advisor, Julie Kientz.

The chapter is organized into two parts. First, I present the development process for the proposed heuristics, the Heuristics for Technologies used by Parents (HTP), which involves a review of relevant literature and collaborative refinement of a set of heuristics. I present the results of an expert evaluation study, which engaged expert evaluators in providing feedback on the heuristics, and comparing the heuristic's performance against a widely used and accepted set of heuristics for evaluating the usability of a technology system. Overall, evaluators found the heuristics suitable for setting design requirements for systems in early design stages, rather than for evaluating user experiences later in the process. This finding indicates that because the heuristics fall short when evaluating later-stages of design, there is an opportunity to improve on them by focusing on human-centered design principles, which I discuss in this chapter. Additionally, evaluators highlighted a need for a framework specifically focused on user experience design principles within the context of cultural considerations, which I discuss in this chapter as well.

Secondly, I discuss the broader implications for human-centered design in mobile health. I emphasize the importance of early engagement with target communities to understand cultural influences on health experiences. I acknowledge the challenge faced by designers and researchers who may lack the resources for this kind of engagement, and explore alternative resources to better align their technologies, such as existing accessibility guidelines and culturally inclusive app design principles. Finally, I suggest ways to improve the accessibility and impact of heuristics for a wider range of researchers and designers. By showing the limitations of the current evaluation methods and proposing improvements that promote cultural safety, this chapter advocates for more nuanced approaches in early childhood health promotion technologies design and research processes, which is broadly applicable to the field of mobile health apps as well.

5.1 Method

5.1.1 Generating Heuristics

Following Kientz's method to develop heuristics for persuasive health technologies (Kientz et al., 2010), we collaboratively developed heuristics for the evaluation of mHealth apps for promoting child health. We recruited five undergraduate and masters' research and design students to engage in a literature review and heuristic generation with the researchers through a two-week group reading activity. Involving undergraduate and masters' students from our university's human-centered design and engineering program in developing heuristics for early childhood health mHealth apps presented both opportunities and challenges. Students in this program are not ingrained in established practices or design conventions, potentially leading to their ability to identify usability issues that experienced professionals may overlook due to ingrained habits. Their training in human-centered design can also help them bring a strong focus on human needs when evaluating technology systems. However, they lacked deep domain experience with child health, health equity, and health informatics topics. To maximize their contribution, we provided some preliminary training on these topics by providing introductory academic literature and having a group discussion to confirm their understanding. By combining these elements, we intended to leverage the students' research and design skills while ensuring the heuristics effectively address the needs of this specific community.

There are several approaches to developing heuristics, which we summarize in the table below (Table 3). Considering the advantages and disadvantages of each approach, we developed our heuristics based on relevant literature in the field. Because a primary aim of this study was to develop heuristics that represented domain knowledge that is currently missing from existing heuristics, we were able to develop heuristics that captured the key considerations when designing mobile health technologies for early childhood health and parents. The first author completed a literature search in PubMed, Scopus, Google Scholar, and the ACM Digital Library for mobile heuristics and mHealth heuristics. The search yielded 6 heuristic frameworks, including Nielsen, Yáñez Gómez, Shneiderman, Lacerda, Dourado, and Monkman (Dourado, 2018; Lacerda et al., 2015; Monkman & Kushniruk, 2013; Nielsen, 2005; Shneiderman et al., 2016; Yáñez Gómez et al., 2014). The first author then completed a second search in the same venues for child development technologies and filtered them to include mobile-based technologies aimed to be used by parents. The search yielded 6 papers to review in the group. The first author randomly assigned readings among the students. Each week, the reading group discussed the content from the literature and documented preliminary heuristics on a map in Miro. The heuristics were then refined during group discussions and tested initially on child development promotion mobile apps from the Apple and Google Play app stores.

Table 3: Summary of Approaches to Developing Heuristics

Approach	Description	Advantages	Disadvantages	Example
Literature Review & Heuristic Generation	Gather information on the specific technology/domain, identify challenges & best practices, then generate new heuristics.	Highly specific and relevant	Requires more upfront research & analysis	(Langevin et al., 2021) - Conversational agents
Adaptation of Existing Heuristics	Modify established frameworks (e.g., Nielsen's heuristics) to address the specific technology/domain.	Leverages existing best practices, saves time	May require significant adaptation, may not capture all domain-specific issues	Ambient displays (Mankoff et al., 2003)
Heuristics Compilation & Refinement	Compile existing heuristics relevant to the target audience/technology and refine them.	Efficient starting point, leverages existing knowledge	May not be as specific, requires additional refinement	Smartphone apps for older adults (Silva et al., 2015)

5.1.2 HTP heuristics vs. Nielsen heuristics: Evaluating Usability of Mobile Apps

We then conducted an expert evaluation study following the protocol used by Mankoff and colleagues (Mankoff et al., 2003). Participants were randomly assigned to conduct a heuristic evaluation on three mobile apps that we identified, using either Nielsen’s heuristics, which are used widely in professional design settings (Nielsen, 2005), or the heuristics generated in the reading group. We aimed to assess the performance of the HTP heuristics against Nielsen’s heuristics in identifying usability issues, and assessing the severity of the usability issues. Each expert engaged with one set of heuristics throughout the entirety of the study, either the HTP heuristics or the Nielsen heuristics.

We recruited design professionals using a public posting in a university Slack channel. We recruited designers who 1) had prior experience conducting heuristic evaluations, 2) had more than two years' experience in their industry, and 3) had a functional mobile device and computer or laptop they could use for the evaluation. We recruited 10 participants, and they were evenly distributed into each group. Participants completed a screening questionnaire that documented their demographic information, including current occupation, years of experience in their field, industry, familiarity with early childhood topics, experience with conducting heuristic evaluation, and experience with user experience (UX) design processes.

We sent the heuristics and link to 3 mobile apps to the designers via email, and set a deadline for them to send their completed evaluation forms. Each expert used one individual set of heuristics, either the HTP or Nielsen's heuristics. Participants were advised to document issues raised by each heuristic in the evaluation form, and assign a severity rating for each issue. The severity ratings followed a 3-point rating scale as follows: " 0 - Cosmetic, 1 - Minor, 2 - Major, 3 - Severe". We also requested that the designers share a reflection on their experience applying the heuristics, through a free response question. We asked respondents, "After completing your evaluation, what do you think are the strengths and limitations of [name of heuristic method], and how does it compare to other heuristic evaluation methods you have used?". We reviewed the results of the evaluations in the reading group, and compiled data on the overall performance of the Nielsen heuristics and the HTP heuristics. We used thematic analysis to identify recurring themes from the evaluator's reflections.

5.1.3 App Selection and Description

We identified relevant apps for the expert evaluation study by searching the internet for child development apps across the Apple and Google Play app stores. We identified one website that provided a ranking of child development apps in each app store. We selected apps that were available for both iOS and Android devices, free to download, and included content related to child development milestones. We selected the following apps for review in the study: "CDC's Milestone Tracker", "Kinedu: Baby Development Plan", and "BabySparks - Development App".

5.2 Results

5.2.1 Heuristics for Technologies used by Parents

The final heuristics, the Heuristics for Technologies used by Parents (HTP) Heuristics, are documented in the table below (Table 4) and Nielsen's Heuristics (Table 5). Further, we provide a table comparing the HTP heuristics to Nielsen's Heuristics (Table 6).

Table 4: Heuristics for Technologies used by Parents (HTP) Heuristics

Heuristic	Definition
Educates the user about content sources	The mobile app provides detailed information that would inform the user about what sources were used to curate health content in the app, including information validated by experts or verified and trustworthy sources. The mobile app does not include information that is misleading or incorrect.
Gives guidance on how to interpret information	If the mobile app monitors trends in the user's health data and presents them visually, or provides any insights based on the user's data, then the app should provide information on how the user should interpret the data visualization or insight summary.
Protects personal information and privacy	The mobile app allows users to maintain anonymity while using the app, and the app transparently explains privacy-related information, including use of data collected by the app. The app does not require personally identifiable information to access the full functionality of the app (for example, you can choose to use a fake name).
Responds to limitations of smartphone interfaces	The mobile app is aware that smartphone interfaces are smaller, and does not overwhelm the user with a large volume of content on a small screen.
Provides a simple experience when entering data	If users are required to enter data in the app, the data entry experience should follow a simple and straightforward workflow (for example, being able to re-do actions rather than starting a workflow from the beginning).
Supports data sharing with non–users	The mobile app should provide a simple pathway for users to share their data with people who don't use the mobile app. The information shared should also be understandable by non-users.
Provides a non-intrusive experience	The mobile app should not be intrusive to the user's daily life (for example, frequent notifications or disruptive advertisements).
Responsive to all literacy levels	The mobile app does not require the user to be proficient in advanced health terms or have a high reading level, and defines any complex terms.
Communicates information in more than one form	The mobile app allows users to engage with content in multiple ways (for example, using text, imagery, video, or audio to communicate information).
Tailors or personalizes information based on the user's needs	The mobile app collects necessary information about the user's context, and tailors content to meet the user's unique needs. The mobile app allows the user to personalize their experience with the app.

Table 5: Nielsen's Heuristics (summarized from (Nielsen & Molich, 1990))

Heuristic	Definition	Example

Visibility of System Status	Users should always be informed about the system's current state through clear and timely feedback.	"You Are Here" indicators on maps
Match Between the System and the Real World	Use familiar language, concepts, and real-world conventions.	Stovetop controls matching heating element layout
User Control and Freedom	Users should be able to easily undo or redo actions and exit unwanted processes.	"Cancel" button
Consistency and Standards	Maintain consistency within the product and follow industry conventions.	Check-in counters at the front of hotels
Error Prevention	Prevent errors from happening in the first place through design or confirmation prompts.	Guardrails on mountain roads
Recognition Rather Than Recall	Minimize user memory load by making options and information visible.	Recognizing vs. recalling country capitals
Flexibility and Efficiency of Use	Cater to both novice and experienced users with features like shortcuts and customization.	Maps showing regular routes and shortcuts
Aesthetic and Minimalist Design	Focus on essential content and avoid unnecessary visual elements.	Simple teapot vs. ornate teapot
Help Users Recognize, Diagnose, and Recover from Errors	Use clear, plain language error messages that offer solutions.	"Wrong way" signs on roads
Help and Documentation	Provide easily searchable, task-focused documentation when needed.	Information kiosks at airports

Table 6: Comparison of HTP Heuristics to Nielsen's Heuristics

Heuristic (HTP)	Definition (HTP)	Similar Nielsen Heuristic	Focus
Educates user about content sources	Provides detailed information on sources used to curate health content, including expert-validated sources.	Match between system and the real world	Accuracy & Trustworthiness
Gives guidance on data interpretation	Explains how to interpret data visualizations or insights from user data.	Visibility of system status	User understanding of information presented
Protects personal information & privacy	Allows anonymity and transparently explains privacy practices. Minimizes required personal information.	User control and freedom	User control over data & privacy
Responds to limitations of smartphone interfaces	Avoids overwhelming users with excessive content on small screens.	Visibility of system status & Match between system and the real world	User experience on a mobile device
Provides simple data entry	Offers straightforward workflows (e.g., redo actions) for data entry.	Error prevention	User experience during data input
Supports data sharing with non-users	Enables easy sharing of user data with non-users in an understandable format.	Flexibility and efficiency of use	Sharing information with others
Provides non-intrusive experience	Minimizes disruptive notifications and advertisements.	Match between system and the real world & User control and freedom	User experience & Absence of distractions
Responsive to all literacy levels	Avoids complex health terms and defines them if used.	Match between system and the real world	User understanding of information presented

Communicates information in multiple forms	Offers content in various formats (text, images, videos, audio).	Match between system and the real world	User engagement with information
Tailors or personalizes information	Collects user context and tailors content to individual needs. Allows user personalization of the app.	User control and freedom	User experience & Personalized information delivery

Below, we share the descriptions of each mobile app evaluated in this study and report the findings of the usability evaluations. The sum of usability issues (mild + moderate + severe + cosmetic) is reported, and the percentages of each type of usability issues (count, percentage) is reported.

5.2.2 Comparing Heuristics Results

In this section, we share the results of the expert evaluation study comparing the performance of the HTP heuristics and Nielsen's heuristics. We provide screenshots of each app in Appendix D. The demographics of the expert evaluators included in this study are reported in the table below (Table 7)

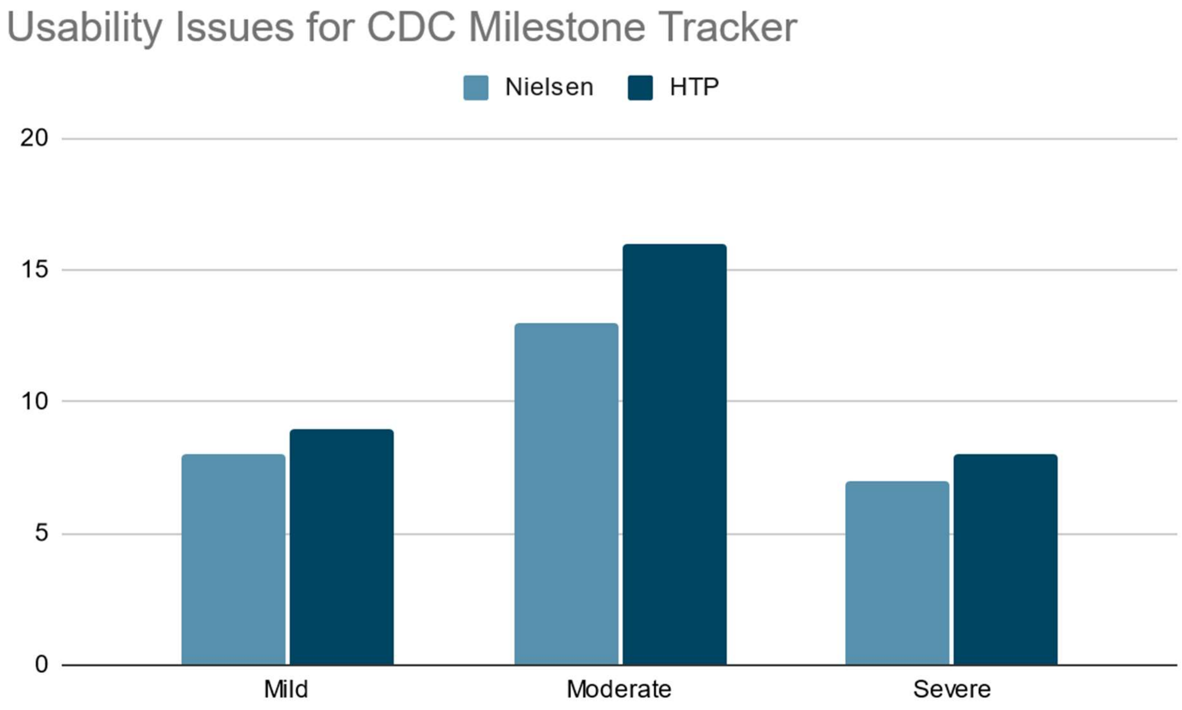
Table 7: Demographic information of participants in expert evaluation study

Participant ID	Job title	Field	YOE	Prior experience with heuristics
1	UX Designer	Cloud Technology and Enterprise Design	2	Used Nielsen's heuristics in 3 prior evaluations
2	UX Designer	Health care and IoT products, Telemedicine	1	Led heuristic evaluations using Nielsen's heuristics for several prior projects
3	Health Systems Researcher	Healthcare Industry	4	Led three heuristic evaluations of workflows using Nielsen's heuristics
4	UX Researcher	Mobility industry, autonomous vehicles	5	Primary research method, uses Nielsen's heuristics alongside personas
5	UX Designer	Software products design	5	Used Nielsen's heuristics in an end-to-end product cycle
6	UX Researcher	Professional networking and job search industry	2	Has completed 2-3 heuristic evaluations using Nielsen's method
7	UX Researcher	Cloud and AI Services	5	Has led heuristic evaluation studies using Nielsen's heuristics
8	Research consultant	Federal, State, Local Government	8	Has used Nielsen's heuristics for software and mobile apps

5.2.2.1 CDC Milestone Tracker

The CDC Milestone Tracker mobile app is a free app aimed to support parents in tracking their child's developmental milestones starting at 2 months and through 5 years old. The app includes interactive milestone checklists, including some photos and videos demonstrating milestones. The app also includes activities that parents can try to encourage their child's development, and enables data sharing with their child's healthcare provider. The app includes reminders for appointments that parents enter in the app, and reminds parents when they should complete developmental screenings. The app is available for iOS and Android devices, and supports English and Spanish. Below, we share a chart providing a visual representation of the severity of usability issues in both Nielsen and the HTP heuristics to compare their performance (Chart 1).

Chart 1: Severity Ratings of Usability Issues Identified in CDC Milestone Tracker



5.2.2.1.1 Results from heuristic evaluation with Nielsen's Heuristics

Of the responses, evaluators identified 31 usability issues for the CDC Milestone tracker app. Most (13, 42%) of the usability issues identified had a moderate rating, while mild issues were second most (8, 25.6%), and severe issues (7, 22.6%) were the least. Cosmetic issues made up 9.68% (3) of the total usability issues identified. Across severity ratings, the most mentioned issue was related to the creating, tracking, and making notes for appointments feature. Among the moderate rating usability issues, concerns included disorganization in the information architecture, lack of emergency exits in the app, and clutter in the user interface that could cause cognitive overload. Severe issues included missing back buttons, poor visual balance, and lack of boundaries and direction for key functionalities in the app. Mild usability issues included repetitive requests for data entry, outdated menu navigation design, and inconsistency in status of buttons (i.e., if buttons are clickable or not). Cosmetic issues included visually unappealing aesthetics, confusing icons, and unfamiliar button placement. Overall, "Aesthetic and minimalist design" was the heuristic with the most issues identified for this app. Evaluators also shared positive comments about the app, including that it used plain language, and included consistent categories across checklists.

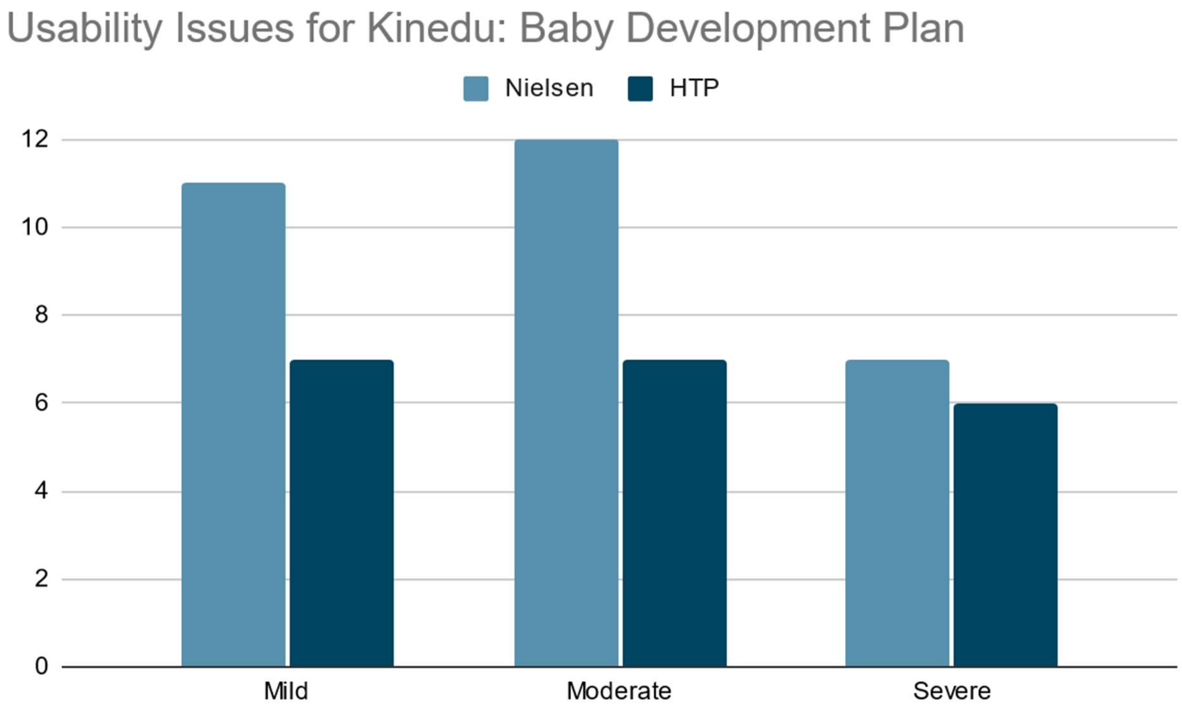
5.2.2.1.2 HTP heuristics ratings

Evaluators identified 37 usability issues using the HTP heuristics. Like the results from the ratings with Nielsen's heuristics, most (16, 43.2%) usability issues identified were categorized as moderate, mild issues were second most (9, 24.3%), severe issues were third most (8, 21.6%), and cosmetic issues had the least (4, 10.8%). Across the usability issues of all severity categories, the most mentioned issue was related to lack of customization in the app that responds to parent input. Evaluators mentioned that while parents can enter information like their baby's age and gender, data entry on the milestone checklists did not impact outcomes for recommendations or explanations of milestones, so it was unclear to the user why that information was needed or what it changed in the user experience. Issues rated as moderate included lack of content sources for milestone checklists, limited media (i.e., photos and videos) demonstrating milestones, text heaviness, and repetitive requests for information (i.e., language preference) in the app. Mild usability issues included buttons that were too small to interact with, unclear instructions in the onboarding page, and missing explanations for functionalities in the checklist feature. Severe issues identified included small font sizes, lack of information about privacy and data sharing, lack of detailed explanations for milestones, and lack of translations beyond English and Spanish. Cosmetic issues included issues with button styles and status. Overall, the heuristic with the most issues identified was “Tailors or personalizes information based on the user's needs”. Only one evaluator shared a positive comment about the app, which mentioned that data entry in the note-taking feature was a simple experience.

5.2.2.2 Kinedu: Baby Development Plan

The Kinedu: Baby Development Plan app provides parents with guidance on how to support their baby's development from birth to age 4. The app provides age-specific activities that promote development for parents to do at home with their children. The app generates personalized outlines of activities based on information about the child entered into the app by the parent, including the child's birthday and gestational age at delivery. The app has a library of 1,600 activities and 450 parenting articles, and also includes opportunities to connect with child development professionals directly through the app, and supports plan sharing with other family members. The app is available on iOS and Android devices. However, many of these features require a paid subscription on a monthly, quarterly, or yearly basis. Parents can still create a profile and access sample activities, milestones, and child development information. In this evaluation, we asked the evaluators to create a free profile to access the initial functionality of the app. The comparison of the performance between the HTP heuristics and Nielsen heuristics are visually shown in Chart 2.

Chart 2: Severity Ratings of Usability Issues Identified in Kinedu: Baby Development Plan



5.2.2.2.1 Results from heuristic evaluation with Nielsen's Heuristics

Evaluators identified 36 usability issues using Nielsen's heuristics. Like the other app evaluations, moderate usability issues (12, 33.3%) were the largest portion of the sample, and mild issues (11, 30.6%) were the next largest group. Severe usability issues (7, 19.44%) superseded cosmetic issues (6, 16.7%). The most mentioned issue was related to cognitive overload imposed by constant redirections in the app to subscribe to premium features, even while using features in the app that were free. Among the moderate issues, usability issues included usage of terms throughout the app that were not coupled with definitions or explanations, lack of emergency exits when navigating menus or navigating away from pop-up ads, and incomplete task flows when marking milestones as completed. Mild usability issues included unfamiliar patterns in creating comments on milestone activities, ineffective searching and filtering mechanisms, redundant content shown in the app, and small button and text sizes. Cosmetic issues included issues with opacity of design elements and text, misleading button and menu designs, and inconsistent headers that misconstrued information architecture in the app. Lastly, severe issues spanned problems with the push for premium subscription in the app and lack of in-app content related to core functions of the app. Evaluators mentioned that the app regularly disrupted task flows by redirecting users to the web to watch videos corresponding to the milestones in the app, rather than housing those videos in the app to streamline the user experience. Two evaluators mentioned that the app has a high risk for cognitive overload, as several pages in the app share redundant information spread across multiple pages. Excessive visual competition in colors, images, and promotions for premium features made it difficult to focus.

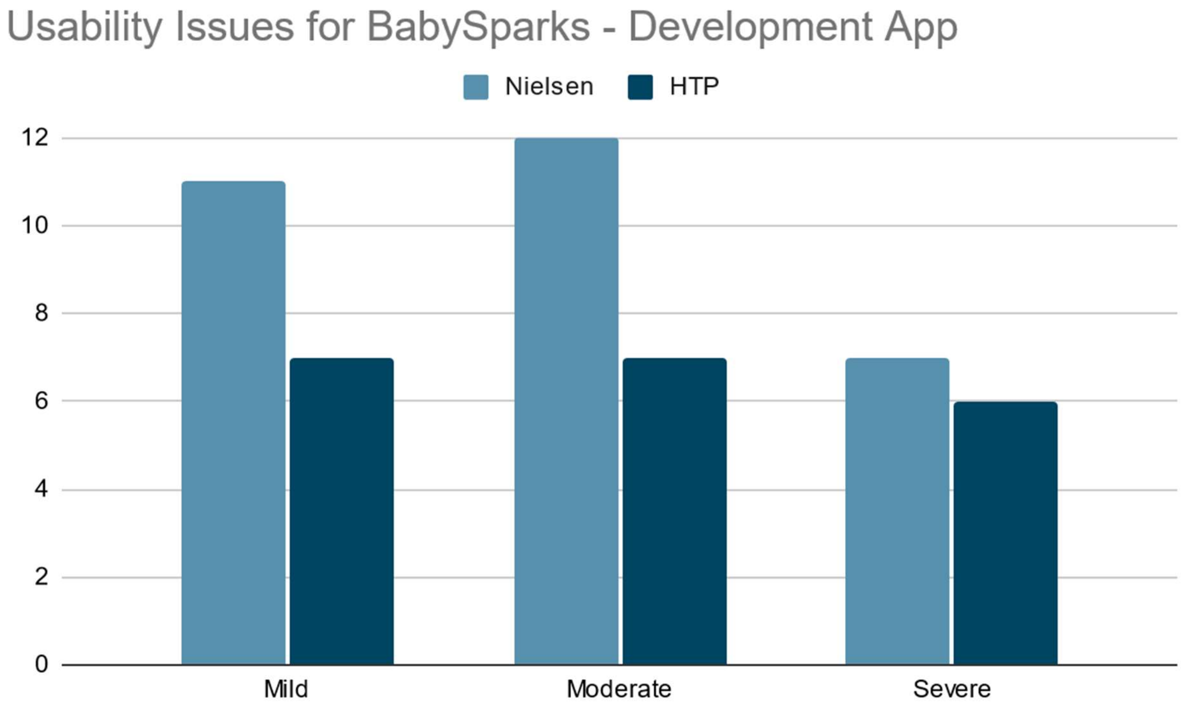
5.2.2.2.2 HTP heuristics ratings

Evaluators identified 26 usability issues using the HTP heuristics. Evaluators identified an equal number of moderate (7, 27%) and mild (7, 27%) usability issues, and an almost similar number of severe issues (6, 23.08%). Evaluators identified the same number of cosmetic issues (6, 23.08%). Across severity ratings, external links to content outside the app and prevalence of promotional materials were mentioned as highly disruptive to the user experience. Mild usability issues included a lack of progress indicators within the milestone tracking pages, misleading questions about parent and baby status during the setup process, and inconsistent classification of children (i.e., the app enables data entry for twins, but it is unclear how to add options for second children). Moderate issues included a lack of flexibility in the data entry process for children with identified developmental delays, complicated information architecture and gesture input types, and complex terms introduced in the app that were not coupled with definitions or explanations. Severe issues spanned disruptions with external linking, small text sizes for critical content, and lack of explanations and guidance for interpretation of complex milestones and activities. Evaluators did not classify any of their identified issues as cosmetic in this section.

5.2.2.3 BabySparks - Development App

The BabySparks baby development mobile app creates a personalized program for parents wanting to engage in meaningful and developmentally appropriate play with their child. The app is designed for children ages 0 to 3. The app provides parents with daily activities, presented through instructional videos. Parents can enter specific information about their child, including if the child was premature at birth, and the app adjusts plans based on the parent's data entry. The app supports plan creation for multiple children, and plan sharing across devices. The app is compatible with iOS and Android devices. The app requires a monthly or yearly subscription to have access to the full library of activities, milestones, articles, and tracking tools. The comparison of the performance between the HTP heuristics and Nielsen heuristics are visually shown in Chart 3.

Chart 3: Severity Ratings of Usability Issues Identified in BabySparks - Development App



5.2.2.3.1 Results from heuristic evaluation with Nielsen's Heuristics

Across evaluations, 22 usability issues were identified using Nielsen's heuristics. The majority of usability issues were classified as moderate (9, 40.9%). The second largest category was severe usability issues (5, 22.7%), and mild usability issues were the least (3, 13.6%). Evaluators identified five cosmetic issues (5, 22.7%). Across all severity ratings, evaluators mentioned inability to recover from issues as a key usability issue. Moderate issues included navigation challenges from inconsistencies in the menu bar, lack of guidance to help users recover from errors, especially those related to informing the user when they access paid content. Severe issues included a high risk of cognitive load from too many visual elements presented on the screen at once, and constant introduction of new concepts and topics without clear explanations. Mild issues included redundant information being presented across pages in the app, and uncertainty on how to access the sync functionality. Cosmetic issues included confusion about icon meanings and inconsistent typefaces. Evaluators included positive comments in their evaluation as well, including that the app had simple FAQs and help documentation.

5.2.2.3.2 HTP heuristics ratings

Evaluators identified 28 usability issues for the BabySparks - Development App. The majority of usability issues were categorized as moderate (11, 39.3%), the next most categorized as mild (8, 28.6%), and severe issues (6, 21.4%) had the least. Three cosmetic issues (3, 10.7%) were reported across all evaluations. Moderate issues included concerns with a lack of instructions for daily activities provided, introduction of complex health terms without definitions, and advertisements for premium features that were disruptive to task flows. Mild usability issues spanned not including a feature to share information with a child's care provider, lack of clarity on how personal information is being used, and inclusion of generic information about the sources of developmental health recommendations. Severe issues included lack of guidance on how to interpret insights generated by the app on a child's milestone data, delegation of search and filtering to the user for specific information, and inclusion of text-heavy explanations. Across all severity categories, evaluators mentioned that the advertisements for premium subscriptions were highly disruptive when completing tasks. Cosmetic issues included small font sizes and opacity of text and buttons.

5.2.3 Expert perceptions of heuristics

After completing the evaluations using the HTP heuristics, we asked respondents to complete a free response essay question to reflect on their experience with the heuristic evaluation methods. We asked respondents, "After completing your evaluation, what do you think are the strengths and limitations of Health Equity-Focused Mobile App (HTP) Heuristics, and how does it compare to other heuristic evaluation methods you have used?". In this section, we document salient themes from their reflections.

There were two primary themes identified from the reflections on the HTP heuristics. First, we identified that evaluators recommended to use the HTP heuristics earlier in the evaluation process, to inform significant changes to the mobile app. Evaluators felt that the HTP heuristics felt more like a list of requirements to meet when creating a system, rather than a set of principles to follow in the design and interaction experience. As such, they explained that requirements are better suited as a checklist before designing any elements associated with the interface of mobile apps. One evaluator shared, "This [method] is important for making technologies accessible to people, but it does not really get the reviewer to think about interaction experience together. There are design principles for UIs that every app designer should pay attention to. I think it would work better if you use it when you're deciding what the app would be like to change the specifications and then use a different set of heuristics like Nielsen's heuristics for [reviewing] the interaction experience." Other evaluators shared a similar sentiment; they reflected that none of the heuristics in the HTP heuristics explicitly named important principles that are prevalent in other user experience design heuristics.

Second, evaluators shared that the HTP heuristics would be inadequate for identifying specific issues related to interaction experiences, aesthetics, and visual design. One evaluator shared, "Nielsen's heuristics are good rules of thumb for designing interfaces. I'm not sure if there [are heuristics] for apps but I'm sure [they] exist. They help in finding usability problems before you show it to users and anyone can use [Nielsen's heuristics]. The [Heuristics for Technologies used by Parents (HTP) Heuristics] would not be helpful for people who don't know about [user experience research] because they would not know what to look for. I knew about [Nielsen's heuristics] already so I relied on my [knowledge] for my answers". Like this response, several other evaluators mentioned relying on their prior knowledge to inform how they evaluated the mobile app, and then translated that knowledge into how they applied the HTP heuristics. Evaluators also reflected that the HTP heuristics were "important", "address accessibility", “inclusive”, and important for creating mobile app experiences for parents that support “children with disabilities” and “users with dyslexia”.

5.3 Discussion

Our results demonstrate that evaluators using Nielsen’s heuristics identified more usability issues than those identified by the HTP, however severity ratings across both Nielsen’s heuristics and the HTP heuristics were consistent. However, from evaluator’s descriptions, it is clear that the heuristics were understood as requirements across the content and design of the mobile app, and not specific to user experience design principles. Evaluators categorized the heuristics as a useful tool, but ineffective for the stage of evaluation we asked them to engage in. While both methods identified issues, evaluators treated the HTP heuristics as requirements, not user experience principles. HTP’s emphasis on clarity and understanding may better align with setting design requirements at the outset. However, both methods uncovered usability problems of similar severity, which may suggest that Nielsen’s heuristic may still be valuable for identifying issues in early stages of design as well. Future work with evaluators should provide more insight in refining how the HTP heuristics could be used during the design process.

5.3.1 Using HTP for design decisions

Evaluators felt that the HTP heuristics were more like design requirements than an evaluation tool. This suggests HTP’s focus on core principles aligns better with setting clear requirements upfront, ensuring that technology systems are fundamentally understandable systems. They praised HTP’s focus on accessibility and inclusivity, and could be potentially useful for people with disabilities and varying literacy levels. Evaluators also recommended using the HTP heuristics earlier in the design process to inform more significant design changes. This highlights the potential for HTP to also be a beneficial tool in preventing usability issues before extensive design work is done, and reinforces the value of HTP in promoting the development of mobile health apps that meet the needs of a wider range of people. Relatedly, while evaluators felt that HTP was a useful tool for foundational aspects, they also felt that it lacked specific guidance on the interaction design and visual elements. This suggests that HTP could be a valuable early-stage tool to identify more core usability concerns, while Nielsen heuristics might remain valuable for later-stage evaluations focused on interaction and visual design. These methods could work in concert to engage in more comprehensive evaluations of technology systems.

In the human-centered design process, early engagement with target communities can improve the technology outcomes, by contextualizing the design process in a deeper understanding of the nuances in peoples’ experiences. Researchers have identified improvements in acceptability and relevance of health technologies from early engagement (Rajamani et al., 2021). Researchers have also reported using checklists or principles to guide their engagement with communities, particularly when discussing the specifications of systems or evaluating prototypes (Culhane-Pera et al., 2023; Skolarus et al., 2018). While there are resources available to specifically guide the inclusion of culture and context in technology design specifically (Airhihenbuwa et al., 2014), these models are critiqued for their focus primarily on Western constructs, and for sorting the nuanced beliefs and concepts of people into discrete domains (Iwelunmor et al., 2014). The HTP heuristics may be useful as a guiding resource for framing discussions where requirements for systems are being generated.

In the fast-paced design industry, resource constraints often limit designers' ability to directly engage with target communities. As a result, designers rely on established frameworks to guide their design decisions. This is particularly common in the mobile app design industry, where smaller companies or individual designers do not have the resources to connect with their target audience. Instead, they can rely on guidelines for how to design their mobile apps to be accessible, usable by people of all literacy levels, and compatible with different device types (Ostroff, 2011). As the primary app stores available to people globally, Apple and Google have also developed guidance for app developers as they create inclusive experiences (Apple, 2024; Google, 2024). Reflections from the evaluators and issues identified indicate that the heuristics might be beneficial for designers in early stages of their design processes as well. However, considering that academic publications can sometimes be difficult to navigate for people outside of academia, a revised version of the heuristics, published in a public forum (e.g., blog, social media) may be more accessible and impactful for designers.

HTP provides a general framework, but it cannot capture the specific needs, preferences, and contexts of a target community. Direct engagement with communities allow designers to understand the nuances in their experiences and tailor the technologies responsively. Further, HTP may not cover all potential usability issues, especially those that are unique to a specific community. Further, HTP provides a one-time evaluation approach. Designers can address these limitations by engaging people in the design process when possible. For example, user testing of a completed app can help identify unforeseen issues. Preliminary interviews could reveal preferences in the design and content of systems. Working consistently with people can also allow for ongoing feedback and refinement throughout the design process. Overall, for health-focused technologies, HTP should be seen as complementary to working with target communities.

5.3.1 Approaches to developing heuristics

As mentioned in the related work, there are several approaches to developing and validating heuristics. Our approach shares some strengths with other methods, but also has distinct challenges and features. When developing heuristics, researchers have employed a variety of approaches depending on the prevalence of other heuristics or evaluation methods that exist. Researchers have engaged directly with established methods for heuristic evaluation and refined them to apply to their specific technology context. Many researchers have used Nielsen's heuristics as a starting point for developing their heuristics, by using Nielsen's heuristics to categorize their proposed heuristics (Langevin et al., 2021), or using an independent review and addition or removal or heuristics that are relevant to their domain (Mankoff et al., 2003). In research areas where there is existing research that surfaces usability concerns or evaluation metrics (such as ours), researchers have used literature reviews (Langevin et al., 2021; Munson et al., 2022; Silva et al., 2015), grounding heuristics in existing research. Others have used more ground-up approaches where they surface usability concerns through direct observation of people using technology, and organize patterns in their observations into heuristics (Samarakoon et al., 2021), or by engaging with usability issues surfaced in the evaluation of relevant technologies in other studies (Munson et al., 2022).

When developing heuristics, some researchers have employed collaborative approaches to developing and refining heuristics as we have. For example, Langevin et al., Mankoff et al., and Silva et al. all engaged experts in the refinement process to improve on the content of the heuristics. By leveraging the expertise of design professionals working in this space, the heuristics across the studies mentioned (and our own) were improved to be better aligned with professional's needs and expectations, as well as better aligned with the usability concerns that are likely to surface for those technologies. Experts have also been engaged directly in evaluating the performance of the heuristics proposed and widely used heuristic evaluation methods (Langevin et al., 2021). This process for validating the performance of heuristics contributes to an understanding of how effective the proposed methods are compared to established methods.

Reviewing the approaches in other studies also surfaces potential limitations in our approach to developing and refining the heuristics. For example, our experts involved in creating and refining the heuristics were design students, who may not have the depth of expertise compared to other professionals; in Silva et al. 's work, engaging HCI professionals led to surfacing more complex and detailed refinements to their heuristics. It is possible by diversifying the knowledge and experience of the people involved in creating and refining our heuristics, we could have surfaced more complex issues. Further, other researchers have taken ground-up approaches that draw on prior research surfacing usability concerns. This approach can capture a broader spectrum of potential usability issues, and potentially increase the generalizability and credibility of the heuristics compared to those developed solely through expert opinion. As such, we employed a review of literature that involved both existing heuristic evaluation methods and studies on technologies aimed to be used by parents. However, an earlier review of the proposed heuristics by experts (both in designing parent-focused technologies and evaluating usability) may have led to significant improvements in the heuristics that surfaced in the validation study. Overall, it is likely that employing an approach that balances content from literature review and expert perspectives can lead to more comprehensive evaluation methods.

5.3.2 Limitations

There are several limitations for this study. First, we included a small sample of evaluators with diverse experience using heuristic methods. A larger sample may provide more clarity in the performance of each heuristic method in identifying usability issues. Evaluators with prior usability experience relied on that knowledge to apply HTP, suggesting that the current format might not be intuitive for beginners. It is possible that evaluators with more experience with heuristic evaluation would have more detailed comments in their reflections, specifically related to their past experiences. Additionally, we did not provide specific tasks for the usability evaluation. For this reason, evaluators mentioned spending more time than expected on the evaluation, and may not have explored all possible tasks within the mobile app. Future research could involve testing HTP with a larger and more diverse group of evaluators, incorporating it into an iterative design process, and comparing how it performs against other mobile app design guidelines and heuristics.

5.4 Conclusions and Future work

Heuristics are used widely in the field of human-centered design, however, no heuristics exist for evaluating technologies used by parents for supporting children's development. We present the results of a heuristic evaluation study comparing performance of Nielsen's heuristic method and culturally-informed heuristics. We identified that Nielsen's heuristics identified more usability issues pertaining to design and user experience. However, expert evaluators rated the heuristics as important and necessary in early design processes, to inform content requirements. As such, these heuristics may be better suited for early rather than late-stage design evaluations, as they may be influential in shifting the content of mobile apps. Additionally, because the heuristics performed similarly with Nielsens, both methods may work complementary to one another to identify issues more comprehensively in early design processes. Future research might apply the HTP heuristics early in design processes to demonstrate how they change the specifications of the technology system.

5.5 Chapter Conclusion

In this chapter, I present a new method for evaluating ecHPTs, by providing a set of heuristics for assessing the complex nuances of technologies that deliver information about child development to parents. By focusing on the needs of a specific target audience, parents, and exploring the need for content specificity in early childhood health topics, the proposed heuristics can support designers and researchers in evaluating their systems for more complex issues that are missed by existing heuristic evaluation methods. The heuristics can help identify issues related to how health information is presented, what information is given on trustworthiness of health guidance and how it is displayed, and features that support parents in making decisions between different health information sources.

These heuristics can be used to promote cultural safety in the design process of health technologies in three primary ways. In the heuristics, we focus on accessibility, understanding, transparency, trust, empowerment, and human-centeredness. These principles are directly representative of the core principles of cultural safety. Below, I provide a table mapping the heuristics to specific cultural safety principles (Table 8).

Table 8: Mapping Heuristics for Technologies used by Parents (HTP) to Cultural Safety Principles

Heuristic	Cultural Safety Principle	Relevance
Educates the user about content sources	Power Dynamics & Equity	By informing users about the sources of health information, the app empowers them to critically evaluate the information and avoid cultural bias.

Gives guidance on how to interpret information	Partnership & Shared Decision-Making	This heuristic supports parents in understanding the data presented by apps, allowing them to participate actively in interpreting their child's health status.
Protects personal information and privacy	Equity	Transparency regarding data collection and privacy safeguards ensures trust and protects families from potential discrimination based on their health information.
Responds to limitations of smartphone interfaces	Equity & Reflection & Continuous Learning	Considering limitations of access ensures the app is usable by a wider range of people, which promotes equity. This also reflects a commitment to adapting the technology for diverse needs.
Provides a simple experience when entering data	Equity & Responsive to all literacy levels	A user-friendly data entry process reduces barriers for parents with varying levels of literacy or technical skills, promoting equitable access.
Supports data sharing with non-users	Partnership & Shared Decision-Making	This function empowers parents to share data with trusted individuals, potentially including family members or cultural healers, facilitating shared decision-making.
Communicates information in more than one form	Responsive to all literacy levels	Providing information in multiple formats (text, images, audio, etc.) caters to diverse learning styles and language barriers, promoting inclusivity.
Tailors or personalizes information based on the user's needs	Equity & Partnership & Shared Decision-Making	Tailoring information to a family's context respects individual needs and cultural beliefs, while personalization empowers families to manage their health based on their preferences.

By ensuring that technologies are responsive to all literacy levels, offers information in multiple formats (text, images, audio), and avoids complex medical jargon, technologies can become more accessible to a wider range of people from diverse backgrounds. This is crucial in cultural safety, where ensuring people understand information contributes to their empowerment to participate in their care. Educating people about information sources and data privacy builds trust, which is another critical aspect of cultural safety. People from different cultures may have varying levels of trust in healthcare systems and institutions. Transparency around data use and sources fosters a sense of security and empowers people to make informed decisions. Further, by supporting people to personalize information and share data with others, technologies can respect individual needs and cultural preferences. Overall, by representing the principles of cultural safety through a heuristic evaluation method, we ensure that researchers and designers can directly address cultural safety through their technology design processes.

These heuristics provide a practical approach to integrating some cultural safety principles into the design process, and contribute to preventing inequity in several ways. As shown in our study, these principles may be useful when identifying the design requirements of technology and deciding the design directions. By focusing on accessibility and inclusion, the heuristics ensure that technologies are accessible to people with varying literacy levels and cultural backgrounds. This can mitigate the inequities that can arise when technologies exclude certain populations due to language or educational barriers. The emphasis on educating people about information sources and data privacy builds trust, especially crucial for populations with less trust in healthcare institutions. Transparency empowers people to make informed decisions about their health and interactions with technology, giving them the power to decide how to implement health recommendations into their lives, and deciding when they engage with technology. The heuristics also advocate for features that support user control, like personalization of information and data sharing. This caters to individual needs and cultural preferences, ensuring the technology respects diverse ways of receiving and managing health information. Cultural safety encourages recognizing these differences and avoids a "one-size-fits-all" approach that can disadvantage certain groups.

By systematically evaluating design elements through the lens of cultural safety, these heuristics can proactively identify potential biases or gaps that could lead to inequities. This allows for early course correction and prevents technologies from inadvertently reinforcing existing disparities in health information access and utilization. In essence, these heuristics act as a framework for designing health technologies that are inclusive, respectful, and empowering for all users, regardless of background or cultural context. This proactive approach helps prevent health inequities by ensuring technologies are accessible, trustworthy, and cater to the diverse needs of different populations. This also supports my research questions about how evaluating cultural safety in the design process can prevent inequities. Specifically, heuristics provide a way to proactively identify gaps in design that could lead to limited generalizability of technologies. Further, this contributes to our ability to design more effective tools that are respectful and empowering, by affirming the different identities and experiences of people.

In the next chapter, I discuss a study where I worked with parents and designers to create a conversational agent for early childhood health promotion. This study will further demonstrate how these heuristics can be applied to the design process, and will provide more tangible and actionable recommendations for integrating cultural safety into the design process. Because that study is deeply focused on how cultural safety is represented in the prototype, it was useful to have the HTP heuristics, as well as the heuristics for conversational agents developed by Langevin et al., to help guide the early design requirements, and conduct a comprehensive evaluation of the prototype and further refine the design recommendations for future technologies that we put forth in the paper.

Chapter 6: Enacting Cultural Safety in a Prototype of an Early Childhood Health Promotion Conversational Agent

As the technical capacity of accessible devices like smartphones increases, researchers are finding ways to create health technologies that address the nuances of health experiences. While the landscape of health interventions is changing broadly, technologies aimed to improve child health outcomes may be particularly impactful, due to their potential to have significant, long-term effects on the lifelong health of children and their families. Early childhood health encompasses the healthy development of children from birth to age five, a critical period during which a child's brain development sets the foundation for all of their future learning and growing experiences (Hagan et al., 2017). Because this period is so crucial, researchers have developed technologies for parents to use that support them in engaging in behaviors that promote their child's healthy development. For example, technologies exist that help parents screen their children for developmental delays sooner and encourage follow-up with healthcare professionals, or provide guidance on parenting strategies and activities that foster language development (de Cock et al., 2020; Mildon & Sellen, 2019; Zolfaghari et al., 2021).

However, a lack of cultural safety in technology design can contribute to existing inequities being exacerbated. Considering the diversity of families and their needs is an important consideration for providing relevant and meaningful child development support, and this notion extends to technology design. Across research happening in the medical field, computing field, and health informatics field, research demonstrates that providing generic, context-agnostic health information through technology is less meaningful (and thus potentially less effective) than personalized, tailored information (Jimenez et al., 2023). Further, research on these technologies is primarily exploratory, meaning there has been a lack of research on their impact on bridging health inequities for diverse communities (e.g., immigrant or refugee, African American, Latinx) (Karri & Yarra, 2022). While prior work has focused on the accessibility and usability of systems like texting programs, mobile apps, telehealth consultations, and interactive learning platforms, demonstrating that they are technically feasible for these communities, there is a gap in our understanding of how these technologies can be designed to ensure alignment with unique, diverse needs and have a meaningful impact on child health outcomes.

Cultural safety is an approach to healthcare that intends to move beyond mere acknowledgment of diversity. Developed in the context of training nurses to engage with people in Indigenous communities (Taylor & Guerin, 2019), it emphasizes creating spaces where people from various cultural backgrounds feel safe, respected, valued, and empowered. This approach recognizes that lack of cultural safety can lead to harm, such as reduced access to care, poorer quality of care, and worsened health outcomes. By contrast, achieving cultural safety involves actively working to understand and respect the unique contexts, experiences, and needs of diverse communities. It requires ongoing collaboration and openness to feedback from these communities.

Incorporating community-based research approaches can support more nuanced understandings of the cultural and contextual factors that influence how people from diverse backgrounds interact with technology. Community-based research (CBR) involves active collaboration with communities in the development, design, and implementation of technologies. This process allows researchers to gain a deeper understanding of the specific needs, values, and social contexts of diverse communities. Methods like focus groups, workshops, and interviews with community members have been commonly used in this space to develop an understanding of the community context. While Human-Computer Interaction (HCI) researchers have employed methods like participatory design and co-design to capture nuances for designing technology for specific groups of people, community-based research allows for an even deeper level of insight and collaboration. Because health inequity is often deeply intertwined with the social determinants of health, historical and ongoing disparities, and the infrastructure of communities, understanding these nuances is crucial for technology researchers and designers.

Further, conversational agents (CAs) systems that aim to mimic human conversation through text or spoken language (Langevin et al., 2021), have the potential to be powerful tools for promoting cultural safety in health technologies. Technical advances in areas like voice recognition, natural language processing, and artificial intelligence have led to CAs becoming increasingly sophisticated and capable of engaging with people in different ways (Montenegro et al., 2019). Because CAs can process different information formats (e.g., text, voice, physiological data), they have the potential to provide personalized and deeply tailored experiences. Research has shown that CAs can improve health outcomes by changing the behaviors that people engage in (Laranjo et al., 2018). While much of this work has focused on adults, the documented evidence that CAs can increase access to important health information suggests that their impact can likely expand to other domains as well. For example, CAs could be used to support diverse communities in accessing health information and services by providing culturally appropriate and language-accessible content.

While Conversational Agents (CAs) offer a promising avenue to make early childhood health care more accessible and interactive, their ability to cater to the diverse needs of families and their backgrounds may be limited. CAs rely on programmed responses and may struggle with the complexities of human communication, especially across language, emotion, and tone (Luria et al., 2019). Without the ability to understand nuanced social and cultural contexts, CAs risk being insensitive to the specific needs of different families. Additionally, early childhood healthcare needs can vary widely depending on the family's context; CAs that are designed as "one-size-fits-all" solutions may not be capable of providing targeted advice or addressing concerns that are specific to a family's situation. Lastly, concerns about data privacy around sensitive health information can lead to hesitation to engage with CAs (Schlimbach & Khosrawi-Rad, 2022), especially if families are uncertain about the security of their data or how their information is being used. These limitations can undermine a family's sense of cultural safety when interacting with CAs.

However, these limitations do not necessarily negate the potential of CAs to support early childhood health promotion. By incorporating the principles of cultural safety into their design, CAs can be transformed into tools that effectively respond to the diverse needs of families. Cultural safety emphasizes building trust, respecting cultural differences, and ensuring that power balance leans toward patients. These principles strongly align with the challenges identified in CAs. For example, building trust with families requires understanding their specific contexts and needs, which can be learned and developed through open-ended conversations with parents. Similarly, respecting cultural differences and power balance would mean designing CAs to be adaptable, inclusive, and empowering for families.

To explore how cultural safety as an approach to designing CAs may improve their ability to support diverse family needs, we collaborated (*For the rest of the chapter, the wording “we” is used throughout to represent the collaborative efforts between me, David Nguyen, and Julie

Kientz) with parents to create a set of requirements for a child development support chatbot. We aimed to develop an early prototype that represented their ideas and gather additional feedback. This collaborative process allowed us to gain deep insights into the specific needs and contexts of diverse families. Through engagement with community members, we were able to understand the nuances of communication, the importance of culturally specific advice, and the concerns around data privacy that are crucial for designing culturally safe CAs.

From this process, we developed a set of design requirements for conversational agents created to support early childhood health. These included features like the ability to adapt to different communication styles, provide culturally appropriate content, and ensure transparent data practices. We also learned about the benefits and challenges of engaging in community-based research in the co-design process for technology-based solutions. Parents appreciated the opportunity to have their voices heard and influence the design of a tool that could support their child's health. However, challenges like finding time for participation and ensuring representation from diverse families were also highlighted.

We aimed to answer the following research questions in this study:

1. What design elements of health promotion technologies contribute to culturally safe experiences for parents?
2. How can community-based research support generating and evaluating culturally safe practices in health technology design?
3. What are the benefits and challenges for parents when engaging in community-based research in the co-design process for technology-based solutions?

6.1 Method

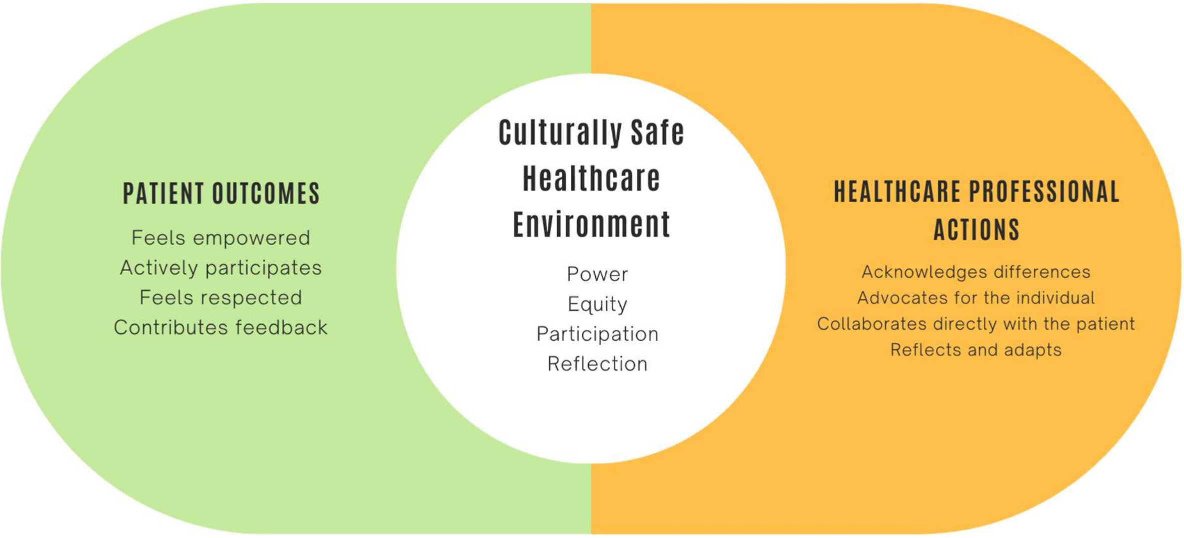
In this section, I detail the theoretical frameworks that guided our research as well as the data collection and analysis methods used to address our research questions. We employed a community-based research (CBR) approach, where we actively involved parents in the research process. Parents were engaged in refining the research activities, as well as participating in them (through co-creation of knowledge and a technology prototype). We completed our study activities over a seven month period: the first two months were dedicated to recruiting parents to participate as co-designers, months three and four were dedicated to interviewing and hosting co-design sessions with the parents and developing a set of criteria for the technology prototype, month five was spent evaluating and refining the prototype with the parent participants, and month six was spent further evaluating content from the interview, co-design, and feedback sessions. In month seven, we briefly connected with the parents to get feedback on an academic presentation of the research work.

6.1.1 Guiding Theories: Cultural Safety

During the 1980s in New Zealand, Māori nursing students raised concerns about feeling unsafe within an education system that promoted one dominant culture. From feeling that their cultural knowledge and perspectives were not valued, they felt that the broader healthcare system in New Zealand was not well-equipped to address the specific needs of their communities (Papps & Ramsden, 1996). In response, scholars like Irihapeti Ramsden and Elaine Papps created cultural safety, to move beyond acquiring knowledge about different cultures, and instead create healthcare systems that are responsive to the specific needs and perspectives of diverse communities, while acknowledging the historical and ongoing power imbalances that can affect health outcomes. Cultural safety differs from other approaches by emphasizing a focus on creating safe environments for patients, addressing power dynamics, considering the historical context and impact of colonization, and empowering patients to define what cultural safety means in their experience, instead of the healthcare professional (Curtis et al., 2019). At the time, other approaches like cultural competence, which focused on providers learning about different cultures, were created to mitigate the experience of feeling unsafe. However, many of these approaches fell short, as they did not challenge the inherent power imbalances in healthcare systems or acknowledge the historical and ongoing effects of colonization on Indigenous health outcomes, both of which contribute to Indigenous communities feeling that their cultural knowledge and perspectives are not only understood but are also not valued.

The core aim of cultural safety is to create a healthcare environment where patients feel safe, by acknowledging the power imbalances between healthcare providers (who are often members of a dominant culture) and patients (often members of marginalized cultures). This process is meant to ensure that they deliver care that is respectful, inclusive, and effective for patients from diverse backgrounds. Beyond language translation or interpretation, culturally-safe care considers cultural beliefs, communication needs, and the historical context that may influence a patient's health experience. Below, we share a diagram highlighting the roles of both patient and healthcare professionals in engaging in culturally safe environments (Figure 5).

Figure 5: Roles of Healthcare Professionals and Patients in Cultural Safety



While cultural safety is a powerful framework in healthcare, applying it to technology-based interactions like conversational agents (CAs) presents a unique challenge. The challenge lies in translating practices that rely on inherent humanness, like self-reflection, into technology that operates based on programmed responses. CA systems lack the ability to critically examine their biases and adapt their health recommendations as a result. However, the ways that CA systems are designed, trained, and implemented provide opportunities to integrate the core values of culture safety. For example, CAs could mitigate bias by using diverse datasets, improve communication quality by offering multiple languages, and have customizable settings that can further adapt interactions to individuals. Like healthcare professionals, they could be designed to be more collaborative by supporting open-ended conversations, and could learn from past conversations to find areas of improvement in how they communicate. These approaches could transform CAs to move from programmed responses to culturally safe tools that promote trust and improve healthcare access. By using cultural safety as a guiding framework, we can design CAs that are focused on providing safe and equitable healthcare.

In the same way that cultural safety can be used to guide the design of healthcare technologies, it can also be used to guide the approaches used in research to create culturally safe environments for people involved in research. Cultural safety emphasizes creating a respectful and equitable space for patients, particularly those from marginalized and vulnerable communities. In our work, we were inspired to consider how we could use cultural safety in our research to create a respectful and equitable space for the community we wanted to do research with. As such, we looked to integrate a community-based research approach that would support us cultivating a culturally safe research environment. Community-based research (CBR) is an approach that emphasizes participation and influence of people, who are not academic researchers, in the creation of knowledge (Israel et al., 1998). CBR involves the equitable engagement of researcher partners in all aspects of the research process. CBR has been used to design meaningful and effective community health interventions that are culturally and linguistically relevant for communities (Bogart & Uyeda, 2009).

There is a strong overlap between the tenets of cultural safety and the CBR approach. Both healthcare professionals and researchers are positioned as knowledge authorities in the United States, having credibility and authority in knowledge and practice (Bunton & Petersen, 2002). CBR and cultural safety both emphasize the importance of knowledge that may be outside the mainstream narrative (Israel et al., 1998; Taylor & Guerin, 2019). The CBR approach provides practical strategies for addressing real-world needs in collaboration with communities most affected by those issues. It provides guidance for identifying priorities, building trust, understanding community context, and promoting sustainability of research engagements. In CBR, it is important for researchers, especially those collaborating marginalized communities, to be aware of their position and how it might influence the research. While there is extensive training available to faculty-level research scholars, there is limited research examining training and critical reflexive process from the perspective of graduate students who engage in CBR (Tang Yan et al., 2022). Based on perspectives shared by faculty and other scholars, graduate students integrating CBR into their research may face challenges related to power dynamics, racism and institutional barriers (Burgess, 2006).

As graduate students conducting this research (one doctoral student and one masters student), we looked to cultural safety to learn how to critically reflect on the biases and assumptions that influence our worldview, engage in active listening and avoid making assumptions, and use clear and respectful language. Further, we used cultural safety to establish our commitment to equity by adapting our research approaches to accommodate the community context, and understood the history and context of health inequities for the community we were working with. We also engaged in regular reflections on our interactions with the community, identifying areas for personal and professional growth, and ensured to present the research in a means that facilitated active and informed participation from the community. To achieve these aims, we completed readings on cultural safety prior to the start of the research project, and explored how we met or did not meet these aims in a research team debrief at the end of our research sessions.

6.1.2 Recruitment and Participation Logistics

Following cultural safety and CBR as guiding theories, we identified an opportunity to engage parents in the design process as co-creators of the technology prototype. We recruited parents as a community advisory board (CAB) from King County, Washington, which is where our university is located. We recruited parents through community organizations, email lists, social media, and physical flier posting throughout King County. On each posting, we shared a link to a screening survey using Google Forms to determine respondents eligibility to participate in the study. Initially, we received over 200 responses to the screening survey that we identified as potentially fraudulent responses. Recent studies have explored the prevalence of fraudulent participants in online research recruitment, so we transferred the survey questions to Qualtrics to enable verification of responses. To offer parents more convenience and flexibility to participate in the research study, we hosted the study virtually. Based on our prior experiences working with parents, reducing the time commitment (not requiring parents to organize childcare or transportation) and creating flexible scheduling can include more parents who otherwise may not be able to participate in research.

We selected parents based on their availability for the study and whether they met the following criteria: must have at least one child under age five; speak and read English fluently; have access to a stable internet connection and a laptop, desktop computer, or tablet; and identify as American Indian/Alaska Native, Black, Hispanic, or Native Hawaiian/Pacific Islander. We aimed to recruit these communities because of their underrepresentation in early childhood health technology research (DeWitt, Kientz, Coker, et al., 2022). Because the study was completely virtual, we were unable to recruit parents that had limited internet and technology access. However, we tried to accommodate parent’s needs while enabling them to meaningfully participate in the study by allowing them to use their smartphones to participate in the study, by texting study materials rather than emailing when parents requested us to, and by using the dial-in feature on Zoom to call in to meetings. None of the parents we enrolled in the study required the dial-in accommodation, however.

We scheduled 15-minute phone calls with parents to share more information about the research study and to confirm their informed consent to participate in the study. Once we enrolled parents, we asked them to complete a virtual sign-up form to attend sessions at times that worked best for them. We emailed the study materials to parents a week before their first scheduled sessions and sent a reminder for each session a day before their scheduled time. Some parents requested to reschedule their study sessions to later times, and one parent requested to cancel one session due to a family emergency. Overall, each parent participated in five hour-long study sessions with the research team. Each session included between two to five parents and the two members of the research team. We conducted each session on a virtual Zoom call and recorded and stored the calls in the University of Washington Zoom cloud. The call recordings included audio and video recording, however only the transcripts from the audio recordings were used in the data analysis process. For participating in the research study, parents received $200 for attending and participating in 5 sessions, and completing an exit survey on their experiences in the research study.

6.1.3 Parent Demographics

Our study consisted of six parents (self-identified as three women and three men) of young children who lived in King County at the time of the study. Each parent had at least one child under age five, and identified as Black or African American, Hispanic, or Pacific Islander. Their ages ranged from 29 to 43 years old, and three parents held a bachelor's degree or higher. Their income levels ranged from $50,000 a year to $100,000 a year. As of 2020, the median household income in King County is $99,158. Their children ranged in age from newborn to 14 months old. Each parent had a spouse that they co-parented with in the home, and one parent expressed that they regularly get support from a grandparent in the home. The demographics for the parents in this study are reported in Table 9.

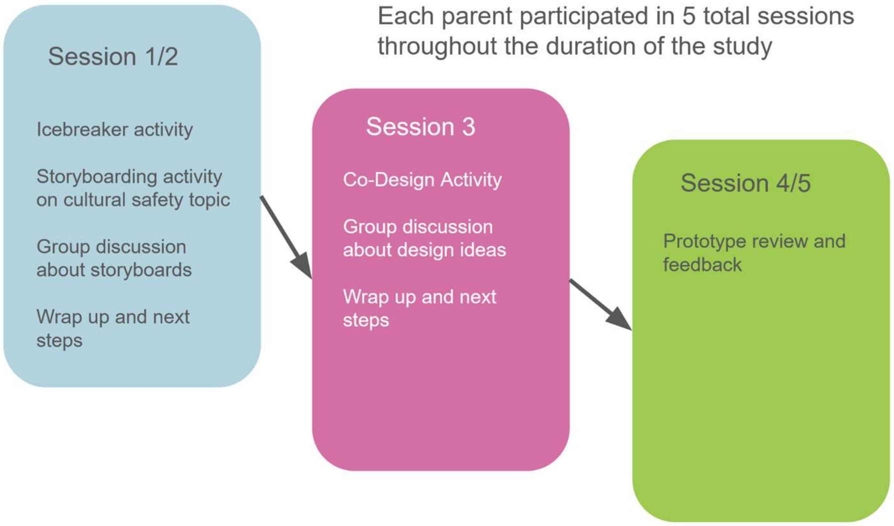
Table 9: Demographics of Study Participants

Pseudonym	Self-identified parenting role	Race/Ethnicity	Age	Age of youngest child	Number of Children in Household	Education	Income (per year)	Caregiving Support
Allan	Father	African American	32	4 months	2	College	Not reported	Wife
Arthur	Father	Black	29	Newborn	2	College	$76k	Partner
Keith	Father	Hispanic	30	1 year 2 months	1	College	Not reported	Wife, Parents and in-laws
Sara	Mother	Hispanic	32	8 months	1	High School	Not reported	Wife, Parents and in-laws
Amy	Mother	Black	28	Newborn	1	Graduate degree	$156k	Partner, Mother
Claudia	Mother	Pacific Islander	32	13 months	1	High School	Not reported	Husband, Parents and in-laws

6.1.4 Study Activities

We planned to hold 25 hour-long sessions with parents. However, each parent was only required to participate in 5 sessions total. Each session included between two to five parents at a time. We repeated the storyboarding, co-design, and prototype feedback sessions across the 25 sessions so that each parent could participate in the activity on multiple occasions. Our initial meeting with the parents involved introductions and overviews of the study. The research team introduced ourselves and provided a brief presentation with the motivations for the research study and technology design. We also provided a week-by-week breakdown of the study activities. To build trust in the research engagement, in the research team introductions, we acknowledged the expertise that we brought to the project based on our research positionality, and acknowledged the gaps in our knowledge that the parents brought to the project. We also recognized the ways that the research project may feel limiting to parents- for example, we had a discussion about the duration of the project and activities that would be completed during that period. We acknowledged that parents may be frustrated that they won’t have access to a fully functional tool at the end of the study, despite their extensive contributions. Afterwards, we asked them to provide their initial thoughts or questions about the research and to share one or two outcomes of the study that they are expecting. The research team addressed the questions and took note of the outcomes, initial thoughts, and questions that parents had. The research team met briefly after the meeting to discuss the outcomes and ways to incorporate them into the study activities going forward. In the next meeting with parents, to make sure expectations were clear, we communicated what changes we could make to the study with the time and resources we had available. The changes made to the study activities are documented in the results section. Below, we show a diagram of the study activities and each stage (Figure 6).

Figure 6: Overview of Study Sessions and CAB Participation



6.3.4.1 Parents as Partners

By employing a CBR approach, we aimed to engage parents in the research, not just as participants, but as partners during the research process engaging in active collaboration with the research team. Parents were active contributors during the design process for the technology prototype. Their ideas directly influenced the direction of the prototype. We also incorporated parent feedback through the process. Parent's perspectives shaped the design of the chatbot prototype through multiple rounds of evaluation. Further, we had multiple opportunities available to parents to give feedback on the research process and activities. The research team also made a conscious effort to acknowledge the expertise of parents as invaluable to the research project, treating them as experts in their experience. Lastly, the research team openly communicated the limitations of the research, such as not having a fully functional technology prototype at the end of the project. Overall, we communicated to parents that their role as a CAB member would be to engage in group discussions, design activities, advise on the content of the research activities and how parents would participate, and provide guidance and oversight in the design of a chatbot prototype.

6.3.4.2 Storyboarding Activity

We asked parents to participate in a storyboarding activity to hear about their experiences with healthcare and technology broadly. The storyboarding worksheet included six boxes for parents to draw or write out their stories, although parents had creative freedom to represent the ideas in the storyboard as they preferred. For example, many parents that did not feel confident in their drawing skills opted to use the boxes to write their stories instead of drawing them. Parents completed the storyboarding worksheet synchronously at home and sent in photos of the storyboards to the research team. The research team then used the Zoom presentation feature to project the completed worksheet in the Zoom meeting. Then, the parents talked through their storyboards. After, the research team proctored a group discussion where parents could reflect on the similarities and differences of their experiences with other parents. After sharing their stories, we asked parents to reflect on what changes could have improved that experience. We also asked parents follow-up questions about their culture in those experiences, including how it was relevant or not relevant, and how they define culture for themselves. At the end of the session, the research team presented a set of key takeaways they had and asked parents to provide feedback on them.

6.3.4.3 Co-Design Activity

Parents also participated in a co-design activity that included drawing out design ideas on worksheets and having group discussions about the design ideas that they came up with. We asked parents to create their designs with the following prompt in mind:

"Imagine that you have a chatbot on your phone that acts as a resource to support your child's development. Thinking about a specific time that you needed parenting advice or guidance about your child's development, design a short conversation you'd have with your ideal chatbot for this situation. Consider these things when designing your chatbot: How would you like the chatbot to present information? How would you prefer to interact with the chatbot? What types of suggestions would you like the chatbot to make?”

The co-design worksheets included an image of a generic smartphone with a blank screen, and parents could write or draw on the screen. The worksheet also included space around the smartphone for parents to draw or write additional details about their designs. Parents completed the co-design worksheets synchronously during the session and sent a photo (through text or email) to the research team to present on the Zoom call. The research team used the Zoom presentation function to project the worksheets during the sessions, and parents talked through them. The research team asked follow-up questions to parents to understand the details of how the design would work, where parents expect their designs to be implemented, and who would have access to it. The research team also proctored a group discussion where parents could ask questions about other design ideas and be inspired to refine their designs. At the end of the session, the research team presented a set of key takeaways they had and asked parents to provide feedback on them.

6.3.4.4 Prototype Evaluation

The research team met during one week to review the content shared in the co-design and storyboarding activities. During that meeting, the research team identified design requirements for the conversational agent prototype and discussed ways to portray those features in a Figma prototype. Figma is a popular web-based design tool used for creating user interfaces (UI) and user experiences (UX) for websites and apps. These design requirements were informed by the key takeaways from the end of each parent session, individual notes taken by the research team during the sessions, and a comprehensive review of the session transcripts. One member of the research team, who is an expert in designing mobile interfaces in Figma, took a first pass at designing the conversational agent interface. Next, the research team met with parents to present the initial prototype and get feedback for improvements. This process was repeated five times with parents, where in each new session they provided feedback on the prototype that was refined with their feedback.

6.3.4.5 Exit Survey

In the last session, the research team asked parents to reflect on their overall experiences in the research study through a virtual exit survey. The survey asked parents to reflect on their understanding of their role as a study participant, how they would describe this role to another parent, what they liked most and least about participating in the research study, ways that the research team could improve the research study, and perceptions about the value of their contributions from the research team and other parents. The research team reviewed these responses and identified key themes that are documented in the results section.

6.1.5 Data Collection and Analysis

We had several qualitative data sources that informed the content of the results and discussion. We collected demographic data from the parents in the study through the screening survey and initial consent process. In each study session, we recorded the Zoom sessions and produced transcripts from the sessions using Zoom's built-in transcription service. We also analyzed the content from the session worksheets and the exit survey that parents completed. To analyze the content of the transcripts and exit survey, we used a grounded theory approach, allowing us to identify themes that emerged in response to RQs (1 and 2). This method uses the constant comparative approach defined by Glaser, described by Strauss and Corbin, and communicated as a process for HCI researchers by Muller and Kogan (Muller & Kogan, 2012). We extracted themes in three phases. First, we transcribed the audio recordings and used an open coding process to identify major theme categories. Second, we used an axial coding process to identify sub-categories and cluster the codes into thematic categories. Overall, from the session transcripts and exit survey, we identified 12 open codes, which we clustered into 3 themes.

6.1.6 Position Statement and Ethical Considerations

The research team consisted of two individuals who identified as BIPOC (Black, Indigenous, People Of Color). Each team member lived in Seattle during the time of the study. One member had recently moved to Seattle within the last two years, and the other had lived in Seattle for 8 years. One research team member had extensive experience navigating child development as a parent of two children. For the study activities and recruitment, this study was declared exempt by the University of Washington Institutional Review Board. Prior to participating in the study, all parents provided verbal consent after the research team read the informed consent form to them. The research team also sent a copy of the verbal consent form for parents to have access to for the duration of the study. The parent participants received compensation of $30/hour per session and an additional $50 upon completion of the exit survey. They received a link to a virtual Tango Card that provided a lump sum payment that could be used at a variety of businesses.

6.1.7 Expert Evaluation using Heuristics

We engaged user experience research and design professionals in a final review of the prototype after we refined it with parent's feedback. During this phase, we conducted two separate evaluations of the prototype, using heuristics we developed in a previous study for evaluating technologies that provide health information or guidance (HTP), and heuristics developed by Langevin et al. (Langevin et al., 2021) for evaluation conversational agents. The intention of this approach was to gain a more comprehensive understanding of potential usability concerns, including things like ease of use and efficiency, information architecture, and accessibility. We recruited seven professionals with varying degrees of expertise, and they conducted their evaluations individually over an hour-long period. Each evaluator used one set of heuristics (either those developed by Langevin et al. or the HTP heuristics) to evaluate the chatbot prototype. The evaluators were given time to read through the heuristics and familiarize themselves. Then they were given time to review the prototype and share any high-level impressions. Then, the evaluators review the prototype by screen in sequential order. They reviewed the heuristics on the right side of the laptop screen and the prototype on the left side, or clicked between tabs, depending on their preference. One member of the research team documented the issues they identified and categorized them under each heuristic. At the end of the evaluation period, the researcher asked the evaluators for any final comments on the prototype, as well as their opinion and reflections on using the heuristics to evaluate the prototype. One researcher then organized the comments by combining them based on the heuristic method, and then using a comprehensive bottom-up thematic analysis approach (Braun & Clarke, 2021) to generate key themes within the usability issues identified. This study was exempt as determined by the University of Washington Institutional Review Board through an amendment to an existing IRB application for a separate research project. The demographics of the participants in the expert evaluation study are documented in Table 10.

Table 10: Overview of Participant Characteristics

P ID	Job title	Field	YOE	Prior experience with heuristics	Experience evaluating conversational agents
1	PhD Student	Teaching UX Design and Research	2	Used Nielsen’s heuristics in evaluations before.	None.
2	UX Design Student	User Experience (UX) Design	1	None.	None.
3	Full-time Masters student in Human-Centered Design and Engineering	User Experience Research	3	Evaluated two user interfaces: a complex workflow within an internal financial tool (despite lacking specific financial knowledge) and the home screen of a mobile banking app.	None.
4	PhD Student	Human-Computer Interaction Research and Practice	6	Learned user experience (UX) skills in their Master's program, collaborating with companies to research user needs and redesign interfaces. Familiar with usability evaluation methods like heuristic evaluation, and has created specialized methods before.	None.
5	Full-time Masters student in Human-Centered Design and Engineering	UX Research and Strategy	2	Conducted heuristic evaluation for multiple projects while working in a design consultancy, mainly for social media apps.	Evaluated conversational agents for mental health applications for a self-learning project while working for an agency through exploratory research.
6	UX Researcher	UX Research (Qualitative)	2	Conducted heuristic evaluations for product app while interning at a tech company as a design researcher	Most recent study was conducting a mixture of generative and evaluative research on conversational agents.
7	UX Researcher	Research	1	Evaluated identity and access products at my internship, prior to usability evaluation with users. Also conducted heuristic evaluation as a part of coursework.	Has developed a conversational UI as a software developer. Created a different chatbot for student support.

6.2 Results

6.2.1 Changes to Study to Incorporate Parent Expectations

We introduced the study in its entirety to parents during the consent process meeting. During this meeting, the research team explained the content of the research study and expectations for the outcomes of the study, so that parents could decide whether or not to participate in the study. During these meetings, we asked parents if they had initial questions or feedback on the study activities. The research team clarified that we wanted feedback on the study activities and not logistics (i.e., scheduling, compensation), however if parents had questions or concerns about the study logistics, they could follow-up with the principal investigator. We also provided parents with an overview of the study activities for them to take home to review and determine if there were changes we could make to the study activities to improve their experiences. Below, we include the study description shared with parents to get their feedback on (Textbox 3).

Textbox 3: Overview of Study Activities shared with Parents

This study focuses on parents' experiences with raising children aged 0-5. It explores how culture, child development, and health technologies influence parenting. We will ask you to collaborate with us in a community-advisory board (CAB) in designing a prototype for a chatbot that gives parents guidance about child development.

Here's what you'll be doing as a CAB member:

- **Group Discussions:** You'll talk with researchers and other parents about the role of culture in parenting, child development, and health tech use.
- **Design Activities:** You'll collaborate with other parents and the research team on a creative activity to design a chatbot. You will also give feedback on a prototype that the research team will create using your ideas.
- **Advising the research activities:** You'll advise researchers on how they can change the study to improve your experiences.

These sessions will be held online via Zoom, sometimes using an online workspace tool called Miro. The discussions will be recorded for analysis.

Example Questions:

- How do your cultural traditions or beliefs influence how you raise your child?
- Have you found any health technology tools helpful in your parenting journey?
- What challenges do you face when using technology to support your parenting?
- How could technologies be designed to better support parents from diverse cultural backgrounds?

Important Points:

- Participation is voluntary. You can withdraw anytime without penalty.
- You'll be compensated for your time.
- You have the right to skip any questions or activities that make you uncomfortable.
- All your information will be kept confidential.

Parents did not share any changes to the study activities based on the information we provided them. Instead, they had more requests about the logistics of the research study. Some parents expressed that they preferred different time windows than provided. To specify, we used a time slot management tool to schedule parents to participate in the study. We initially provided times in the morning, afternoon, evening, and late evening during specific weekdays within a month-long timeframe, but some parents expressed that days or times provided did not align with their schedule. To accommodate them, the research team provided additional days and times that they could participate in the research study. Parents also expressed preference for sharing their completed study activities in different ways than the research team expected. For example, we requested that parents email or text their completed worksheets to the research team. One parent asked if they could show their worksheet on camera during the Zoom meeting, and have the research team take a screenshot. Another parent used a camera scanner app to share a cleaner version of the worksheet.

Because parents did share feedback on the study activities and how their overall experiences could have been improved during the exit survey, it is possible that the study activities description and accompanying explanation by the research team was not sufficient in helping parents develop a comprehensive understanding of the research activities to give feedback on them. It is also possible that the research team had not developed the needed rapport with the parents yet to help them feel comfortable enough to give meaningful feedback on the study activities. However, the research team did provide time before and after the research sessions for parents to give feedback on the study activities to make changes prior to the next session. Still, no parents provided feedback on the study activities or communicated opportunities for the research team to improve the research study experience. One possibility to consider is that this may be the first time parents have participated in a research study. Since it's a new experience, they might not have a frame of reference for what aspects of the study activities could be improved. This could explain the lack of feedback during the initial request for feedback, despite the opportunity provided by the research team before and after the sessions, and explain the amount of more feedback and more detailed feedback shared in the exit survey.

6.2.2 Findings from Storyboarding Activity

Below, we shared the findings from the storyboarding activity and subsequent discussions with parents about their experiences navigating child development guidance, interacting with different people in their support networks, and ways that they felt their values and identity were relevant in those experiences. The following images show a few examples of the storyboards created by parents in the study.

6.2.2.1 Navigating Parenting Advice from Extended Family

Parents discussed their experience navigating parenting advice from older family members, which included grandparents and aunts or uncles. All except for one of the parents shared stories about resolving conflicts between parenting advice they received from older family members (who shared the same cultural backgrounds as them) and the beliefs that they or their partner wanted to act on. Despite parents sharing that they had the same “cultural background” (which they discussed in terms of race or ethnicity and religion), it was common for parents to disagree with some or all aspects of the advice they were receiving. In several parents' experiences, these conflicts arose from misalignment in beliefs or values that the parents wanted to promote in their household. Parents highlighted one reason for this disagreement as both the parents and grandparents desire the same for the child (e.g., to grow up healthy), but having different expectations for what to prioritize.

Amy shared a similar experience where the grandparent recommended for the child to wear gloves to keep warm (Storyboard picture). However, in Amy’s experience, she had a conversation with the grandparent about their child wearing gloves, which led to the grandparent adjusting their behavior. Amy expressed, *“I understand that my mom just wants [the child] to be warm…but we have our reasons…I told my mom, ‘Mom, we like her to be able to move her hands.’ Of course [my partner and I] want her to be warm but we also want her to explore…In the end, my mom still does put gloves on, but only when her nails are long”* (Amy). In this instance, Amy prioritized her child’s ability to explore and move their hands freely, valuing sensory development and more hands-on learning. Despite those priorities, Amy also acknowledged the grandparent’s good intentions to keep the child warm. For the parent and grandparent, communication about the values led to adjustments in the grandparent’s caring practice, showing a willingness to respect the parent’s values. Open communication between parents and grandparents can lead to a compromise that respects the values of both people while prioritizing the child’s well-being

Parents also talked about conflicts in how advice was being shared or followed up on. In contrast, in another parent’s, Sara, experience, the grandparents shared advice on healthy feeding practices without being prompted to share, and the parent preferred to receive information when she asked about it. She shared, *“Even though I myself believe in healthy eating and want to do everything for my daughter…sometimes it gets really frustrating when [my parents and in-laws] keeps on asking and telling me what to feed my daughter…Ultimately, my daughter is benefiting [from what I do], is gaining healthy weight, is active”* (Sara). She expanded on this experience by describing the ways that her child’s grandparents were not receptive to the ways that she was currently feeding her child. This parent values their autonomy and responsibility to make independent choices about their child’s diet. At the same time, in our discussions, she expressed that for their family, extended family plays a significant role in raising children. Despite her confidence in her choices leading to her daughter being healthy, she still felt judged and frustrated by the advice they gave her.

Other parents discussed instances where the advice they received from family members were already well-aligned with the values the parent and their partner had for their household. One parent shared that their father helped them identify the values that they wanted to maintain in their household from their home country. In this scenario, while there was strong alignment between this parent and their father's view, they expressed that it felt difficult to practice those values in a new environment. They shared, "It becomes an issue when it's repetitive, it keeps coming, it keeps coming. But I have to create, myself and my wife, a situation [for my kids to learn], but sometimes I've noticed it's a good strategy. Maybe it's just different from where I come from…so you find my wife busy working on the home like that" (Allan). In this case, this parent felt that within their city, people had different values that sometimes felt in conflict with the values they wanted to raise their children with. For this reason, they spent time working with their partner (instead of their father) to find ways to maintain those values for their family. This parent curated time to connect with people who shared similar values, for example, in religious and community spaces. While they had strong alignment with the views of family members from their home, they worked within the context of where they are living now to ensure those values are maintained for their family. Overall, these experiences highlight the complexities of navigating advice from extended family, particularly in respecting parent autonomy, finding balances between advice and support, alignment and cultural differences, and the ways that parents adapt their strategies.

In instances where parents worked with their partner to set goals for their child, the process involved discussion and negotiation of the beliefs and values that each parent had. For example, one parent discussed their experience with setting a goal for their child to hold their bottle by three months old. She shared, *"I felt unsure that [my child] could hold her bottle so early! It's like we're noticing that she's getting to be more independent. And that sort of thing like, oh, this is probably a good time to let her try more…But [my partner] was positive and encouraging throughout the whole process…But there was never a time when I was like, Oh, maybe we shouldn't have to do this, like I felt like it was a really good idea.."* (Amy). In this parent's example, she was initially uncertain about if her child was ready to hold her bottle early, despite having a desire to promote her child's independence. Encouragement and reassurance from her partner improved her confidence and ability to follow through on the goal during meal times. In this example, the parent's uncertainty about her child's capacity to hold a bottle also suggests that she may have had certain beliefs about appropriate developmental milestones. Despite any hesitation, this parent did want to see her child become more independent, wanting to foster autonomy for her child. Her partner's encouragement throughout the bottle holding process helped support their daughter's work toward both goals. Overall, parents collaborating in goal-setting for children may be impactful for navigating conflicting beliefs and fostering child development. By working together, parents can overcome individual hesitations, reconcile their viewpoints, and create a more unified approach to nurturing their child's development.

Navigating parenting advice from older family members and extended family can be complex. While cultural backgrounds might be similar, parents often have different values and priorities for their children. Effective communication, compromise, and adapting strategies are critical for respecting both parents and extended family members' perspectives while prioritizing the child's well-being.

6.2.2.2 Parenting Experiences and Concerns when Navigating Culture

During the sessions, parents did not discuss or label their experiences as explicitly “cultural” or pertaining to their “culture”. They broadly discussed experiences related to their race or ethnicity, religion, or country of origin, although we discuss below as “cultural”. When discussing these experiences, they explored the ways that their culture may influence their child’s ability to reach their full potential. In our discussions, parents focused on the ways that their cultural practices are perceived by others, and in turn, may affect their child’s treatment by people outside of the home. One parent shared, *“Based on our religious beliefs, we are pure vegetarians. We do not eat meat or even eggs. When we meet other parents here, they ask questions such as: ‘How is your child going to become strong?’. Made me feel like whether some of our religious beliefs will affect how our daughter grows up”* (Keith). For this parent, they felt that stereotypes associated with their vegetarian diet led to questioning. The way that these questions were raised implied that the vegetarian diet was not the normal or healthy way to raise a child. The overall focus on the choices that the parent made, instead of the overall well-being of the child, led to them feeling like their family’s beliefs were under scrutiny. Cultural background, even if not explicitly discussed, can influence parent’s concerns about their child’s development and how they are perceived by others. This highlights the potential for cultural differences to create anxieties for parents, particularly when they feel their choices are questioned or their child’s well-being is not the primary concern.

Another parent, Allan, shared that they experienced conflict between the values they set for their children at home compared to expectations of their behavior or engagement elsewhere. For example, their child participated in an activity at school that their teachers encouraged, but the parent felt that this experience was not aligned with their family values. The parent shared, “*I haven’t much exposed my children to anything apart from school. I haven’t exposed them to what other people teach them, because I really understand the culture in America will be different…If they are not at school, they are at home. If they are not at home, we are at the church. If we are not at the church, we are at the park. We are learning with them while enjoying it…Church is a place that is fully aligned with my family’s values, the only place they go is school which is not aligned fully with my family values. But yeah, that is life*”. The parent expressed that it felt stressful to try to counteract the things their child learned at school with the values and teachings that they maintained at home. The parent tried to resolve those differences in values by talking directly with their child about their family values, based on their “however he said culture”, and emailed the teacher to ensure that they were aware which activities their child could not participate in. We also discussed the underlying assumption that the school’s values take precedence. This assumption led to the parent feeling that their values were secondary or incompatible with their child’s education. This experience highlights the challenges that parents can face when their cultural background differs from the dominant culture in their environment (e.g., school systems). It also emphasizes the need for open communication to find solutions that respect all values.

Another parent, Claudia, shared a personal experience from when they were enrolled in elementary school. They shared that as a child, their family immigrated from another country. When they were placed in school, *“It was kind of automatically assumed that I would be in the*

ESL class, from the school district, but I did know English, and maybe I wasn't as vocal. But in [my home country], I studied in an English school. And they put me in that class. I think it was unfair, because I did not need to be there. But they put me there for half a year…and I feel like I could have learned more, or my skills would have gone further if I started right away…it was biased and it interfered with my ability to grow and further enhance my English" (Claudia). This parent explained that their identity led to assumptions about their English language skills, and they felt worried that their child would experience the same once they enrolled in school. This parent worried that their child would miss out on experiences to learn and grow, as they did, based on assumptions made based on the immigration status. The parent also expressed that this misplacement did not consider their specific language background, and instead generalized them into the ESL class, leading to missed opportunities. This experience emphasizes the importance of fair and individualized assessments for children from diverse backgrounds, particularly from immigrant backgrounds. This highlights how biases can negatively impact their educational experiences as well.

Another parent shared their experience navigating a difficult diagnosis for their unborn child. They shared, *"At [the third trimester], the doctor said that our child had a [low estimated weight] which was abnormal. Then she was out and another doctor gave the ultrasound and said everything looked fine. A few weeks later [my partner] was referred to get an MRI second opinion. [My partner] was then told our child had a [developmental concern] but [the other doctor] never mentioned that even though it was in the notes. After the MRI we were told our child had a rare genetic disorder and he would not live long. They said we had 3 options: terminate the pregnancy, go through with it and not provide respiratory support or support him if he survives. [My partner] was [farther along in the pregnancy] at this point. I felt very conflicted and angry and confused. We had to create a birth plan that outlined what we wanted to happen if he did not survive and one if he did survive…[the doctors] ultimately told us a lot of things that weren't true, or things they thought were true. It changed our lives and was the most difficult and traumatic experiences I ever had in my life. We moved [states] to get him extra support services. It just made us advocate for him even more and do the best we can, and take it day by day…We are his best advocates, and no one else can really tell us about him, more than we know about him"* (Arthur). This parent's experience highlights several areas where the healthcare professionals they interacted with did not provide a safe experience during a particularly difficult time. For example, breakdowns in communication between doctors (specifically a lack of clarity and consistency) led to the parents feeling conflicted, angry, and confused during a vulnerable time. We also discussed the stress that came with having to navigate these concerns during later stages of pregnancy, with limited options of what the parent felt they could do. Relatedly, this parent expressed that the doctors they interacted with did not present their options in a sensitive way, especially through the lack of transparency and empathy. They made suggestions to their family that did not prioritize their well-being and safety, which made this parent feel as if they were looking to get rid of them sooner. This parent attributed much of their experience to their racial identity, and felt that the doctors overlooked many opportunities to provide more sensitive and respectful care. Overall, this parent's experience represents the impact of healthcare systems not providing safe and respectful environments for families and their children, leading to missed opportunities to ensure that parents can make informed decisions about their children's health.

While parents may not explicitly label their experiences as "cultural," their background (race, ethnicity, religion, origin) can significantly influence their concerns about their child's development and how they navigate the world. This can lead to anxieties when cultural values clash with societal expectations or the dominant culture in their environment. Open communication, advocating for their child's needs, and finding solutions that respect all parties' values are crucial for navigating these challenges.

6.2.3 Design Requirements from Storyboarding Activity and Heuristics

Following the storyboarding activity, the research team met to identify high-level themes and create a preliminary set of design requirements for a technology support system based on the collective understanding of parents' experiences. The research team employed a collaborative qualitative coding approach to identify key themes from parent experiences. We began by reviewing transcripts from parent conversations together, utilizing a bottom-up approach to identify high-level themes. This collaborative process ensured consistent code application through initial code development, refinement discussions, and the creation of a formal coding scheme. After establishing a shared understanding of the codes, we divided the remaining session transcripts equally for independent coding. We then reconvened to discuss the prevalence of existing codes, incorporate newly identified ones, and review all codes together to identify overarching themes. These themes were then mapped to the cultural safety tenets and the HTP heuristics to explore potential crossovers and prioritize areas for further discussion. Recognizing one team member's expertise in user experience design, we leveraged their knowledge to inform the design requirements and actionable recommendations derived from the identified themes. Once a set of actionable recommendations was established, we presented them back to parents for their feedback (Table 11).

Table 11: Researcher-generated design requirements

Themes from Storyboarding activity	**Related cultural Safety Tenet (Yeung, 2016)**	**Design requirement**	**Actionable recommendation**
Information vs. Advice Tone Personalization Comprehensive/ Holistic Care	Partnership and Participation: Patients and healthcare systems collaborate in designing care and services, fostering trust and collaboration	Support shared decision making	Provide easy access to accurate and up-to-date information on parenting topics, child development stages, and healthcare options The information shared should acknowledge diverse parenting styles, values, and beliefs, so that parents can make informed choices that align with their values and needs. Offer interactive elements that help parents to explore different options and feel confident in their decisions.
Parent autonomy in conversations Transfer of power in conversations	Focus on power dynamics: acknowledging power imbalance and how power	Promote communication and respectful communication	Include features that can translate information or connect parents with interpreters to ensure clear communication. Translations should be accurate and make sense in context.

	dynamics influence interactions		Include spaces where parents can connect with each other and share experiences to improve their sense of community and help them feel less isolated.*
Identifying risk without assumptions Improve trust	Commitment to Equity: Not expecting patients to assimilate	Empowering parents by reducing bias and barriers	Personalize technology based on a parent's preferences, their child's age, and specific family needs. Learn how to personalize experiences based on engagement with the parent, instead of making assumptions based on their identity. Personalization should also change over time as families and their needs change. Offer tools for parents to assess their child's developmental progress and identify potential concerns. Identify where parents need additional support and connect them to relevant resources in their community.

*While features promoting parent autonomy and transfer of power directly address power dynamics in conversations, creating spaces for connection addresses the risk of feeling isolated weakening a parent's voice. By sharing experiences, parents gain confidence, learn from each other, and potentially identify areas for collective advocacy. This could foster empathy, improve communication skills, and contribute to a stronger sense of community, all of which could indirectly empower parents to navigate power dynamics in their individual conversations with greater confidence and effectiveness.

We shared these actionable recommendations with parents at the beginning of the research session and requested their feedback on the requirements. However, none of the parents had modifications to the recommendations after viewing the list. Parents shared that they felt that the actionable recommendations seemed comprehensive in an initial review, but they could not be certain of the comprehensiveness until they saw the final prototype. Instead, the co-design activity served as a frame for them to share their expectations for the design recommendations. We share images of the designs that parents created in Appendix F. We asked parents to create their designs with the following prompt in mind:

“Imagine that you have a chatbot on your phone that acts as a resource to support your child’s development. Thinking about a specific time that you needed parenting advice or guidance about your child’s development, design a short conversation you’d have with your ideal chatbot for this situation. Consider these things when designing your chatbot: How would you like the chatbot to present information? How would you prefer to interact with the chatbot? What types of suggestions would you like the chatbot to make?”.

6.2.4 Design Requirements from Co-Design Activity

We employed a collaborative co-design process. In each session, parents presented their sketched ideas for the technology, outlining functionalities and features they envisioned as beneficial. The group discussion then delved deeper, with parents explaining the reasoning behind specific design choices and highlighting elements they considered crucial. This open dialogue fostered an exchange of perspectives, allowing parents to learn from each other's ideas. To solidify these insights, the research team summarized the key themes and design elements identified during the discussion, seeking parental confirmation and feedback on their interpretations. These design elements are summarized in the textbox below (Textbox 4).

Textbox 4: Parent-Generated Requirements for Child Development Support Chatbots

The chatbot should fit within the network and ecosystem of things parents already rely on, not overtake it. For example, they are not looking for the chatbot to replace conversations with their doctor or with a family member. Instead, it should work as a new resource in addition to those things.

The chatbot should offer new and relevant information. Parents are not looking for information that they already know.

Let parents decide when they want to engage with the chatbot and when they don't. For example, let them decide when they do not want to talk with the chatbot anymore and want to talk to a human, like a doctor or nurse.

The chatbot should be aligned with what parents believe individually. It should not try to promote a single parenting philosophy, and should not judge or contradict a parent's personal beliefs.

After all co-design sessions concluded, the research team convened to consolidate and refine the design requirements that emerged across all sessions. Focusing on the underlying needs and functionalities, we sought to move beyond specific features and identify the core principles guiding the technology's operation. Once these requirements were established, the research team presented them to the parents in a subsequent session. Here, parents offered their valuable feedback, and expressed satisfaction with how accurately the requirements captured their needs and their excitement to see these concepts translated into a tangible technological prototype. During this review process, parents came up with the following requirements for chatbots that they may use to promote their children's development (Textbox 5):

Textbox 5: Parent-Centered Chatbot Design Requirements

Respectful Integration
- The chatbot complements the resources parents already have, not replace them.
- Parents get to choose when and how they interact with the chatbot.

Information
- The chatbot offers new and valuable information beyond what parents already know.
- The chatbot acknowledges diverse parenting styles and beliefs, allowing them to make informed decisions that align with each family's values and needs.

Supporting decision-making
- The chatbot should support parents with working with other caregivers and making decisions together.
- The chatbot has features that help parents explore options and be confident in their choices.

Communication
- The chatbot should have clear communication (which includes accurate and context-aware translations and interpretation), and be able to communicate information in

different formats.
- The chatbot should be able to connect parents with relevant people, like healthcare providers or teachers when it is needed.

Community
- The chatbot should have spaces where parents can connect, share experiences, and build their community.
- The chatbot should identify when parents need resources, connect them, and help them with the sign up process.

Empowering and respecting parents
- The chatbot should tailor information and recommendations based on a parent's preferences, their child's age and growth, and their specific family needs. This personalization should change as families and their needs change.
- The chatbot should avoid making assumptions based on identity. Personalization relies on a parent's engagement with the technology instead. Parents should still benefit from the technology if they don't want to share certain information.
- The chatbot should provide tools for parents to assess their child's developmental progress and identify potential concerns.

6.2.5 Prototype evaluation process and summary of changes

Using the design requirements, the research team developed a static, low-fidelity prototype to enact the design requirements. We engaged in an iterative process that involved parents giving direct feedback on the low-fidelity prototypes and the research team making refinements to the prototype. We used a low-fidelity prototype as it enabled the lead designer on the project to have a quicker iteration and exploration of design ideas, and not requiring extensive time or resources. Because we were focused more on refining the design requirements rather than focusing on the functionality of the tool, a low-fidelity prototype enabled us to communicate design ideas without being focused on aspects of the interaction experience, like usability issues. The final prototype can be viewed in Appendix G.

To ensure unbiased feedback, we conducted individual sessions with parents. Before each session, we explained the iterative refinement process. We informed them that they might see different versions of the prototype as we made adjustments based on ongoing feedback. However, we would provide links to all versions, which would allow them to track the prototype's development if they were interested. Overall, we conducted six feedback sessions with parents. Lastly, we shared the final version of the technology prototype with parents during the final synchronous session. We gave parents the opportunity to share additional feedback and complete the exit survey for the research study. Currently, we are still incorporating the design issues highlighted in the expert evaluation study, however, once we have integrated those changes, we will share a link to the Figma prototype so they can view it if interested.

During each parent feedback session on the technology prototype, we followed a consistent structure:

1. **Presentation:** We first presented the current low-fidelity prototype, designed using Figma, in full-screen mode.
2. **Independent Exploration:** Parents then had dedicated time to explore the prototype independently.
3. **Think-Aloud Walk-Through:** Following exploration, we asked parents to walk us through the prototype page by page, verbalizing their thoughts and observations using a "Think-Aloud" process. The research team documented their insights throughout this phase.
4. **Feedback Discussion and Refinement:** After the walk-through, the research team summarized their notes on potential improvements for the next iteration. We facilitated a discussion to ensure parents felt the proposed changes addressed their feedback effectively.
5. **Team Debrief and Iteration:** Following each session, the research team met to solidify the changes based on the collected feedback for implementation in the next version of the prototype. The designer on the team then took those refinements and added them to the prototype prior to the next feedback session.

Informed by parent feedback during the iterative design phase, we implemented several key changes to improve the prototype's clarity, functionality, and ability to guide decision-making. The onboarding process and user flow were reworked to clearly explain data requirements and sharing policies, similar to existing apps. We expanded the prototype to showcase interactions with doctors, other parents, and the chatbot, providing parents with a better understanding of the app's full potential, and how it can support them in various scenarios. Additionally, the design now illustrates how to escalate concerns to healthcare professionals.

A significant portion of the design focus was on refining the chatbot to enhance its ability to guide parents through decision-making. We created a new user flow to illustrate how the chatbot could help parents make decisions about their child’s care, by including a dialogue between the chatbot and a parent that showed a series of questions to help them consider different factors. From a parent’s recommendation, we included a scenario of helping a parent choose a daycare. We also added an open-ended input box during onboarding to personalize interests and tailor the chatbot's responses. We also incorporated features like password/pin options for security and the ability to provide feedback on specific chatbot responses. To improve information clarity, text is now presented in bullet points, and parents can customize the chatbot's background and pictures. These high-level changes directly addressed parent concerns about clarity, functionality, and user experience, leading to a more robust and user-friendly prototype that empowers parents to make informed decisions.

6.2.6 Findings from Exit survey

Below, we share the feedback that parents provided us at the end of the study. Overall, there seemed to be a mixed understanding of the CAB role among the parents. Some parents expressed a clear understanding of the role, mentioning things like “bridge between the community” and “voice for the people”, which accurately reflect the role of a CAB member. Other responses focused on sharing personal experiences and feedback, which captures part of the role, but misses the advocacy aspect of being a CAB member. One parent just responded "parent" which lacks context and may suggest that they had a limited view of just representing a parent in the research study. When asked about how they would describe the CAB role to other parents, parents shared that they saw the CAB as a way for community members to influence decisions made by "universities" or "non-profits". Some parents saw the CAB as an opportunity to "provide input on a project" and "play a role in the project directions". Still, some of the responses again focused more on sharing personal experiences than advocating for the broader community.

The overall sentiment of parent's experiences participating in the CAB was very positive. Parents felt that their opinions matter and were appreciated by the research team (across all responses). Two parents shared that they enjoyed knowing that their feedback could improve resources for all families. Other parents shared that they appreciated feeling comfortable to talk about their experiences honestly. One parent mentioned that they appreciated the flexibility in the meeting times. Two parents also expressed that they were motivated by the opportunity to contribute to a positive change and being part of a like-minded group of people. When asked about what they liked least about participating in the CAB, there were mixed experiences. Two parents shared that they had no negative experiences. One parent said that they would have preferred talking about community resources for medical and educational support, rather than focusing on the app prototype. Another parent shared that the time required for the research study was excessive. Overall, the parents felt empowered by their participation in the CAB and valued the opportunity to make a difference in their community. However, while some found the experience positive overall, there are aspects that could be improved, like offering more diverse topics and accommodating busier schedules.

We also asked parents to share to what extent they thought their contributions would benefit their community. Overall, the sentiment from parents had cautious optimism about the impact on the community. Most of the responses from parents highlighted the potential benefits for the community, like easier access to resources, reduced stress through a helpful chatbot, and a broader consideration of diverse needs. One parent expressed doubt about the impact depending on how the prototype was further developed. They shared that if the chatbot focused narrowly on developmental resources and it had low adoption within the community, the benefits would be limited. Still, there is a shared hope that the project goes beyond a single app and addresses wider community needs based on the discussions held. Overall, parents believe their contributions have the potential to benefit the community, but some are unsure about the actual implementation and its reach.

6.2.7 Results from Expert Heuristic Evaluation Study

Overall, the analysis revealed that the most critical areas for improvement are related to protecting privacy, educating people about data sources and information interpretation, and responding to the limitations of small screens. Across all evaluations, evaluators mentioned the difficulty of conducting a comprehensive usability assessment without being able to experience the full user experience. However, evaluators left comments on the HTP heuristics, sharing that overall they were generally well-received and effective in identifying potential communication issues. They suggested improvements in clarifying the wording of the HTP heuristics. They also commented that conducting the evaluation through side-by-side layouts was valuable.

Both sets of heuristics provided different insights into the usability and content of the chatbot prototype. The analysis using Langevin's heuristics identified both strengths and weaknesses in the chatbot prototype's design and usability. Evaluators identified that the chatbot clearly indicated when it is online and offers an option to end the conversation (visibility of system status). They also identified that the conversation format mimics similar chat layouts and feels familiar to the person using it (match between system and the real world). Further, the visual layouts, color palettes, and text directions were consistent, but sometimes the fonts and letter case were inconsistent (consistency). Evaluators also rated the learnability of the chatbot as high, as they felt confident to begin their interaction with the chatbot based on clear instructions and options (learnability), although questions came up for them about the contingencies that could potentially arise during the interaction (e.g., where a clickable link will take them and how it will present in the interface). Evaluators also felt that the chatbot was effective in providing options that could guide people through conversations as they are getting started (help and guidance). Lastly, all evaluators commented on the cleanliness of the design choice and minimalism in the colors being used.

There were several weaknesses that evaluators highlighted as potential ways to improve the prototype in future iterations. First, there were issues with the clarity about the capabilities of the chatbot (clarity). For example, because there was limited onboarding in the prototype, evaluators felt unsure if they had explored the full functionality of the chatbot. Within the prototype, there was limited control over the progression between pages, although some evaluators assumed that this feature would be included as a part of the device interface. As mentioned, the prototype had some inconsistencies in the font usage (consistency). Trustworthiness was also explored; while data privacy information was included in the onboarding process, evaluators highlighted the need for the chatbot to indicate how conversations and information about the person was being stored (trustworthiness). Lastly, evaluators felt that they could not effectively assess the following heuristics: "Help users recognize, diagnose, and recover from errors" and "Context preservation". However, some evaluators still speculated on context preservation, highlighting the missed opportunity to indicate how the chatbot may reference past messages, and enable the user to access their personal information, as well as access the content of past conversations. Overall, evaluators using Langevin's heuristics highlighted that the chatbot has a good foundation, but can be improved in clarity, user control, and building trust with users.

Evaluators using the HTP heuristics highlighted several areas to improve the user experience of the chatbot. Evaluators found that there was a lack of clarity about the data sources included in the chatbot, why links are recommended for parents to engage with, and the purpose of manual data entry. Evaluators suggested that the app could benefit from explaining these aspects to people early on in the interaction experience (transparency and user education). Further, evaluators recommend reevaluating the privacy and data sharing practices in the app, particularly by further explaining the benefits and limitations of choosing to create or not create an account, and related to conversations that they have with real people through the chatbot app. For example, when a parent requests to talk to a nurse or another healthcare professional in the app, there should be clarity in how their data is accessed and shared (privacy protection). Lastly, while the app offers different formats for content, which was highlighted as a positive aspect, how parent's interests and content recommendations are personalized remains unclear (personalization). Overall, evaluators suggested that the app should focus on improving the transparency of how data sources are used, how information from the user is interpreted, and refining the personalization approach.

We also provided the opportunity for evaluators to give open comments on the core functionalities of the chatbot. We organized the comments thematically and provide the high level themes here. Evaluators highlighted how multilingual capabilities could be improved, specifically through automatic language detection, more diverse language options (i.e., dialects), and clear translations with transparency about accuracy. They also shared that the chatbot could set further boundaries, by acknowledging its limitations more, offering escalation options for complex issues, and redirecting people to external appropriate resources when necessary, including relevant people in their community. Evaluators shared that this approach may improve the trustworthiness of the chatbot. Related to the aforementioned issues with how data is stored and shared, evaluators shared that a dedicated page explaining the data storage and usage would address those concerns. Further, evaluators commented on the user interface (UI) design. They shared that features like adjustable font size and undo and redo options would enhance the accessibility and user control. Conversation management features were also mentioned, including topic labeling, searchable archives, and enhanced information about humans that are available to talk to as a part of the chatbot service. Lastly, evaluators gave several additional considerations that did not fall into the mentioned categories. One evaluator suggested that the chatbot could support the primary user asking questions on behalf of a friend, which could increase access to the chatbot for others. Two evaluators (4 and 7) spoke to the logistical considerations behind enabling access to talk to a human in real-time. For example, understanding cost and billing for healthcare professionals who provide services through the chatbot interface is crucial, and integrating the chatbot with insurance or other healthcare payment services could make that feature more accessible.

Overall, combining both the parent and expert evaluations of the prototype have highlighted several opportunities for immediate improvement in the prototype. We look forward to integrating these changes in future iterations of the prototype.

6.3 Discussion

Throughout the study, we identified opportunities to improve parent experiences by promoting cultural safety in the context of their children's health. Cultural safety emphasizes understanding and respecting the cultural backgrounds and beliefs of patients, and adapting healthcare practices to meet their needs. Parents in our study navigated conflicting beliefs and practices from various sources, including family, friends, healthcare professionals, and childcare providers. Their experiences highlighted the need for respectful and responsive healthcare that aligns with family needs. This section discusses how we reflected these values in the chatbot prototype developed collaboratively with parents.

6.3.1 Communication, Partnership, and Respect

Cultural safety encourages open and respectful communication between patients and health professionals. This principle is crucial when designing early childhood health support technologies, especially conversational agents (CAs), to engage in true partnerships with parents rather than providing one-way information. In our study, we saw how open communication between parents and people involved in their child’s development led to more meaningful interactions, and parents feeling respected and trusted in their knowledge and values. For example, Amy preferred keeping her baby's gloves off to support sensory development through exploration, while her grandmother valued keeping the baby warm. Open communication between them led to a compromise that represented both perspectives. Cultural safety tells us that respectful and collaborative communication is essential to empower people to share their experiences and perspectives and actively participate in their care.

We extended this principle to the CA prototype in several ways. First, we embedded features where the chatbot would acknowledge its cultural background and biases. During the onboarding process, the chatbot introduced itself by stating it was created by a team with specific intentions and positionalities, and communicated that it may influence the chatbot’s responses. We also showed how the chatbot could offer services in multiple languages, and further explored how it could acknowledge cultural variations in communication styles in the expert evaluation process. Relatedly, we considered readability, avoiding medical jargon, and avoiding judgmental language. By including these features, we intended for parents to feel empowered, informed, and confident in their engagement with the chatbot. When practically implementing these features, it would be important to consider how the data included in the CA could perpetuate cultural biases. For example, researchers have explored ways to mitigate bias in data sets when training artificial intelligence models (Pfohl et al., 2024). That chatbot could also identify potential biases in its responses and flag them to the parent, offering alternative phrasings or explanations. This approach has been used in other fields to improve the transparency of technology systems (Roselli et al., 2019).

We also aimed to foster collaboration rather than one-way communication. Parents in our study expressed a preference for technology that supports, rather than replaces, existing resources and knowledge within their communities. The chatbot we developed achieved this through enabling collaborative decision making, and providing features that support parents’ communication with people outside of the chatbot. It guided parents through decision-making processes that considered their values and priorities for their child, empowering them and avoiding imposing a single "correct" solution, by engaging in dialogue with parents and providing meaningful responses. The chatbot also provided detailed information about the sources of recommendations made, so that parents could understand why certain content was recommended to them and better decide if they wanted to incorporate the feedback into their parenting practice. In future iterations, we plan to explore how the chatbot can facilitate conversations between parents and their child's support network. This feature would address the burden parents often face in explaining their decisions and navigating disagreements with caregivers like grandparents. By acting as a mediator, the chatbot can ease communication and convey information neutrally. This approach fosters open dialogue and active listening, promoting mutual understanding between parents and caregivers. Furthermore, these conversations can be opportunities for shared learning, allowing grandparents and others to gain knowledge about new child development approaches. Ultimately, facilitating communication within the support network empowers parents, reduces conflict, and paves the way for collaborative decision-making and a more unified approach to raising healthy children.

We also saw the need for clear and consistent communication during stressful times. Cultural safety requires that healthcare providers communicate in ways that are aligned with a patient's needs. In our prototype, we provide culturally safe communication by using plain language and visual supplements, confirming parents' understanding of information through prompts, and requesting information about preferred communication styles. Relatedly, research on conversational agents has explored processes to integrate approaches like active listening (Xiao et al., 2020), or ways to improve perceptions of trustworthiness or respect (Clark et al., 2019). While work on health-specific conversational agents has focused more broadly on 'personality' traits that can change the style of communication (de Haan et al., 2018), Tudor Car et al. (2020) conducted a prototype review of conversational agents used in healthcare and found that attempted to replicate the demeanor of healthcare professionals, engage in informal or friendly conversation, or communicate as a coach would (i.e., providing encouragement, motivation, or nurturing) (Tudor Car et al., 2020). Their review highlights the lack of consideration for the conversation facilitation techniques, beyond tone and conversation style.

To facilitate active listening in our chatbot, we primarily used open-ended questions to encourage parents to share their questions without judgment and in their own words, and clarification prompts to demonstrate engagement, and to learn more about the parent. The intention in including these features was to prevent the chatbot from making assumptions based on the parent based on demographics or keywords, and instead rely on the parent's narrative for context. The chatbot also included summaries of key points from conversations to ensure the conversation is on track for the parent. We also included mechanisms for parents to provide feedback on its responsiveness. When practically implementing these features, it is important to consider how the chatbot's training data and responses could be continuously updated based on the parents feedback and lead to the chatbot evolving in its responsiveness.

As demonstrated, adopting a cultural safety approach could provide a different lens to understand how chatbots communicate with parents. By actively involving parents and community members in the co-design process, we were able to create a chatbot prototype that better aligns with the communication and decision-making needs that parents have.

6.3.2 Commitment to Equity

From the storyboarding activity, we highlighted conflicts between parents' values and societal "norms" and institutional practices. Both Keith and Allan had experiences where the values they had for their family were undermined through engagements with the dominant Western cultural perspectives (e.g., eating vegetarian diet, disagreeing with their child participating in some school activities). Similarly, Sara and Allan felt devalued when external opinions about their parenting were imposed without space for their own perspectives. Cultural safety emphasizes respecting parent’s values and adapting care to their cultural context, rather than assuming that parents and their families should assimilate to the dominant culture. By assuming that parents and families should assimilate, we risk excluding people that reserve the right to maintain their cultural identity and values. This principle also represents a commitment to equity by providing experiences that are meaningful within parents’ unique experiences. The features mentioned in the previous section have dual purpose in facilitating meaningful communication, respecting parents’ values, and adapting recommendations based on parents’ knowledge and experiences. However, there are additional considerations not included in our chatbot that should be considered in future designs.

Health technologies can perpetuate the beliefs and values of dominant cultures in the information they provide, as well as how it is delivered. Many health technologies rely on the standards and guidelines for health put forth by Western medical authorities (Llorens-Vernet & Miró, 2020). Within these standards, there is generally a strong emphasis on the biomedical approach, which is focused on diagnosis and treatment of disease, specifically through medication or surgical intervention. This approach can overshadow the healing practices valued in other cultures (Ibeneme et al., 2017). Further, the western healthcare system still struggles to integrate health practices from other cultures (Giordano et al., 2002). This exclusion of knowledge and strategies for health can lead to people feeling unheard or unvalued due to their perspectives, creating a strong disconnect in their healthcare experience. Western medical models also primarily position healthcare professionals and governing healthcare bodies as authorities with complete knowledge. This can be disempowering for people from other cultures, especially if their values or beliefs are in conflict with the dominant models.

As such, designers should take care to develop technologies that are respectful of cultural differences in beliefs and values, while still providing impactful care. Cultural safety can be used to inform the design of technology that achieves this aim. One core tenet of cultural safety is a commitment to equity, where people are not expected to assimilate to the dominant culture they experience health in. Instead, healthcare systems and professionals adapt their care plans and approaches to accommodate the person’s cultural context.

We envision this being represented in future CAs in several ways. To practically implement a commitment to equity and dismantling discrimination, the CA should be built to identify and flag potential disparities based on factors like race, ethnicity, or socioeconomic background. In this feature, the CA could analyze a parent’s data (with the appropriate data privacy measures) and adapt its recommendations to respond to these potential disparities, by connecting the parent with relevant people or resources in their community that could mitigate those risks. Further, the CA should be trained on data that is representative of the history of health inequity and how it affects different communities. This would enable the CA to understand and address health inequity in a more meaningful way. Including information about the social determinants of health and how they impact health outcomes in the chatbot (e.g., income, education, access to food) could improve the CA’s handling of complex and nuanced health issues. This could also enable the CA to validate the parent’s experiences.

In our study, parents expressed that they wanted the chatbot to have a deep alignment with their individual beliefs, and not promote a single parenting philosophy or judge/contradict a parent’s personal beliefs. There are challenges in creating a chatbot that perfectly aligns with individual beliefs while also offering valuable information and promoting child well-being. However, we suggest a few design features that may address this complexity. For example, instead of aligning with every belief, the chatbot can focus on common ground between the parent and chatbot, the well-being and healthy development of the child. In discussions between parents and their extended family, they were able to reach a common ground in their different perspectives by focusing on the child. The chatbot could act similarly by offering evidence-based information and resources while acknowledging parental autonomy in decision-making. Another example could be that the chatbot uses open-ended questions to help parents clarify their values and goals for their child’s upbringing. This could both provide the chatbot with more information about their individual beliefs, and offer more clarification on why those beliefs are important in their child’s development. It could also inspire parents to engage in self-reflection about beliefs that are potentially in conflict with their child’s long term development and well-being. It could also help the chatbot identify when connecting a parent with trusted sources like parenting websites, hotlines, or healthcare professionals, who can provide additional support and guidance tailored to their situation, may be better suited for certain topics.

Further, the chatbot could, while avoiding judgment, offer alternative viewpoints on parenting approaches that are supported by research, expert opinions, and community knowledge. By providing a diversity of perspectives, parents can make informed choices even if they differ from their initial beliefs. The chatbot could also offer optional modules where parents can delve deeper into specific parenting topics or challenges. This would allow them to explore new information about their beliefs while maintaining control over the level of detail they share. Overall, the expectation is that over time, the chatbot should develop a more comprehensive understanding and awareness of the parent’s individual beliefs, and the potential perspectives that may be in conflict with those. Even if the chatbot is not perfectly aligned with parents’ beliefs 100% of the time, it is important that the chatbot does not expect them to assimilate to one dominant parenting practice. It is important to acknowledge that the chatbot's role is to be a supportive tool, not a replacement for a parent or professional’s judgment. By fostering critical thinking, offering diverse perspectives, and connecting parents with resources, the chatbot could have a meaningful impact by empowering them to make informed decisions for their child's well-being, even if those decisions do not perfectly align with the chatbot's initial suggestions.

6.3.3 Opportunities for Human- and Community-Centered Design

The iterative design process used to create and refine the chatbot prototype aligns with established best practices in human-centered design (HCD). HCD emphasizes involving people in the target community throughout the design process to create solutions that meet their needs (Gasson, 2003). We followed a similar approach in our study, engaging parents in storyboarding, co-design sessions, and prototype evaluations. This stands in contrast to the more linear approach often described in existing research on healthcare chatbot development (Kumar & Ali, 2020). While some existing studies acknowledge user preferences and interface customizability (Barreto et al., 2021; Maenhout et al., 2021), there is a clear opportunity to expand human-centered design in this field. Integrating feedback loops with people in the target user communities, and allowing for more open-ended conversations, could significantly enhance the user experience and make chatbots even more helpful and engaging. Our study serves as a strong example of how integrating HCD in the early stages of chatbot development can be beneficial. Firstly, by involving parents throughout the process, we ensured the chatbot addressed real-world challenges they face. Without this direct input from people, designers and researchers risk creating a tool that misses the mark on user needs and expectations. Secondly, co-design sessions fostered creative solutions that may not have been initially considered. Parents' unique perspectives led to innovative features and approaches with the potential to significantly enhance the chatbot's utility.

While existing research on chatbot development and mHealth technologies highlights the importance of prototyping and user testing (Abdelhalim et al., 2024; K. M. Unertl et al., 2016), the extent of iteration and refinement in our study is important to share. Most studies present a single prototype and gather feedback, whereas we iteratively refined the prototype based on parent feedback across multiple testing rounds. Our commitment to transparency and collaborative decision-making with parents further sets our approach apart. Acknowledging knowledge gaps and actively seeking parent input demonstrated respect for their expertise, fostered trust, and ensured their voices were valued throughout the process. However, a limitation of our study is the lack of documented usability metrics with parents (particularly related to usability and feasibility in their everyday lives), which is common practice with more fully functional prototypes.

Overall, our community-based, iterative design process with extensive parent involvement aligns well with the best practices of human-centered design approach. Utilizing multiple frameworks to inform the design process provided a more comprehensive understanding of key focus areas from the outset. This comprehensive approach likely resulted in a more robust and human-centered chatbot prototype compared to design approaches typically described in existing literature. Further research could explore how our findings on parent feedback and iterative design compare to chatbot development processes in other domains beyond child health. This comparison could identify potential generalizable best practices for a wider range of chatbot applications.

6.4 Limitations

This section outlines several limitations in the methodology of our study. First, our research study only included six parents (who identified as Black, Hispanic, and Pacific Islander) who live in King County, Washington and had consistent access to the internet. Because the sample size is small and we did not recruit people from a larger diversity in backgrounds, it may limit the generalizability of the research findings to a broader population. Our sample is also unlikely to reflect the full diversity of parents who could benefit from the technologies we propose in this study, as we focused on the specific experiences of parents and families living in King County, Washington, and excluded parents that have limited internet access.

Additionally, we did not engage with parents over a longer time frame (e.g., more than 5 months). Longer engagements may have enabled us to establish better rapport and trust with the parents, and may have led to an overall more meaningful engagement and stronger partnership with the parents in this community. For example, a longer research period would have allowed us to develop a stronger rapport with parents and work together more closely on developing the research materials together. This could have contributed to their better understanding of the project and enabled them to give more detailed feedback on the study activities and aims before they participated in it. In community-based research literature, building trust with a community takes time. Through sustained engagement, researchers can establish stronger relationships with participants, fostering open communication and a willingness to share more personal experiences and insights (Wallerstein & Duran, 2003). Relatedly, in community-based participatory research, partnerships begin before research questions and study aims are defined, such that the community partners have leverage in the research questions and aims. This study adopted a traditional research approach where the research questions and aims were defined prior to engaging with the community. While the community provided valuable feedback throughout the research process, a more collaborative approach, where community partners are involved from the very beginning, could have yielded deeper insights and potentially identified discriminatory practices within the design and development process itself. Future iterations of this research could benefit from incorporating a community-based participatory approach, fostering co-creation and empowering the community to have a stronger influence on the research direction.

We could have also developed a more enhanced understanding of the context that parents were in. Complex social issues and community needs are often nuanced and multifaceted. Longer-term collaboration allows researchers to gain a deeper understanding of the historical context, cultural norms, and power dynamics within the community (Israel et al., 1998). Lastly, parents in our study expressed a deep interest in engaging in the process for building a fully functional chatbot. Developing solutions that are truly sustainable within a community requires a thorough understanding of its needs and resources. Longitudinal engagement allows researchers to work alongside community members to co-create interventions or tools that are culturally appropriate and have a higher chance of long-term success (Viswanathan et al., 2004).

Lastly, we did not actually test the use of the chatbot prototype with parents in their day to day lives, or with another group of parents to introduce new perspectives. This means that we did not get an understanding of how the chatbot actually performed in their lives. This type of evaluation could also give more information about the technical feasibility, generalizability of the content to other communities, and related things. Overall, the limitations of this study reflect common challenges in the field of chatbot development. They underscore the importance of addressing issues like sample size, diversity, engagement duration, and real-world testing in future research. By doing so, researchers can work towards creating chatbots that are more robust, inclusive, and effectively meet the needs of the users they aim to support.

6.5 Chapter Conclusion

In this study, we developed a chatbot prototype for child development support that enacted the principles of cultural safety, to enable parents to engage in more meaningful and relevant interactions with a chatbot. Because parents are a highly diverse group of people, and their needs can change and their children grow, it is important for technology to be flexible and address their needs. Early childhood health promotion technologies exist that aim to support parents as they navigate their children's development, but many of these technologies are designed to be context-agnostic to the unique needs of diverse families. Because cultural safety has been used as an approach to make healthcare more respectful and based directly on the lived experiences of people with marginalized identities, we aimed to use this approach to design a chatbot to be sensitized to the contexts, identities and values of families.

We engaged six parents from King County, Washington in storyboarding, focus group discussions, and co-design activities to understand their requirements for technology. We coupled their design requirements with design requirements that the research team generated from the cultural safety approach. We then created a static, low-fidelity prototype using Figma to get feedback from parents and design professionals on the interface design and content of the chatbot.

Throughout the study, we identified opportunities to improve parent experiences by promoting cultural safety in the context of their children's health (This aligns with RQ1: How do health technologies risk perpetuating child development inequities if they do not consider the unique contexts, needs, and values of families?). Cultural safety emphasizes understanding and respecting the cultural backgrounds and beliefs of patients, and adapting healthcare practices to meet their needs. Parents in our study navigated conflicting beliefs and practices from various sources, including family, friends, healthcare professionals, and childcare providers. Their experiences highlighted the need for respectful and responsive healthcare that aligns with family needs (This aligns with RQ2: How can cultural safety be integrated throughout the design and research processes of health promotion technologies?). This chapter discusses how we reflected these values in the chatbot prototype developed collaboratively with parents.

A longer engagement period with parents could have provided a deeper understanding of how their experiences navigating conflicting beliefs evolve over time (RQ1). This could have informed the design of features that adapt to these changing needs. However, the design of the chatbot prototype demonstrates the value of cultural safety principles in designing technology that respects diverse family contexts (Dissertation Contribution 3: Applying cultural safety in practice). We embedded features where the chatbot would acknowledge its cultural background and biases. The chatbot could also identify potential biases in its responses and flag them to the parent. Parents in our study expressed a preference for technology that supports, rather than replaces, existing resources and knowledge within their communities. The chatbot we developed achieved this through enabling collaborative decision making, and providing tailored and context-driven information. The features mentioned in this chapter can also potentially facilitate meaningful communication, respecting parents' values, and adapting recommendations based on parents' knowledge and experiences. In future iterations of this work, I plan to explore how the chatbot can facilitate conversations between parents and their child's support network. This approach fosters open dialogue and active listening, promoting mutual understanding between parents and caregivers.

By following these principles, the chatbot development serves as an example of how cultural safety can be applied in practice. While a longer engagement period would have provided further insights (limitations), this study demonstrates the potential of cultural safety in designing health technologies that are more responsive to the needs of diverse families (RQ1 & RQ2).

Chapter 7: Discussion

Throughout this dissertation, I have explored designing technologies that create culturally safe experiences for parents navigating child development. A key finding is that existing early childhood health promotion technologies (ecHPTs) often overlook two crucial aspects of families' experiences that can lead to these technologies being inequitable. First, these technologies fail to consider the social determinants of health (e.g., income, access to resources) and cultural contexts (e.g., beliefs and values) of marginalized families. This oversight has the potential to widen health disparities rather than reduce them (Veinot et al., 2019). Further, current ecHPTs often focus on delivering information or changing parent behaviors without acknowledging the broader challenges that parents face. These technologies risk being irrelevant or even harmful to certain communities, by ignoring the unique and nuanced aspects of their lived experiences.

To address these limitations, I propose a new approach to technology innovation in ecHPTs that is centered on cultural safety. In healthcare, cultural safety is an approach to patient care that acknowledges the power imbalances between patients and healthcare professionals, and empowers patients to actively participate in their care. When applied in the research and design process, cultural safety emphasizes valuing and respecting the perspectives of people throughout the research and design process. In the context of working with parents, this process involved understanding and designing for the unique circumstances of families in mind, prioritizing community voices to ensure that technology is responsive to their needs and preferences, and respecting cultural values and beliefs by avoiding perpetuating stereotypes and instead acknowledging the cultural diversity of families. By adopting these principles in my research, I have demonstrated that this approach can enable us to create ecHPTs that are inclusive, empowering, and effective for all families, regardless of their background or circumstances. In this chapter, I explore the benefits and challenges of practicing cultural safety through the research and design approach, as well as integrating cultural safety into the design of technology specifically.

7.1 Cultural Safety Framework for Research and Design

Traditional design approaches often focus on user needs and functionality, implicitly assuming a certain level of cultural homogeneity. This can lead to designs that fail to account for diverse cultural perspectives and potentially cause harm. In contrast, the framework I present below is grounded in cultural safety principles, which explicitly address power imbalances, bias, and community ownership. These principles contrast traditional design approaches in several ways. First, traditional approaches may not acknowledge the inherent power dynamics between researchers and designers and the communities they study or design for. My framework emphasizes reducing these imbalances by fostering collaboration and ensuring community voices are heard and valued throughout the process. Second, traditional approaches might not prioritize self-reflection from researchers and designers. My framework centers on ongoing self-reflection to identify and mitigate unconscious biases that could influence design decisions. Lastly, traditional approaches might prioritize designer expertise or client needs over community involvement. My framework prioritizes community ownership and control throughout the process, ensuring designs are culturally relevant and address the specific needs identified by the community itself.

In developing this framework, I began by immersing myself in the literature surrounding cultural safety. Through this reading, I gained a strong understanding of the core principles and their potential importance in research and design. Additionally, I reflected on the challenges and opportunities I encountered while trying to incorporate these principles into my own work. This process involved brainstorming key considerations for both the research and design stages, as well as the technology itself. By critically analyzing my experiences and learnings, I aimed to identify areas where the framework could offer more rigorous guidance.

Below, I present a framework that outlines key considerations for integrating cultural safety into the research and design process, and the content of technologies that aim to promote cultural safety. I use a concentric circle nested diagram to indicate the relationship between the core principles of cultural safety, the research and design process, and the considerations for when we design technology (Figure 7). First, I illustrate at the core the principles of cultural safety. These principles are defined as follows:

Foundational Principles of Cultural Safety

- **Respect:** Treating all people with dignity and value, regardless of their background.
- **Power Dynamics:** Acknowledging power imbalances and how power dynamics influence interactions.
- **Commitment to Equity:** Not expecting people to assimilate to our processes and the technologies we create. Instead, we facilitate spaces where they can thrive as they are.
- **Partnership and Participation:** People and professionals collaborate to design technology and resources, fostering trust and collaboration.
- **Continuous Reflection and Learning:** Because cultural safety is not a fixed state of knowledge, professionals learn from interactions, find areas for improvement, and adapt their practices.
- **Reflexivity:** Professionals engage in critical self-awareness, by examining their biases, assumptions, and cultural background.

Research and Design Process

- **Positionality assessment:** This aligns with reflexivity. By understanding your own position (background, experiences, biases), you can better understand how you might interact with others from different positions and backgrounds.
- **Active listening, open-mindedness:** Core aspects of respect, which ensure that you pay attention to others' perspectives and avoid imposing your own views.
- **Diversity and inclusion:** By including people from diverse backgrounds, you gain a broader range of perspectives and experiences.
- **Address systemic bias:** Cultural safety acknowledges the existence of systemic biases within institutions and society. This concept goes hand-in-hand with reflexivity as you identify and work to mitigate these biases.

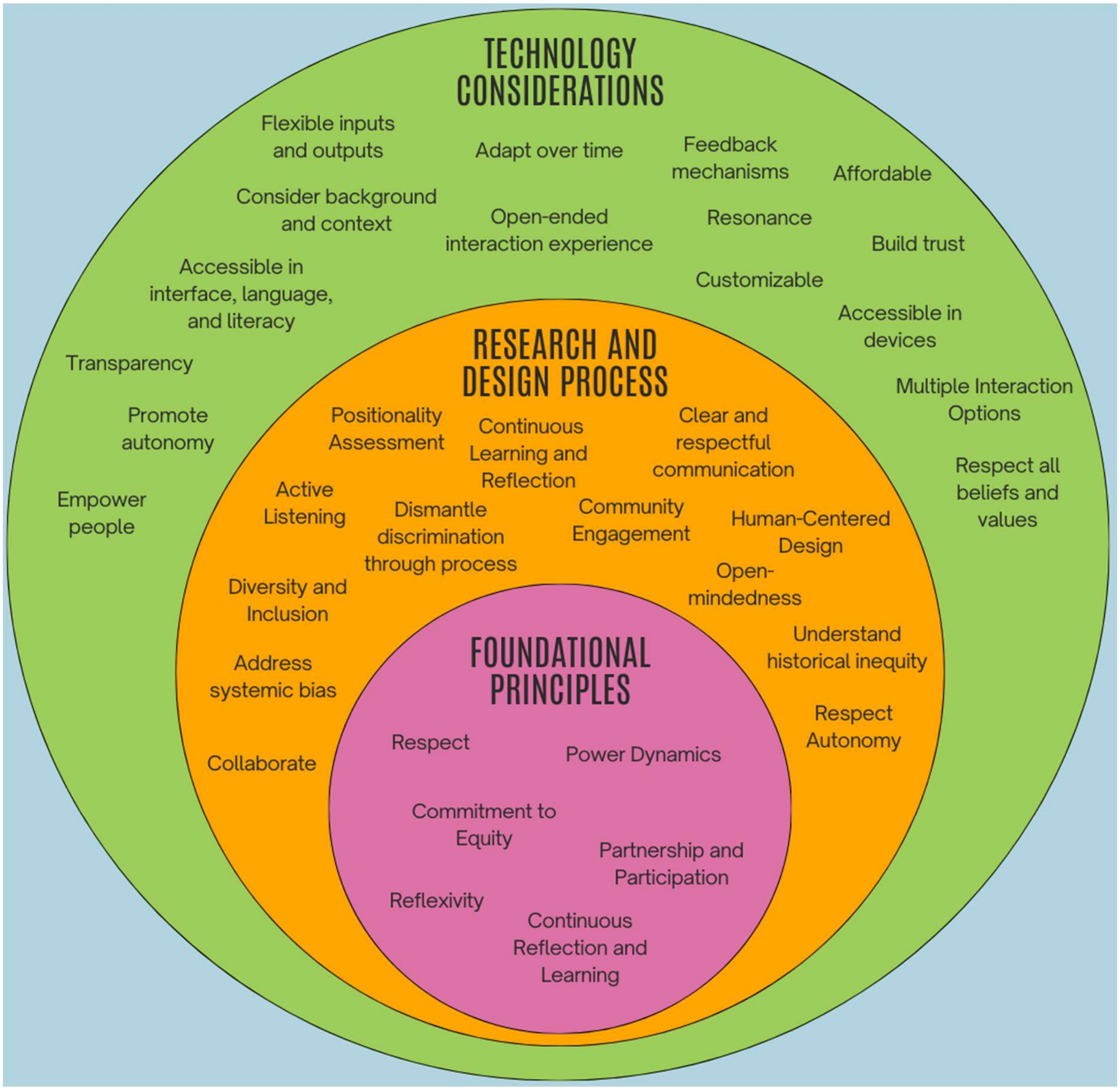
- **Collaborate, dismantle discrimination through process:** Working together with diverse communities, you can identify and dismantle discriminatory practices within the design and development process, and within broader societal issues.
    - **Co-creation and Participatory Design:** Workshops, Focus Groups, Community Advisory Boards
    - **Centering Community Voices:** Research with diverse communities, storytelling about lived experiences.
    - **Empowering Communities:** Capacity building, skill sharing.
- **Continuous learning and reflection:** Cultural safety is an ongoing process. As you learn more about different cultures and your own biases, you can continuously improve your practice.
- **Community engagement:** Actively involving the community throughout the research and design process is essential for ensuring the technology is culturally safe and meets their needs.
- **Human-centered design:** This design philosophy prioritizes understanding peoples
- needs and experiences. It aligns with cultural safety by ensuring technology is designed to be inclusive and respectful of diverse communities.
- **Clear and respectful communication:** This is crucial for building trust and rapport with people from different backgrounds. It involves using language that is easy to understand and avoiding anything offensive or disrespectful.
- **Respect autonomy:** Cultural safety empowers individuals to make their own choices about their health and how they interact with technology.
- **Understand historical inequity:** Recognizing the history of discrimination and health inequities faced by different communities is important. This understanding can help you design technology that addresses these issues and promotes health equity.

Technology Considerations

- **Empower people, promote autonomy:** Cultural safety respects peoples' agency. This means allowing people to control their data, privacy settings, and how they interact with the technology.
- **Transparency:** Being transparent about data collection, usage, and potential risks can build trust with people.
- **Accessible in interface, language, and literacy:** Ensuring the technology is accessible for people with disabilities and offering it in multiple languages with varying literacy levels in mind promotes inclusivity.
- **Consider background and context:** Understanding a person's cultural background and the context in which they'll use the technology allows for culturally sensitive design.
- **Flexible inputs and outputs:** Catering to diverse needs by offering options like text, voice, image input, and visual or audio output makes the technology more accessible.
- **Adapt over time:** Technology should be able to evolve based on peoples' feedback and changing cultural needs.
- **Open-ended interaction experience:** Allowing some flexibility in how people interact with the technology empowers them to explore information and complete tasks in ways that suit their preferences.

- **Feedback mechanisms:** Integrating clear and accessible feedback mechanisms allows people to provide input and suggest improvements.
- **Resonance:** Design features and content that resonate with a variety of cultural norms and communication styles by prioritizing open-ended engagement.
- **Customizable:** Offering customization options within a defined framework allows people to personalize the technology and feel more comfortable using it.
- **Affordable:** Making the technology affordable for the target communities ensures everyone has access to its benefits.
- **Build trust:** Building trust with people from diverse backgrounds is essential for cultural safety. This involves being respectful and transparent.
- **Accessible in devices:** Considering the technology being accessible across various devices used by different communities promotes inclusivity.
- **Multiple interaction options:** Offering various interaction methods (voice, touch, text) caters to different peoples' abilities and preferences.
- **Respect all values and beliefs:** Cultural safety acknowledges and respects the diverse values and beliefs of different communities.

Figure 7: Cultural Safety Framework for Research and Design of Technology



7.2 Centering Cultural Safety in Technology Innovation

My research emphasizes cultural safety as a central theme in the research and design of early childhood health technologies. Cultural safety is an ongoing process that goes beyond simply learning about different cultures; it requires creating an environment of respect, trust, and empowerment for people of all backgrounds who are participating in research. Inspired by the ways that healthcare professionals can improve patient experiences by practicing cultural safety, I explored opportunities to practice cultural safety as a researcher. Particularly, it is imperative to understand the health experiences and develop better interventions for marginalized communities. However, research with these communities can be flawed if researchers misrepresent the experiences of the people engaged in the research.

Throughout this dissertation, I have touched on how cultural safety may fit into both the methods of design (i.e., throughout the design and research process) as well as the technologies that are developed as an outcome of those processes. In this section, I reflect more on the integration of cultural safety in both steps. For example, in Section 7.2.3, I explore the utility of systematic literature reviews and content analyses. I mention strategies for how we can broaden the research perspectives included in these methods. I suggest strategies for identifying research from underrepresented groups, like exploring global health databases, collaborating with researchers from diverse regions, or utilizing search engines in other languages. When using content analyses, we can strengthen our analysis of technology by including coding schemes that consider broader cultural contexts, in things like languages, imagery, or the content presented. I also discuss the tension between standardization and customization in culturally safe design. By integrating cultural safety principles throughout the research and design process, mHealth applications can be developed that are not only effective but also respectful and empowering for all users. This requires a commitment to ongoing community engagement, a focus on both standardization and customization, and the use of human-centered design principles.

7.2.2 Researcher Role

This section explores the critical role of practicing cultural safety as researchers. Foucault's notion that power is intertwined with knowledge production (2002) highlights the dominance of Western perspectives in research. This dominance often overlooks or negates alternative viewpoints, particularly when working with marginalized communities. Researchers must critically examine the epistemology (foundational knowledge) guiding their work. This is particularly important for researchers who are engaging in health technology innovation.

Cultural safety offers a means to address the power imbalances between researchers and communities, especially those who have been historically marginalized and exploited. Cultural safety emphasizes self-reflection and humility as a way to understand our personal biases and how they come up in our professional practice. Instead of focusing solely on learning the practices of research participants and partners, researchers should reflect on their biases and cultural backgrounds. Asking ourselves questions like, “How do my cultural experiences influence my research design?” are crucial for self-awareness. I practiced self-reflection throughout the research process. I examined how my experiences, such as my mother’s teachings on social structures and discrimination, shaped my research interests. I also reflected on my background as a childless Black woman. In my reflections, I realized that while this knowledge and experience helped me grasp nuanced concepts in peoples’ health experiences, it was limited in capturing the full complexity of parents’ experiences. Further, my background in cognitive science, which draws on aspects of psychology, linguistics, philosophy, and computing provided me with the skills to navigate interdisciplinary research. At the same time, my training as a graduate student in human-centered research also highlighted some conflicting perspectives in my training, particularly around the production of knowledge and the value of hearing stories from people who lived them. Researchers must be critically conscious of how their identities and biases might influence their work. In realizing the limitations of my knowledge in working with parents, I actively strived for an empathetic and open approach to facilitate my learning.

By practicing cultural safety, you can conduct research with a strong awareness of your positionality. This awareness allows you to be more mindful of potential biases and power imbalances, ultimately contributing to a more ethical and culturally safe research practice. Positionality refers to the standpoint or perspective that a researcher brings to the research process (Milner IV, 2007). This perspective can be shaped by several factors, including their identity (background characteristics like race, gender, class, or queer identity), personal experiences, and disciplinary background (lens for interpreting data and forming research questions). To understand their positionality and engage in practices that mitigate how it influences research, researchers can engage in different practices. For example, reflexivity involves critically reflecting on how positionality influences research design, data collection, analysis, and interpretation (Corlett & Mavin, 2018). This can be done by writing a position statement that acknowledges their background and potential biases. Transparency is another practice that can support people that are engaging with research (for example, through reading), particularly in understanding the researcher’s perspective and how it may have shaped the research findings. Lastly, recognizing positionality allows researchers to be more aware of potential biases and take the steps to mitigate them. For example, this might involve seeking out diverse perspectives in their research process, employing multiple methodologies, and critically evaluating their own assumptions (Shaw et al., 2020). Overall, acknowledging positionality is crucial for conducting rigorous and ethical research, as it fosters a more nuanced understanding of the research topic and allows for a richer interpretation of the findings.

I do think that designers and researchers can implement a systematic process in their work to mitigate bias throughout the design and development process. In my own case, introspection involved journaling about my background and how it might influence the project's direction. This awareness informed decisions like deciding to bring on a designer who had life and work experiences that were vastly different from my own. I also think there is significant value in engaging with the work of others in critical ways, to engage with a broad range of perspectives. While I was not directly intentional about seeking out this work, I think the nature of my experiences (e.g., taking several classes outside my primary department, participating in reading groups on topics not related to my work, and engaging with other forms of knowledge like videos, zines, etc.) contributed to me being exposed to different points of view. I think researchers and designers could employ either of these techniques in more systematic or intentional ways, such as scheduling journaling before, during, and after projects or having a weekly goal to engage with work outside of their primary field.

Mitigating the influence of power dynamics in research is also important. Across my research, I have faced several power imbalances, which I relied on cultural safety to understand how to navigate. As a younger graduate student, I sometimes felt a power imbalance with the parents I worked with, especially those that had more life experiences. On several occasions, parents asked me if I had children of my own or would include a caveat with their stories (e.g., “You may not understand this yet because you are young”). Mainly, these experiences were uncomfortable for me to navigate. At the same time, I was learning to navigate the institutional power that the university has, and how this trickled down to me as a researcher. For example, parents may have felt that they had to cooperate with the research activities I had planned due to my position. Relatedly, while I share a marginalized identity with the parents that I worked with, there were nuances within their specific community that I have never experienced.

To address this, I focused on being a respectful learner. I reflected on my own background and how it might shape my research. I emphasized the shared experiences of being part of marginalized communities to build trust where it made sense (e.g., sharing that I felt similarly as a Black person living in Seattle). I also made transparency a priority, explaining my research goals, limitations, and potential biases. In each project, I introduced myself in a way that explained the knowledge and experiences that I was bringing to the research project, as well as my motivations and hopes for the research. Sharing my limitations was also especially important in my partnership with FFYB as we navigated challenges together with my university's payment requirements and hurdles. Empowering the parents was another key aspect. I actively sought their input in designing the research, collecting data, and interpreting the findings. Building relationships came first, so I invested time in getting to know them before diving into the research itself. Finally, I explored ways to give back to the community beyond the research. I supported FFYB with a grant application to secure more funding for their programming. I also aim to find ways to share my research findings with the broader community in an accessible way. By taking these steps, I aimed to create a collaborative research space where everyone felt valued and heard.

7.2.3 Research and Design Process

In this section, I reflect on ways that future work could implement cultural safety in the methods used in my dissertation research.

In my preliminary research, I wanted to develop an understanding of the existing research landscape of early childhood health promotion technologies (ecHPTs), and engage in a deeper exploration of a specific dataset within that area, which involved ecHPTs delivered through mobile apps. While both of these methods were complementary in identifying the gaps in research, I identified opportunities to promote cultural safety through a retrospective analysis. Systematic Literature Reviews are primarily used to provide a strong foundation for new research by identifying gaps in existing knowledge, by synthesizing findings from multiple studies to draw broader conclusions about the field (Nightingale, 2009). I noticed that both the research databases and publications in my study were dominated by specific cultures, languages, and locations (e.g., English, United States). This is directly related to my choice of databases and languages that I included in my search criteria (i.e., I only conducted my search in English and for US-based journals). However, this approach likely skewed the results of my study by possibly excluding research from other cultural perspectives, which limits both the generalizability and relevance of the findings to a global perspective. To address this challenge, when utilizing systematic reviews, researchers could make an effort to incorporate a wider range of databases, including those from underrepresented regions, and research published in languages other than English. This process can contribute to a more inclusive and representative understanding of people's lived experiences. Further, this approach values the knowledge being produced in non-dominant spaces that are neglected in our field, due to research being dominated by Western institutions. Considering the inequitable nature of academic research publishing, researchers using systematic literature reviews can practice cultural safety by valuing and promoting knowledge from underrepresented communities.

Content Analyses can provide a quantitative approach to analyzing significant amounts of data, and can be used to understand the content of a specific dataset, to uncover patterns, trends, and themes (White & Marsh, 2006). When reflecting on my approach to review mobile health apps for promoting child developmental health, I focused on the process of deciding on a dataset and the related coding scheme. To develop the coding scheme, my approach involved reviewing prior research on child development and user burden, and collaborating with my co-authors to refine the final set of codes. One strength of this approach was including perspectives from multiple researchers who had expertise in different fields (developmental screening/pediatric health promotion and computing), which contributed to the coding scheme being more comprehensive. I think collaboration from researchers in other fields, like public health and health equity, as well as community perspectives could provide additional insights into specific content or interaction experiences in the apps that contribute to inequitable experiences. Similarly to the systematic literature review, I think there was a missed opportunity in this study to expand the assessment of these apps to those published in other countries and in other languages. Because we focused on apps that were accessible in the United States and focused our assessment on information presented in English, it is possible that content presented in other languages or apps in other countries were more or less effective. By including a more diverse research team (e.g., people located across countries and speaking different languages), we could expand the reach of the study to provide a more broad understanding of the quality of apps at a wider scale.

In my dissertation research, I utilized co-design and focus group methods, but future work can further promote cultural safety through these approaches. While these methods allow for collaborative exploration, it is important to ensure balanced participation and utilize specific facilitation techniques to ensure that these approaches are meaningful for the communities involved. While recruiting diverse communities is important, having balanced participation ensure that engagements are meaningful. For example, active recruitment of people from diverse cultural backgrounds can both represent the target population, and ensure a variety of perspectives are present (i.e., avoiding dominance by any one group of people). Second, during these sessions, integrating facilitation techniques can further promote cultural safety. During discussions, for example, researchers can encourage all voices to be heard by using techniques like round-robin speaking or ensuring that discussion prompts do not favor specific cultural experiences. Additionally, co-facilitation with someone from the target community could further ensure sensitivity and understanding throughout the process. By focusing on balanced participation and culturally sensitive facilitation, co-design and focus groups can be powerful tools for inclusive research. In future studies that employ these methods, I and other researchers could practice cultural safety by incorporating these suggestions into early research plans.

7.2.4 Technology Design, Content, and Experience

My dissertation provides a valuable framework for cultural safety in technology design. However, translating those principles into concrete technology features can be challenging. This section explores how the framework can guide the user interface (UI) design, content creation, and interaction patterns to ensure cultural safety.

There is a strong, salient, and inherent tension between the push for standardization in technology and the high degree of customization required from cultural safety, especially when applied in healthcare settings. Striking a balance between them is challenging in healthcare (Sinsky et al., 2021). Standardized technology offers benefits in the healthcare space, by improving the efficiency and consistency of information and care provided, enhancing communication and collaboration by creating shared understandings among healthcare professionals, systems, and patients, providing seamless data integration for comprehensive record-keeping, and being more cost effective, scalable, and easier to implement. At the same time, customized technology can enhance the patient experience and their engagement, enable more focus on specific health concerns in context, and provide care that is more accessible and inclusive. Further, customization can reduce the workload of health systems by improving how resources are allocated. However, too much customization can require more resources to develop and maintain, introduce bias, and be limited in scalability. Excessive standardization can oppress, disempower, and restrict both healthcare professionals and patients and lead to worse health outcomes.

I believe that a multi-pronged approach to address both standardization and customization is needed to effectively create technologies that are culturally safe. Within design, offering modular components can provide a baseline of consistency while offering flexibility in the user experience. For example, core functionalities like a library of developmentally appropriate activities in a mobile app could be standardized to include details like age range, skills targeted, and a description of the activity. The specific activities in the app could be modular, allowing for updates with new activity ideas and customization based on specific needs, like the family's interests, time, or environment. Including customizations options within a defined framework as well can prevent information from diverging from standardized health information, like developmental benchmarks. Another approach could involve prioritizing interoperability. Considering how technology can be seamlessly integrated with other healthcare systems (regardless of how customized they are) can facilitate data sharing and prevent information silos. This is particularly important for technologies that are being used alongside other forms of healthcare. Relatedly, using standardized data formats can ensure that information collected through customization can be integrated and analyzed alongside other technologies effectively. For example, the CDC's Milestone Tracker offers a standardized report of developmental milestones to share with a provider, despite the milestone data being deeply customized to each family.

While standardization and customization have their place, truly culturally safe technology goes beyond these approaches. Research consistently demonstrates that culturally sensitive design significantly improves outcomes and experiences with technology (Sun, 2012). Human-centered design (HCD) can empower designers to actively integrate cultural safety principles into their design processes. Unlike traditional top-down design, HCD acknowledges that people, not designers, are the ultimate mediators of cultural safety. This means deep and ongoing community involvement, encompassing every stage of the design process, from initial brainstorming to final testing and human feedback.

There are also specific design elements that emerge from my dissertation research. Content can be culturally sensitive, relevant and inclusive. For health information apps for example, offering content in multiple languages and incorporating traditional healing practices alongside modern medicine significantly improves health outcomes for diverse populations. There are ways to enhance cultural safety in the UI design as well. This can involve letting people customize their experiences through color, icons, images in ways that resonate with them, rather than picking designs on their behalf as is commonly recommended (Sun, 2012). Allowing for multiple customization options enables people to find a design that truly fits their needs and cultural background. By providing simple navigation options alongside more advanced features, people can choose their comfort level. This inclusive design approach ensures that the technology is accessible to all, regardless of technical literacy.

It is imperative to also discuss the challenges of excessive customization. Recent research on artificial intelligence systems highlights that there is a significant environmental impact of the computing power of these systems (Wu et al., 2022). Further, these systems can become expensive and difficult to implement, especially in areas where there are financial limitations. This limits the scalability of these technologies for the communities that need them most, undermining the most significant goals of culturally safe design. While AI personalization can be beneficial, technologists should consider offering core functionalities accessible to all people using the technologies without extensive customization. This approach could reduce environmental impact and development costs, making the technology more sustainable and accessible. For communities with limited internet access, exploring offline versions of the technology or partnering with local organizations for data access points could enable systems to continue to function regardless of infrastructural changes. These strategies ensure that culturally safe technology can reach all individuals, regardless of their technological resources.

Culturally safe technology, enabled by human-centered design principles, is essential for creating inclusive, accessible, and sustainable solutions. Designers and technologists should embrace these approaches and create health technologies that truly empower and respect all people.

7.3 Community-Based Research (CBR) Learnings

While I initially aspired to conduct Community-Based Participatory Research (CBPR), where the community takes on a greater leadership role in co-creating the research agenda and process, my experience revealed some limitations that necessitated the Community-Based Research (CBR) approach instead. In this section, I reflect on the shift in aspirations and the lessons that I have learned throughout this process.

My initial understanding of “community” was geographically-bound (King County, Washington) and within a group of people with a shared experience (parents of young children). However, through my initial engagement with this community, I was exposed to the more multifaceted nature of this concept. Across studies, parents identified with their neighborhoods but also felt connected to communities based on other shared experiences and identities, like immigration experiences or types of parenthood or family models. This new knowledge challenged the limitations of defining community solely along geographic or demographic axes. Relatedly, the strategies that I used through the research process to engage the community presented challenges, although overall was enriching to the research process. Defining the target community for the Community Advisory Board (CAB) was difficult, as I struggled to balance representativeness of the CAB with the logistical challenges of doing virtual research. Further, the CAB’s initial unfamiliarity with the research area limited their critical feedback. Even though I implemented strategies to improve the transparency and understanding (e.g., I used plain language and relatable examples in the research materials), the limited engagement timeframe (3 months with more sporadic meetings) likely hindered their capacity to develop a more meaningful, in-depth understanding of the work and further hindered their ability to develop rapport with the research team and with each other. These experiences highlight the importance of having extended timelines to foster trust and enable deep understandings with the community. However, in my work, balancing respect for participant’s limited time with the need for in-depth discussions continued to present as a challenge.

Beyond the time constraints, there were other ways I have reflected on in my role as a graduate student presenting challenges to fully implementing a method like CBPR. I think if I had a clearer picture of the long-term investment in projects, for example in my work I did with FFYB, I could have been more deliberate in thinking about ways to solidify long-term partnerships and findings ways to fully understand the research priorities I had. At the time, FFYB had many ideas for the future of the partnership and what they could gain from working with me and my collaborators, however, it was difficult for me to understand my capacity to support them with those projects, especially in areas where my skills were still developing (e.g., their request to do multi-year survey to check in with parents on the quality of their program offerings, applying for large-scale grants). Many of my research ideas and research expertise were still developing at that time, and my priorities were constantly shifting. I think the transient nature of me being a student also limited my view of opportunities for long-term projects. I also noticed the ways that I struggled to translate the knowledge from my classes on CBPR to practice in leading my own research projects. The combination of my evolving research interests, the transient nature of being a student, and the difficulty translating theory into practice all contributed to the shift in methodology. Overall, the shift in approaches stemmed from these complexities, especially in creating strong community engagement within the study timeframe and with my experience level as a graduate student. Still, CBR offered a valuable approach to incorporate community voices, especially in giving me a more flexible framework to allow me to engage with the community within the timeline of my PhD and even with my evolving research focus and skills. More broadly, this experience highlighted the importance of long-term planning and community partnership in CBPR, which I think will be invaluable in my future research work.

7.3.1 Evolving Definitions of "Community"

Understanding "community" is crucial for effective engagement in community-based research (CBR). This process clarifies who participates in research, as well as who experiences the research impact. Multiple research fields, including the growing discussions in the Human-Computer Interaction field, grapple with defining community from various perspectives. These discussions have covered defining community through geographical boundaries, shared lived experiences, shared beliefs or interests, and the metaphorical usage of community potentially weakening its meaning (MacQueen et al., 2001). Barbara A. Israel, a leading scholar in community-based research, “recognizes community as a unit of identity and emotional connection to other members, shared values and norms, mutual influence, common interests, and commitment to meeting shared needs” (Israel et al., 1998).

My research with parents in King County, Washington (a community defined by shared experience and location) and a community organization serving South King County contributes to the evolving understanding of "community" in CBR in two ways. First, by collaborating with the community organization First Five Years and Beyond, I learned more about the nuances in their definition of "community", which primarily aligned with their geographic service area (South King County). However, they also acknowledged the higher Black, Indigenous, and People of Color population within that area. This highlights how some definitions of community can encompass both geographic location and demographics. FFYB also offered programming aimed toward African immigrants and African American youth, which further emphasized their commitment to specific identity-based communities within their service area.

Alternatively, my conversations with parents offered a more nuanced view of "community" from the perspective of individuals. While they identified with their local neighborhood, they also felt connected to communities based on racial/ethnic identity or parenthood. Immigrant parents, for instance, connected with others who shared their immigration experiences. One parent of twins shared that while she was a member of FFYB, she joined a “Parents of Twins” Facebook group to connect with the “parents of twins” online community. While geographic proximity was sometimes a way to frame “community”, parents had a sense of belonging across communities that intersect with their diverse identities and lived experiences.

While CBR ideally involves co-constructing a definition of “community” with the community, it can be challenging. Initially, I envisioned a “community” as parents of young children in a specific location. However, the research revealed that the reality was more complex. Parents, despite their shared geographic location, participated in multiple communities simultaneously, based on aspects of their lived experiences or their personal identity. This highlights the limitations of defining a community solely based on geographic location, lived experience, or identity. My research highlights the multifaceted nature of "community" within CBR: my work indicates that it goes beyond geographic boundaries to encompass shared experiences, identities, and connections. My work emphasizes the importance of understanding "community" through the lens of people who are members there, to understand the nuances in their definitions. By acknowledging this complexity, and empowering the community to define their experience, researchers can foster more meaningful partnerships and impactful CBR projects.

7.3.2 Strategies for Engagement in Health Tech Research

This section delves into the strategies I employed to partner with the community in the research process. Community participation can be multifaceted, ranging from the co-creation of technologies to feedback on existing ones. Within my studies, I concentrated on two primary approaches: direct participation, where parents actively engaged in the research activities, and feedback and advisory, where parents provided insights on the research content, participation format, and direction through a Community Advisory Board (CAB). My dissertation research encompassed two direct engagements:

Focus Groups: Recruitment of parents occurred though a community organization (FFYB). FFYB leadership also provided valuable guidance on the research materials and effective engagement strategies. This partnership increased the accessibility of the research sessions by offering both online and in-person options to participate, and offering childcare and food during in-person sessions. FFYB's feedback on the focus group questions also helped me better align the content and wording of the questions, to ensure the conversation was better aligned with parents' experiences and perspectives, which the FFYB leadership was better informed about.
Community Advisory Board (CAB): Direct recruitment of parents from King County established the CAB. Parents in the CAB provided feedback on the research content and format before, during, and after the research activities, functioning as both participants and advisors.

The community engaged approach significantly enriched my dissertation research process by incorporating a wider range of perspectives. Still, there were challenges in achieving meaningful participation and representation in the projects for several reasons. For the research project that involved the CAB, defining the target community was a difficult process, which made it harder to address the diversity and representation of the CAB with the broader King County parent community. Further, it made it difficult to assess barriers to participation that parents may have experienced. While I attempted to identify potential barriers through engagement with prior work on community-based research with marginalized communities, it is possible that there were barriers to participation that were deeply context-specific. As such, I worked with the designer on the project, who was a Seattle native and a parent, for guidance on the technical barriers while we were planning the research. We also worked together to identify spaces in the local community that would be best to advertise the study to reach the community I was interested in working with. Relatedly, partnering with FFYB broadened the recruitment reach and addressed barriers to accessibility that were specific to the community they served. This experience underscores the value of collaboration with community organizations, who have a deep understanding of the community's needs and preferences.

Initially, parents involved in the CAB were unfamiliar with the research area and the scope of the research project, which contributed to their hesitation to provide critical feedback. I learned this through the conversations we had after the research session, and from the post-study survey that parents completed. The designer on the project also pointed out ways that the study materials may be confusing for parents. However, because I had several strategies that I employed to improve parent's understanding of the research process that did not seem effective, I want to reflect on the factors that may have contributed to that. I made a conscious effort to improve the transparency and explainability of the research process and focus, by explaining the research using relatable examples and plain language, detailing the expected research outcomes and their role in the project, and emphasizing the values of their contributions. I also provided regular updates on how their recommendations were incorporated into the research study, and provided realistic expectations for their role as decision-makers in the research project. I want to highlight that parent engagement in the CAB study only lasted for three months, and meetings were sporadic (e.g., twice a month). I think this shortened timeline contributed to a lack of rapport being developed between the research team and the parents, despite our efforts to facilitate rapport-building through icebreaker activities and introductions.

CBR researchers regularly communicate that CBR thrives when collaboration is built from a foundation of trust. They also communicate that trust is developed over time (Wallerstein et al., 2005). Taking time to interact with the community and build rapport can create more open and productive partnerships. Further, they share how effective participation takes time. People need time to understand the research, ask questions, and provide informed feedback. I struggled to find a balance between respecting parent's limited time (which is especially true for parents of young children) and ongoing commitments I had as a PhD student. As a negotiation of time, I did schedule longer sessions with parents, to facilitate longer, more detailed discussions. Still, some parents expressed that they could not attend the entirety of the research session and requested that we end early. I believe that scheduling sessions prior to the research activities themselves would have been useful for establishing rapport in a different session context, and providing more space for parents to understand the research directions.

Overall, reflecting on this project, I consider the CAB project as a strong foundation for future work. From the exit survey that parents completed, it is clear that they are excited about the research and are interested in future opportunities to participate. They were also excited about the relationships they developed with the research team and with other parents. For these reasons, I hope I can revisit this work in another capacity and continue to involve them, as I believe further research would be even more effective. By acknowledging the challenges and pitfalls of my approaches, my reflections provide considerations for future research that fosters more meaningful and productive community engagement experiences.

7.3.3 Reflecting on disciplinary differences in CBR

There are inherent differences in how research is conducted across disciplines. This can be a hurdle when fostering collaboration through community-based research (CBR). To highlight these challenges, I reflect on my experiences working between the computing and medical fields.

While the inherent differences in research structures and norms across disciplines can pose challenges to fostering collaboration through community-based research (CBR), these barriers are not too big to overcome. My experiences working at the intersection of computing and medicine have highlighted the potential for synergy despite some initial frictions. The research structure and decision-making processes can differ across fields. In hierarchical disciplines, like medicine, follow a pyramid structure, where senior researchers make key decisions and guide projects, and junior researchers or students follow the established protocols and directions set by senior researchers. Flat disciplines, like computing, follow a more horizontal structure, where senior researchers, junior researchers, and students work together through open participation and collaboration, to make collective decisions on projects (Diefenbach & Sillince, 2011). This can lead to perspective differences on the ways to partner with communities and conduct community-based research. It can also lead to differences in how community-based research is defined and the expectations for how research teams engage in these projects.

By acknowledging and proactively addressing these differences, researchers from diverse backgrounds can create a more inclusive and effective collaborative environment. For example, hierarchical disciplines like medicine can benefit from the open participation and collective decision-making common in fields like computing. Alternatively, computing researchers can learn from medicine's emphasis on rigorous protocols and established leadership. Ultimately, the path to successful CBR lies in a flexible approach that respects each discipline's strengths while promoting a shared commitment to community partnership and empowerment. This requires recognizing that true CBR is not merely researcher-led with community input, but rather a genuinely collaborative process where the community drives the research agenda and priorities. By moving towards this ideal, researchers across disciplines can overcome structural differences and meaningfully benefit from diverse perspectives to advance knowledge and impact in the communities they serve.

7.4 Path forward for innovation in ecHPTs

There is a pressing need for more rigorous and contextualized research on the effectiveness of early childhood health promotion technologies for marginalized groups. While these tools show promise, existing studies lack the long-term follow-up and fail to fully capture the unique experiences and needs of diverse communities. Collaborative efforts between academia, communities, and industry are vital to advance these technologies to later stages of development and test their sustained impact. By centering community-based methods and perspectives in the research process, we can ensure that health technologies are not only designed for, but truly by and alongside the groups they aim to serve.

In the industry sector, a greater focus on health equity is needed in the design and evaluation of health apps and tools. The current market is saturated with generic tracking apps and broad parenting advice, failing to meet the specific needs of diverse groups. Companies must adopt more nuanced approaches that differentiate offerings for various populations and prioritize human-centered design. The recent updates to the CDC milestone tracker, which incorporates pictures and videos, represent a positive step towards more engaging and relevant content for parents. Those innovations, while important, must be accompanied by a shift in the industry's mindset towards prioritizing equity and integrating these tools into broader healthcare systems.

Across both research and design, there is a crucial need to consider the full spectrum of health practices and social determinants. Technologies should support and reflect the diverse ways people manage their health, rather than promoting a one-size-fits-all approach. By integrating with existing healthcare infrastructure, such as electronic health records, these tools can enable more comprehensive and coordinated care for marginalized communities. This will require a concerted effort from all stakeholders, but the potential benefits in terms of health equity and outcomes for underserved groups are immense.

Cultural safety can also extend far beyond child development support technologies. For example, health apps and devices designed for children should not only focus on tracking growth and development but also promote autonomy and support the development of a strong sense of identity. Allowing kids to customize their health tech to reflect their interests and express their individuality can enhance cultural safety by making the tools feel more personal and less alienating. Similarly, for people living with chronic conditions, cultural safety could promote a focus on care plans and technologies that prioritize their quality of life and abilities over potentially restrictive interventions. Instead of forcing individuals onto specific care paths, technologies could offer flexible, human-centric solutions that enable people to pursue meaningful activities and maintain their independence. On a global scale, cultural safety in health technologies could mean acknowledging and addressing health disparities between different populations. Scaling health apps and services globally could be designed to be accessible and relevant for diverse groups, taking into account local health needs, resources, and cultural contexts. By centering cultural safety in the design of health technologies across more areas, we can ensure that digital tools better support the well-being and empowerment of all people in the world.

I want to also briefly reflect on the ways that the rise of Artificial Intelligence (AI) has brought exciting possibilities for technological advancement, but also significant challenges if we intend to explore cultural safety in this space. Thinking on the specific considerations for cultural safety in AI-based systems, particularly chatbot-like applications, I want to explore some ways that inclusivity may be challenging in AI. One of the main concerns surrounding AI and cultural safety is data bias. Chatbots trained on data sets that reflect the biases of their creators or the regions the data originates from can perpetuate discriminatory outputs when interacting with users from different backgrounds. For example, a chatbot trained on a dataset primarily from North America may not be generalizable to other countries with a different economic system. Further, the "black box" nature of many AI systems raises concerns about fairness and accountability. If a chatbot denies someone access to a service or provides inaccurate information, it can be difficult to understand why this happened. This lack of transparency can reduce trust and create barriers to using these technologies. However, chatbots also offer potential benefits when it comes to cultural safety. They could potentially provide immediate access to information and services, particularly valuable for communities with limited resources or those in remote locations. Additionally, chatbots can be programmed to be multilingual, overcoming language barriers and reaching a wider audience. Chatbots that are backed by AI could be designed to personalize interactions and provide information relevant to a user's specific needs and cultural background. This can be achieved by incorporating culturally safe language, references, and responses tailored to specific populations. Because AI enables technologies to learn from data, it may now be possible for a chatbot to be deeply personalized to individuals based on their interactions with the chatbot. However, the accessibility of these technologies will need to be further explored to ensure that they have meaningful social impact. For example, as mentioned, the Digital Divide can exclude communities with limited access to technology or the internet from utilizing chatbots. The data collected by chatbots raises privacy concerns, particularly for sensitive information. Communities may be hesitant to trust AI systems with their personal data, hindering widespread adoption. Overall, achieving cultural safety in AI-based chatbots requires a multifaceted approach. Developing culturally tailored systems, integrating human oversight, and prioritizing transparency and explainability are crucial steps in building trust and inclusivity. By acknowledging these challenges and actively working towards solutions, AI systems like chatbots can evolve to become valuable tools that empower and serve a wider range of communities across the globe.

Lastly, I think community-based research (CBR) answers a continual challenge that industries developing health technologies face. I see how in today's competitive landscape, companies are increasingly seeking ways to understand and connect with their target audiences. Traditional market research methods sometimes lack the depth and nuance needed to truly grasp the needs and desires of communities. I think this gap is where CBR can emerge as a powerful tool, where it can offer a blend of social responsibility and impact as well as strategic advantage for industry agendas. One of the primary benefits of CBR lies in its ability to foster innovation, by adopting new ways of seeing and thinking about the world. Much of this innovation is unlikely to happen in industry spaces because of the strong focus on market insights and investment in current products. By directly engaging with community members, companies could gain access to a wealth of information about unmet needs and potential markets. Traditional market research might overlook these crucial insights, but CBR could allow companies to identify problems or desires specific to a particular community. Relatedly, CBR could play a vital role in product development. Community involvement in the design process could allow companies to create products that are more user-friendly, culturally relevant, and ultimately more successful (as are the benefits revealed through academic research contexts). CBR also enables real-world testing of prototypes or concepts with target populations, where early-stage feedback would minimize the risk of investing heavily in products that may not resonate with the intended community.

I think CBR could also foster social responsibility and impact among companies, which is especially necessary in tech. Engaging in CBR could be a practice of companies showing their commitment to social responsibility and a genuine interest in the well-being of the communities that it affects, which is more impactful than campaigns without associated action. By understanding community needs and concerns, companies could develop practices that are more sustainable and minimize negative environmental or social impact. However, implementing CBR effectively requires acknowledging its challenges. CBR is a time-intensive process that demands genuine investment and long-term partnerships with communities. Balancing industry goals with community needs can be a *delicate* act, requiring careful negotiation and compromise. The most crucial aspect is ensuring equitable partnerships where community voices are truly heard and valued. Without this foundation of mutual respect, CBR projects risk exploitation and ultimately fail to deliver on their full potential. Overall, CBR presents a unique opportunity for companies to bridge the gap between industry and communities. By fostering innovation, building trust, and promoting social responsibility, CBR offers a strategic advantage that goes beyond traditional market research. By embracing a collaborative approach that values community input, companies can not only fulfill their social responsibility goals but also develop successful products and build lasting relationships with the communities they serve.

Chapter 8: Conclusion

For early childhood health promotion technologies to have a meaningful impact on health inequity, they must begin to understand the nuances of families' experiences and provide recommendations that are aligned with their needs. From my content analysis (shared in Chapter 3), it is clear that these technologies can be published by anyone, anywhere, and often lack a focus on reducing child development disparities. Instead, their primary goal is to attract parents and caregivers through visually appealing interfaces that track basic child health information. As we continue to innovate on early childhood health promotion technologies, I see both opportunity and risk. On the one hand, there is the potential to integrate these technologies with existing community-based support systems and offer more holistic understandings of families' needs. This integration could connect families with crucial resources such as mental health services, food banks, or educational programs. These technologies can also function as platforms to raise awareness about existing resources. Mobile apps, for example, could be designed with searchable databases of local support services, or utilize notification services through text or push notifications to inform parents about relevant programs of events in their communities. On the other hand, there is a risk that these technologies could further widen disparities if they fail to account for the nuances of different family experiences. For example, the "Kinedu: Baby Development App" (which as of May 2024, is still available in the Apple App Store), focuses on tracking milestones like rolling over or first steps, and gives rewards and badges for achieving them. While this approach seems harmless, it could be insensitive to different families' experiences. For example, imagine a single mother working multiple jobs to support her family. "Kinedu" might recommend developmental activities that require considerable time or financial resources, such as enrolling the child in a gym class or purchasing expensive educational toys. This could lead to feelings of inadequacy and stress for the mother, potentially widening the disparity in developmental opportunities for her child compared to families with more resources.

My research on culturally safe and collaborative design aims to create technologies that are more inclusive and address the specific needs of diverse families. Through co-creation workshops with parents from marginalized communities, we can identify potential biases in these technologies. For example, workshops could involve discussions about realistic time commitments for working parents or exploring alternative, culturally relevant ways to promote child development that do not rely solely on expensive resources. Based on this input, the "Kinedu" app could be redesigned to offer a wider range of activities and milestones. It could potentiallyfeatures suggestions for affordable, at-home play activities, or even integrate with local community centers to highlight free developmental programs. Additionally, the app could acknowledge the challenges faced by working parents and offer alternative ways to track and celebrate their child's progress, even with limited time.

Throughout my dissertation work, I have explored the ways that we might use cultural safety as an approach to technology design, particularly in enabling us to develop more equitable technologies. My dissertation examines how technology can be designed to address disparities in child development experienced by marginalized communities. I argue that current approaches to health technologies often overlook the unique needs and contexts of families, potentially worsening existing inequities. I propose cultural safety as a guiding principle for designing health technologies. Cultural safety emphasizes understanding the power imbalances and social inequities within the healthcare system, and respecting the cultural backgrounds and experiences of families. As such, throughout my dissertation, I also advocate for more research and design that is engaged directly with marginalized communities. My research involved a number of studies, including a systematic literature review, content analysis of existing technologies, focus groups with parents, development of a heuristic evaluation method, and a co-design project with a community organization. These studies identified gaps in current practices and highlighted the importance of designing technologies that are inclusive and responsive to the needs of diverse families. My dissertation concludes by outlining a framework for culturally safe design and providing recommendations for future research. This framework can be used by researchers and designers to create health technologies that are more effective and equitable for all children and families. Over these studies, I investigated the following research questions:

1. How do health technologies risk perpetuating child development inequities if they do not consider the unique contexts, needs, and values of families?
2. How can cultural safety be integrated throughout the design and research processes of health promotion technologies?
3. In what ways does community-based research (CBR) promote cultural safety in research engagements with marginalized populations?
4. How can a cultural safety approach:
    a. Prevent health technologies from perpetuating health inequity?
    b. Promote more meaningful and safe engagements between people and technology?

8.1 Contributions

8.1.1 Gaps and Biases in Current Research

My dissertation highlights how current research on early childhood health technologies (ecHPTs) often overlooks the social context and cultural needs of families. This is supported by a systematic literature review of and content analysis of mobile-based technologies for early childhood health. These studies revealed that while many apps exist to support parenting and track developmental milestones, the high volume of low-quality, non-inclusive resources makes it challenging for parents to find effective, evidence-based tools. This fragmented approach undermines the potential of technologies to promote equity and support the diverse needs of families. Academic research faces similar challenges, with many studies failing to progress beyond initial testing due to a lack of rigorous evaluation and collaboration across disciplines. Without more comprehensive, multidisciplinary research and greater engagement with marginalized communities, innovative technologies will struggle to have meaningful impact. The prevalence of single-aspect solutions and neglect of social determinants of health in both research and design further limits the effectiveness of these tools.

I also engaged in a community-based research partnership with a community organization that primarily services families who had recently immigrated from West Africa to South King County, Washington. Through this partnership, I conducted focus groups with parents to learn more about their experiences supporting their childrens' development, and the relevance or irrelevance of technology in their parenting practice. This study revealed that parents in this community have diverse experiences and needs that should be considered when designing early childhood health promotion technologies. While some parents rely on technology for communication and consultation with trusted individuals, others have no interest in receiving developmental information through digital means. Additionally, these parents often prioritize basic needs over seeking out health and developmental information. The research highlights the need for early childhood health promotion technologies to be flexible, adaptable, and mindful of the broader socioeconomic context in which families are living. It also underscores the importance of supporting existing community networks and providing information in ways that are culturally sensitive and inclusive of different parent preferences.

The findings across these studies show that ecHPTs may unintentionally perpetuate stereotypes or fail to consider the realities of marginalized families. To truly promote cultural safety and equity in early childhood health technologies, we must prioritize holistic approaches that consider the full context of children's lives and the diverse needs of their families. By adopting a cultural safety approach and centering the perspectives of marginalized communities, we can create technologies that are more likely to be adopted and beneficial for all. The barriers to equitable health technology design and dissemination are significant, but with concerted effort across research, design, and distribution channels, we can transform these tools into powerful resources that advance health equity for children and families across diverse backgrounds.

8.1.2 Framework for Culturally Safe Design

My dissertation proposes a framework for designing ecHPTs that centers on cultural safety. This framework emphasizes collaboration with diverse communities, active solicitation of their perspectives, and the creation of interfaces and content that affirm and celebrate cultural differences.

8.1.3 Demonstrating how Cultural Safety can be applied in Practice

I also present a new evaluation method for evaluating early childhood health promotion technologies. I provide a set of heuristics aimed toward evaluating technologies that deliver information about child development to parents. The heuristics provide practical guidelines for assessing how health information is presented, the trustworthiness of guidance, and features that support decision-making. By aligning with the core principles of cultural safety, the HTP heuristics promote accessibility, understanding, transparency, trust, empowerment, and human-centeredness in technology design. The heuristics also have the potential to enhance equity by ensuring technologies are accessible to all, builds trust through transparency, respects individual differences, and proactively identifies potential biases that could lead to inequities.

Overall, the heuristic evaluation method provides a framework for designing eHPTs that are inclusive, respectful, and empowering for all people, contributing to the prevention of health disparities and the promotion of cultural safety.

I also completed a case study using the cultural safety approach to develop a conversational agent for early childhood health promotion. In this study, I enacted the principles of cultural safety in a chatbot prototype by engaging parents from King County, Washington in storyboarding, focus group discussions, and co-design activities to gather requirements and ensure the prototype was sensitive to their unique contexts, identities, and values. In this study, I document key considerations for designing ecHPTs that promote culturally safe experiences, enacting community-based research approaches in technology innovation. Further, I discuss how these values of cultural safety were reflected in the prototype, demonstrating a way to integrate cultural safety into the design and research processes of health promotion technologies. This study demonstrates how the cultural safety framework can be applied in practice to create more inclusive and respectful technologies.

Overall, my research demonstrates the importance of cultural safety in designing ecHPTs. I propose a framework, showcase a practical example, and introduce a new evaluation method. My work emphasizes the need to create technologies that are inclusive, equitable, and respectful of all families, regardless of their background or circumstances, and provides directions for future work in this space.

8.2 Future Work

There is a wide variety of potential for this field, however I think the most pressing challenge will be findings ways to build these tools in a way that is sustainable, and that they actually work in the ways I have described (e.g., being highly personalized to each family). Further, the community that I have worked with has expressed a strong interest in having access to functional versions of these tools. To pursue this, I am interested in continuing collaborations with this community to develop these systems. Particularly, I am interested in exploring how an ecHPT might be integrated into existing systems, like Whatsapp or Facebook Messenger, to reduce the resources needed to build a system from the ground up. I would like to engage with the community further to understand high-priority features, and explore a staggered approach to introducing new features and functionalities.

Another crucial area of future work is to evaluate the impact of culturally safe technology on patient outcomes. This could involve a study comparing patient outcomes when using technology designed with a cultural safety framework versus without it. By measuring factors like patient health improvements, adherence to recommendations, healthcare utilization, and overall satisfaction, we could determine if cultural safety translates to improvements in health equity in measurable ways. Further, it will be necessary to understand the scalability and dissemination of early childhood health promotion technologies in this space. How can we effectively scale up these culturally safe tools to reach wider populations? This might involve partnerships with healthcare organizations or technology companies to integrate the tools into existing platforms (e.g., I imagine partnerships with platforms like widely-used interactive patient care systems, like MyChart). Additionally, research on the most effective dissemination strategies for different communities would be valuable. At the latter edge of my PhD, I noticed the industry investment in artificial intelligence (AI) as well, and I am curious how AI may enable or power personalization in ways that have not yet been explored. Can artificial intelligence (AI) be leveraged to further personalize these tools and tailor interventions to individual needs? Exploring how AI can analyze patient data and preferences to deliver culturally safe and targeted support could be a significant advancement in the field. Lastly, future work might consider studying: How can we ensure that culturally safe technology is truly community-driven and empowers the communities it serves? I think that investigating models of co-creation, where community members are actively involved in the design and development process, could be a key factor in long-term success. I think there are further opportunities to consider the community perspective on frameworks like cultural safety and how the principles can or cannot be integrated into the technology design process.

Relatedly, I would like to continue to develop my skills in developing community partnerships and conducting research. I am interested in doing freelance work where I can support communities with their research questions, rather than pursuing my own. I am curious how I can leverage my research skills to support communities in this way. I would like to revisit my relationships with First Five Years and Beyond, as well as the parents involved in the CAB, to see what support I can offer them in research. I think I can also leverage my other skills, for example grant writing or making presentations, to support them with other initiatives as well.

8.3 Limitations

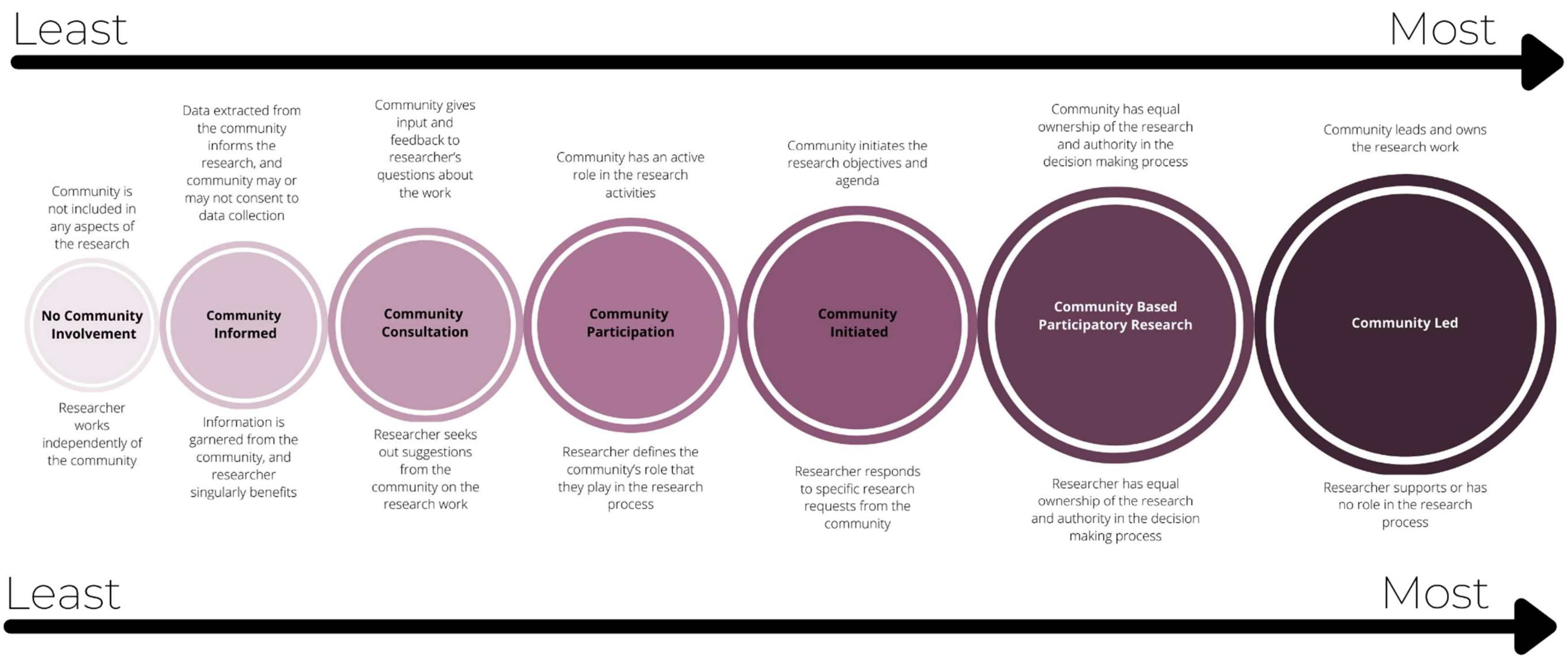
My research has primarily focused on communities in King County, Washington. While this provides valuable insights, the experiences and needs of families may vary significantly in other locations. The generalizability of the findings to other contexts might be limited. My research has also primarily focused on mobile health technologies like mobile apps and chatbots. This limited scope of technologies does not provide insights into the challenges and opportunities when applying cultural safety into other health technologies or health interventions. Further, throughout the dissertation, I acknowledge the difficulty of precisely measuring cultural safety in design. It is possible that the approaches I have proposed in my dissertation may not capture all possible aspects of culturally safe technologies. Lastly, many of the methods I have used in my research have introduced the potential for power imbalances in the research dynamic. Despite the strength of the community-based and human-centered methods that I have used, it is still necessary to acknowledge that I and my research collaborators may have had undue influence, limiting the true voice of the communities that we worked with.

8.4 Conclusion

While well-intentioned, technologies can increase health inequity if not designed and implemented with careful considerations. With the increasing interest in developing technologies that support the development and well-being of young children, there is an urgent need to ensure these systems are designed in a way that does not widen the gap between children, setting the foundation for their future potential. This process requires deep engagement with the diversity of backgrounds and contexts for families as they navigate child development. My dissertation provides insights on how technology designers and researchers can use cultural safety as an approach to designing early childhood health technologies, which enables technologies to provide more equitable, safe, and meaningful experiences, particularly for families in marginalized communities. Going forward, I hope to work toward building and implementing the systems that I have prototype, to have tangible change in the communities that I have worked with.

Appendix

Appendix A: Continuum of Community Engagement



No Community Involvement

Community is not included in any aspects of the research

Researcher works independently of the community

Community Informed

Data extracted from the community informs the research, and community may or may not consent to data collection

Information is garnered from the community, and researcher singularly benefits

Community Consultation

Community gives input and feedback to researcher's questions about the work

Researcher seeks out suggestions from the community on the research work

Community Participation

Community has an active role in the research activities

Researcher defines the community's role that they play in the research process

Community Initiated

Community initiates the research objectives and agenda

Researcher responds to specific research requests from the community

Community Based Participatory Research

Community has equal ownership of the research and authority in the decision making process

Researcher has equal ownership of the research and authority in the decision making process

Community Led

Community leads and owns the research work

Researcher supports or has no role in the research process

Appendix B: Tables and Figures for Systematic Literature Review

Appendix B1: Full Search Strings by Database

PubMed

((eHealth OR "mHealth" OR "mobile health" OR "health promotion" OR "health intervention") AND (mobile phone OR cell phone OR mobile application OR text messaging OR short message service OR smartphone) AND (developmental screening OR developmental milestone OR developmental checklist OR developmental progress OR "ESPDT" OR developmental tracking OR child health OR child development OR "physical well-being" OR "social and emotional development" OR "language development" OR "early literacy")) AND ("infant"[MeSH Terms] OR "infant"[MeSH Terms] OR "infant, newborn"[MeSH Terms] OR "child, preschool"[MeSH Terms]) AND ("Parents"[Mesh] OR "Legal Guardians"[Mesh]) AND ("2011"[PDat] : "2022"[PDat])

EMBASE

('ehealth'/exp OR ehealth OR 'mhealth'/exp OR 'mhealth' OR 'mobile health'/exp OR 'mobile health' OR 'health promotion'/exp OR 'health promotion' OR 'health intervention') AND (((((mobile AND phone OR 'cell'/exp OR cell) AND phone OR mobile) AND ('application'/exp OR application) OR text) AND messaging OR short) AND message AND service OR 'smartphone'/exp OR smartphone) AND (((((developmental AND ('screening'/exp OR screening) OR developmental) AND milestone OR developmental) AND ('checklist'/exp OR checklist) OR 'espdt' OR developmental) AND tracking OR 'child'/exp OR child) AND ('health'/exp OR health) OR 'child'/exp OR child) AND ('development'/exp OR development OR 'developmental progress') AND ([newborn]/lim OR [infant]/lim OR [child]/lim OR [preschool]/lim) AND [2011-2022]/py

CINAHL Complete

((eHealth OR “mHealth” OR “mobile health”) AND (mobile phone OR cell phone OR mobile application OR text messaging OR short message service OR smartphone) AND (developmental screening OR developmental milestone OR developmental checklist OR “ESPDT” OR developmental tracking OR developmental progress OR child health OR child development) AND (infant OR newborn OR child, preschool) AND (parents OR mothers OR fathers OR legal guardian) AND (“health promotion” OR “health intervention”)) **Limiters (must be selected manually): Published Date: Start Month and Year: January 2011, End Month and Year: December 2022

ERIC

((“eHealth” OR “mHealth” OR “mobile health” OR “health intervention” OR "health promotion" Or “mobile health program”) AND (Telecommunications OR Handheld Devices OR Synchronous Communication OR “short message service” OR “text messaging” OR “smartphone” OR “mobile phone” OR “mobile app”) AND (“developmental screening” OR “developmental milestone” OR “developmental checklist” OR “ESPDT” OR “developmental tracking” OR “Child Development” OR “Child Health” OR “Developmental Stages”) AND (Infants OR newborn OR Preschool Children OR Young Children OR Toddlers) AND (Parents OR mothers OR fathers OR legal guardian) NOT (Developmental Delays OR Neurological Impairments OR Disability OR Autism OR “mental disorder”) NOT (Adolescents OR Teenagers OR Preadolescents) NOT ("education" OR “school” OR "child abuse")) **Filter: last 10 years

Compendex and Inspec (Using Engineering Village)

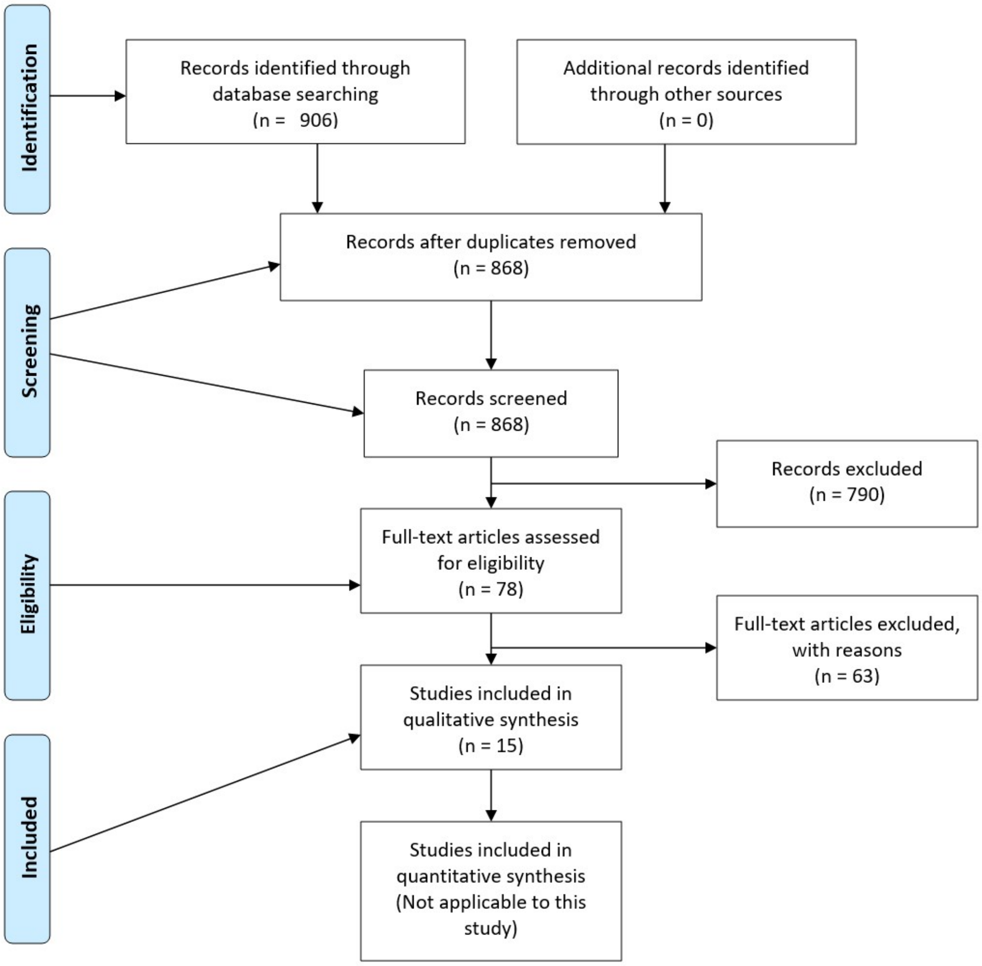
((((((mobile phone OR mobile app OR smartphone OR phone app OR texting OR text messaging OR SMS OR mobile health OR mhealth OR eHealth OR "health promotion" OR "health intervention" OR "public health")) WN ALL) AND ((("developmental milestones" OR "developmental progress" OR "developmental tracking" OR "child development" OR "child health outcomes" OR "developmental stages" OR "developmental screening" OR "developmental checklists" OR "ESPDT")) WN ALL)) AND (((child OR infant OR newborn OR preschool child OR young children OR toddlers)) WN ALL)) NOT ((("pregnant women")) WN ALL)) **Filter: “Published” field to 2011-2022

ACM Digital Library

(ehealth OR "mhealth" OR "mobile health" OR "health promotion" OR "health intervention") AND (mobile phone OR cell phone OR mobile application OR text messaging OR short message service OR smartphone) AND (developmental screening OR developmental milestone OR developmental checklist OR "espdt" OR developmental tracking OR developmental progress OR child health OR child development) AND (infant OR newborn OR child, preschool) AND (parent OR mother OR father OR legal guardian) **Filter: “Publication Date” field: January 2011 - December 2022

Appendix B2: PRISMA Flow diagram of the study selection process.

Figure: Flow diagram of the study selection process for Systematic Literature Review



Appendix B3: Overview and Characteristics of Included Studies

Study	Field	Country	Number of Participants (parents)	ORBIT[a] model classification
Armenta et al, 2019	Computing	United States and Mexico	11	Nonexperimental evaluation of feasibility; no measurement or documentation of child health outcomes
Suh et al, 2014	Computing	United States	14	Nonexperimental evaluation of feasibility; no measurement or documentation of child health outcomes
Olson et al, 2016	Medical	United States	31	Nonexperimental evaluation of feasibility; no measurement or documentation of child health outcomes
Hayes et al, 2014	Computing	United States	14	Nonexperimental evaluation of feasibility; no measurement or documentation of child health outcomes
Huang and Li, 2017	Medical	Cambodia	126	Nonexperimental evaluation of feasibility; no measurement or documentation of child health outcomes
Jacques et al, 2020	Health informatics	Switzerland	12	Nonexperimental evaluation of feasibility; no measurement or documentation of child health outcomes
Jiang et al, 2019	Health informatics	China	558	Nonexperimental evaluation of feasibility; no measurement or documentation of child health outcomes
Khademian et al, 2020	Medical	Iran	211	Pilot and early experimental evaluation of child health outcomes
Lozoya et al, 2019	Medical	United States	33	Pilot and early experimental evaluation of child health outcomes
Nezami et al, 2018	Pediatrics	United States	51	Pilot and early experimental evaluation of child health outcomes
Nolen et al, 2018	Health informatics	United States	8	Pilot and early experimental evaluation of child health outcomes
Nystrom et al, 2017	Medical	Sweden	315	Pilot and early experimental evaluation of child health outcomes
Seyyedi et al, 2020	Medical	Iran	110	Pilot and early experimental evaluation of child health outcomes
Zolfaghari et al, 2021	Medical	Iran	58	Pilot and early experimental evaluation of child health outcomes
Domek et al, 2016	Medical	Guatemala	321	Pilot and early experimental evaluation of child health outcomes

aORBIT: Obesity-Related Behavioral Intervention Trials. The ORBIT model establishes a pathway of phases that supports the translation of information in behavioral and social science research into health interventions (Czajkowski et al., 2015).

Appendix B4: Summary of Findings from Included Studies

Study	Technology description	Study design	Usability and feasibility evaluations of the technology.	Child outcomes	Parent knowledge and decision-making
Armenta et al, 2019	Mobile app for child milestone tracking	Qualitative usability study—evaluated 3 versions of a mobile app: original, translation, and redesign	Evaluated the user interface and workflows for basic functions for the first app to identify objectives for a redesign. Found that the first app had several issues with basic functions (eg, data entry and creating new profiles). Evaluated the redesigned app and successfully resolved usability issues previously identified.	Not measured	Not measured
Suh et al, 2014	Social media network (Twitter), website, and text messaging system for tracking child health milestones	Deployment study and qualitative, exploratory study	Parents reported difficulty with responding to tweets using the program's syntax and did not like that the program used a social networking site. Parents liked the accessibility of the content related to child milestones and opportunities to interact with other parents through the platform.	Not measured	Not measured
Olson et al, 2016	SMS texting with personalized messages about child development	Feasibility study	Parents reported high satisfaction with the frequency of text messages. Parents also shared preference for text messages over website-	Not measured	Parents reported increased awareness of language-promoting activities and local child development resources

Study	Technology description	Study design	Usability and feasibility evaluations of the technology.	Child outcomes	Parent knowledge and decision-making
	and local child health resources		based programs, owing to ease of access.		
Hayes et al, 2014	Mobile app for tracking infant weight, diapers, infant emotions, reminders, and parent moods	Qualitative technology probe, interviews, surveys, and log analysis	Did not track any usability issues. Parent feedback revealed that the app does not require much training to use it as a beginner.	Not measured	Parents expressed that the app supported parent-focused outcomes (tracking mental health) and that using the app did not contribute to additional stress levels
Huang and Li, 2017	Interactive voice response system by using prerecorded voice phone calls	Feasibility study	Intervention was well accepted by parents, as parents expressed interest in paying for the service and referenced the tool's cultural relevance.	Not measured	Not measured
Jacques et al, 2020	Mobile app for recording food quality and intake and tracking nutrition information of foods	Feasibility study	Parents rated the app as high on the ease-of-use scale.	Not measured	Not measured
Jiang et al, 2019	SMS texting with information about feeding and breastfeeding	Quasi-experimental design	Not measured	Measured child's BMI before and after intervention. Intervention did not demonstrate a significant effect on the children's BMI	Not measured
Khademian et al, 2020	SMS texting with information about child oral health	Randomized control trial	Not measured	Not measured	Maternal knowledge about oral health and related practices improved after intervention

Study	Technology description	Study design	Usability and feasibility evaluations of the technology.	Child outcomes	Parent knowledge and decision-making
Lozoya et al, 2019	Mobile app with guided videos, reminders, and social feed for child's oral hygiene	Experimental pretest-posttest and qualitative interviews	Not measured.	Documented dietary habits, oral health practices, and dental appointment attendance for all children before intervention. Did not find any changes to those practices after intervention	Did not find a significant quantitative change in parent knowledge. Found that parents reported a positive experience with the mobile app's reminders and guided brushing features
Nezami et al, 2018	Mobile-optimized website, SMS text messages, and physical list of foods with nutrition information	Randomized controlled trial	Adherence to the intervention was higher than in previous studies with mothers of young children. Dropout was more likely among people of color; however, dropout did not differ by treatment group.	Children consumed less beverages in the intervention group	Not measured
Nolen et al, 2018	Mobile app with videos, reminders, and facts about a child's oral health	Usability study	On average, parents believed that the app could keep them informed about their child's oral health. Parents rated navigation of the interface and design elements as poor. Parents shared that several of the features in the app did not work.	Not measured	Not measured
Nystrom et al, 2017	Mobile app for tracking child's food intake and exercise	Randomized controlled trial	Not measured	Measured child BMI or FMI[a] levels and did not find a change after intervention. Found that child activity levels increased	Not measured
Seyyedi et al, 2020	Mobile app with guidance on feeding and	Randomized controlled trial	Not measured.	Intervention group improved nourishment status	Mother's nutritional literacy improved for both groups; however the intervention group had greater improvement

Study	Technology description	Study design	Usability and feasibility evaluations of the technology.	Child outcomes	Parent knowledge and decision-making
	direct chat with clinicians				
Zolfaghari et al, 2021	Gamified mobile app with tracking and reminders for oral hygiene practices	Pretest-posttest controlled clinical trial	Not measured.	Reported significant improvement in child tooth brushing frequency. Both groups had reduced child plaque measurements, but reduction was higher in the gamified intervention group	Measured improvements in parent knowledge about oral health in both groups, but higher improvement was found in the gamified group
Domek et al, 2016	Vaccine reminder texting program	Pilot randomized controlled trial	Identified that the vaccine SMS texting reminder system is feasible for the LMIC[b] context, and reported high user satisfaction with the technology.	No significant impact on vaccine rates in the intervention group compared with the control group	Parents expressed that the reminders were helpful in following up with their child's vaccine series

Appendix A5: Technology Systems and Features Presented in Included Studies

Studies	Technology system	Functions and features	Early childhood areas (as outlined by Hagan et al [1])	Content sources
Armenta et al, 2019	Smartphone app	Translated version of existing smartphone app (from English to Spanish). Includes developmental milestone tracking through checklists, exporting, and sharing completed checklists, and recording notes about milestones. Supports profiles for >1 child.	Developmental milestone surveillance	First iteration of mobile app developed using the CDC's[a] Learn the Signs. Act Early campaign. The second iteration of the mobile app was derived from the Spanish version of the CDC's milestone list
Suh et al, 2014	Social media network (Twitter), website, and SMS text messaging	Parents follow an account that shares age-based milestone questions (sometimes coupled with images) at regular intervals. Then, the parent can respond by posting a tweet or direct messaging the account.	Developmental milestone surveillance	Not reported
Olson et al, 2016	SMS text messaging	Sends 3 SMS text messages per week for 12 weeks with information on child development and local child health resources. Sends messages with survey questions about parent's strategies to support their child's health.	Developmental milestone surveillance	Not reported
Hayes et al, 2014	Smartphone app	Tracking infant weight, diapers, and emotions. Includes mood tracking for parents. Generates data files for health care professionals and reminders for tracking in the app.	Feeding, growth development, and parent mental health	Not reported
Huang and Li, 2017	Interactive voice response system	Sends prerecorded messages through phone call to parents, starting 3 days after birth. Messages are sent every 4 days until the child is 28 days old. Messages are 60-90-seconds long and have a variety of voices offered.	Developmental milestone surveillance	Consulted with local midwives for more information about message content
Jacques et al, 2020	Smartphone app	Digitizes food recording features, including intake and quantity. Provides information on added fats or sugars in foods after parents use the app to take pictures of food labels.	Food and nutrition	Consulted with expert pediatric dietetics at Geneva Children's Hospital
Jiang et al, 2019	SMS text messaging	Weekly text messages provide anticipatory guidance about feeding, and requests more information from parents about breastfeeding statuses for themselves and their child.	Feeding and breastfeeding	Developed using WHO[b] breastfeeding and infant or young child feeding recommendations. Consulted with local child health care experts

Studies	Technology system	Functions and features	Early childhood areas (as outlined by Hagan et al [1])	Content sources
Khademian et al, 2020	SMS text messaging	Daily SMS text messages provide guidance about oral health. SMS text messages were designed using gain- and loss-frame formatting.	Care of teeth and gums	Consulted with local pediatric dentistry professors and educational management specialists
Lozoya et al, 2019	Smartphone app	Provides documents and videos with oral hygiene instructions. Tracks tooth brushing times and sends brushing reminders. Includes a social feed to share brushing and flossing experiences with a social network.	Care of teeth and gums	Not reported in this paper; documented in preceding paper
Nezami et al, 2018	Mobile-optimized website, SMS text messaging, paper-based list, stickers, and charts	Text message prompt at the end of every week to collect the mother's personal data, which is then used to create a tailored email about nutrition and quality of foods consumed.	Food and nutrition	Not reported in this paper; documented in a preceding protocol paper
Nolen et al, 2018	Smartphone app	Sends tooth brushing reminders for morning and night, tracks frequency of brushing and flossing events, includes videos for guided brushing, and has facts about oral health in articles.	Care of teeth and gums	American Dental Association website
Nystrom et al, 2017	Smartphone app	Mobile app sends push notifications with general information about nutrition and exercise. Provides advice and strategies to change behaviors, supports weekly tracking of child's intake and exercise. App provides weekly feedback (graphical and automated comments) based on personal data. The mobile app also supports direct contact with a dietician or psychologist.	Food and nutrition, physical activity	Not reported
Seyyedi et al, 2020	Smartphone app	Provides articles with age-based guidance education based on feeding children. Provides a chat feature where clinicians can directly answer parent questions in the app.	Feeding and breastfeeding	Maternity Guidelines for Maternal and Child Health Services issued by the Iranian Ministry of Health. Cross-referenced content with guidance from a local nutritionist
Zolfaghari et al, 2021	Smartphone app	Provides written information about oral hygiene, nutrition, fluoride intake, and content of dental visits. Mobile app sends reminders to brush teeth at night.	Care of teeth and gums	American Association for Pediatric Dentistry Guidelines. Mobile app was evaluated by oral medicine specialists, pediatric dentists, and electronic learning and programing technicians

Studies	Technology system	Functions and features	Early childhood areas (as outlined by Hagan et al [1])	Content sources
Domek et al, 2016	SMS text messaging	SMS text message reminders sent to parents at 6, 4, and 2 days before the next scheduled child vaccination date (as part of a 3-dose vaccination series).	Vaccines	Guatemala Ministry of Public Health and Social Assistance, Pan American Health Organization, and project optimize

Appendix C: Tables and Figures for Content Analysis

Table C1: Coding Scheme

Code Source	Code	Definition
User Burden Scale	Requires Help	The app requires help from another person to use it
	Mentally Demanding	The app demands too much mental effort
	Time to Learn	It takes too long to do what you want with the app
	Hard to Learn	The app is hard to learn
	Causes Discomfort	Using the app causes physical discomfort
	Causes Pain	Using the app causes physical pain
	Physically Demanding	Using the app is too physically demanding
	Time Spent	You spend too much time using the app

	Too Often	You use the app more often than you should
	Distracting	The app distracts you from social situations
	Negative Social Impact	Using app has a negative impact on your social life
	Overwhelming Information	The app presents too much information at once
	Feel Bad	Using the app makes you feel like a bad person
	Feel Guilty	You feel guilt when you use the app
	Sharing Concern	You are worried by what information is shared by the app
	Distrust Policy	The app's policies about privacy are not trustworthy
Codes generated by the research team	Privacy Work	The app requires me to do a lot to maintain my privacy within it
	Cost	The app is too expensive
	Upfront Cost	The upfront cost of using the app is too high
	Storage Use	How much phone storage is used by the app?
	Languages Offered	What languages are offered in the app?
	Imagery	Images, videos or audio are personally/culturally relevant to me
	Discoverability	The description of the app in the Store does not help me understand it
	Notifications	Notifications are too frequent and do not allow me to customize
	Personalization	Too many/not enough personalization features

	Perceived degree of 'tailored'	App engagements feels tailored to just me
	Multiple children	Allows you to add multiple children
	Tracking multiple children	Tracking multiple children is not difficult
	Health explanations	Explanations of health recommendations are easy for me to understand
	Multiple caregivers	App supports collaboration between multiple caregivers
	Inclusion of caregivers	Doesn't focus exclusively on parent (e g , accommodates non-parent caregivers)
	Inclusion of family diversity	App does not include assumptions about two parent household or uses gendered language
	A lot of reading required	Large amounts of text without audio instructions or alternative media
	Health Literacy	Terms are not overly medicalized
	Reading level of text	What is the average reading level of text in the app?
	Phone data or WiFi required	Does the app require an internet connection to work?
Bright Futures	Behavior/Behavior Management	How caregiver(s) address various child behaviors in different settings
	Breastfeeding	Current and future breastfeeding plans and any barriers or contraindications to breastfeeding
	General Guidance on Feeding	Current and future feeding plans related to children who cannot feed themselves
	Car Safety	Existing behaviors to keep the child and other passengers in the car safe

	Care of Teeth and Gums	How parents currently care for the child’s teeth pre, during, and post teething May also ask about dental visits
	Childcare	Care of the child when a primary caregiver is not present
	Excretion	Child’s urination and bowel movements
	Family Planning	Future family planning
	Food and Nutrition	Transitioning to solid foods, appropriate portion sizes and types of foods/drinks the child can have
	Formula Feeding	Current and future formula feeding plans and any barriers or contraindications to formula
	Fussing/Irritability/Crying	How parents soothe the child and identify what the child needs, especially in young infants
	Lab Screening	Lab screening results
	Physical Activity	Healthy levels of physical activity for infants/children
	Reading	Age-appropriate assessment of literacy or parent strategies to promote literacy for their children
	Safety	Behavioral and physical environment safety for the child, excluding water and sleep safety
	Screen Time	Time spent viewing electronic screens
	Sleep	Sleep for the child and caregiver, excluding guidance concerning safe sleep practices for young infants
	Sleep Safety	How the parents keep their the child safe while sleeping
	Toilet Training	How parents address toilet training with their child and/or child's progress toward expected toilet training milestones

	Vaccinations	Child’s vaccinations or vaccination status
	Water Safety	Keeping the child safe in and around water
	Play	Parent's play routines or activities with their child
	Family Routines	Established family routines, or strategies parents currently use incorporate routines with child
	Gross Motor Skills	The gross motor development of the the child
	Fine Motor Skills	The fine motor development of the the child
	Cognitive Skills	Guidance related to the development of cognitive skills
	Expressive Language	Guidance related to the development of language and communication tools that the child uses
	Social/Emotional	The child’s communication, interactions, and emotional reactions to/with peers, family, or others as well as guidance related to developments or changes in mood, temperament, or emotions
	Vision/Hearing	The child’s ability to see, hear and eye/ear health
	Developmental Milestone Surveillance	Developmental milestone/progress surveillance
	Growth Development	The physical growth of the child
	Receptive Language	The development of the child’s understanding of words or language/communication
	Physical Exam	Clinician led physical exams of the child

Table C2: App Characteristics

Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Baby Tracker.	Apple App Store	Fitness Labs SRL	Medical	61.8	iOS 13.0 or later	Tracking feeding, diaper, sleep	No
Babio - Baby Activity Tracker	Apple App Store	Martin Steiner	Health & Fitness	4.6	iOS 6.1 or later.	Tracking feeding, diaper, sleep	No
baby breastfeeding tracker app - piyolog	Apple App Store	PiyoLog Inc.	Medical	74.1	iOS 13.0 or later.	Tracking feeding, diaper, sleep	Yes
baby diaries global	Apple App Store	The Baby Diaries Pty Ltd	Health & Fitness	111	iOS 9.0 or later.	Tracking feeding, diaper, sleep	No
Baby Exercises & Activities	Apple App Store	Aalund Consult I/S	Health & Fitness	9	iOS 10.0 or later.	Provides exercises/activities to do with baby	No
baby feeding log	Apple App Store	Aron Beaver	Medical	12.1	iOS 10.0 or later	Tracking feeding, diaper, sleep	Yes
baby journal [babyrepo]	Apple App Store	Permission Inc.	Medical	85.4	iOS 11.0 or later.	Tracking feeding, diaper, sleep	Yes
Baby Loggy - newborn care log	Apple App Store	Wavescape LLC	Medical	11.6	iOS 8.0 or later.	Tracking feeding, diaper, sleep	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?

Baby Sparks - Development App	Apple App Store	BabySparks Inc	Education	149.8	iOS 9.0 or later.	Development screening	No
Baby Steps - Growing Together	Apple App Store	TEDRA SOFT SRL	Health & Fitness	62.1	iOS 8.0 or later.	Development screening	No
baby time (record & analysis)	Apple App Store	Simfler Inc.	Medical	169.5	iOS 11.0 or later.	Tracking feeding, diaper, sleep	Yes
Baby Tracker - Newborn Log	Apple App Store	Nighp Softward LLC	Medical	109.6	iOS 10.0 or later.	Tracking feeding, diaper, sleep	No
baby tracker - nursing helper	Apple App Store	MK App Solutions Korlatolt Felelossegu Tarsasag	Medical	36.1	iOS 10.0 or later.	Tracking feeding, diaper, sleep	No
Baby Tracker & Breastfeeding	Apple App Store	Wachanga LTD	Medical	39	iOS 11.1 or later	Tracking feeding, diaper, sleep	Yes
CDC's Milestone Tracker	Apple App Store	Centers for Disease Control and Prevention	Health & Fitness	58.2	iOS 10.0 or later	Development screening	No
kinedu: baby development plan	Apple App Store	Kinedu	Education	219.4	iOS 12.0 or later.	Development screening	Yes
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?

Circle by providence	Apple App Store	Providence health & Services Washington	Health & Fitness	75.1	iOS 11.0 or later.	Tracking feeding, diaper, sleep	No
Baby Tracker!	Apple App Store	Amila Tech Limited	Medical	23.7	iOS 11.0 or later.	Tracking feeding, diaper, sleep	Yes
babycare tracker: baby journal	Apple App Store	倩 赵 (Maxwell Software)	Medical	29.6	iOS 11.0 or later.	Tracking feeding, diaper, sleep	Yes
BabyDo - Track Your Child's Milestones	Apple App Store	Dr. Jordan Littman, MD	Health & Fitness	24.5	iOS 10.0 or later.	Development screening	Yes
BabyLine - Baby Nursing	Apple App Store	JeongMin Kang	Medical	51.5	iOS 9.0 or later.	Tracking feeding, diaper, sleep	No
Bebeto - Baby Development App	Apple App Store	Burak AYTAN	Health & Fitness	34.8	iOS 10.0 or later.	Quiz/Trivia about child health	Yes
BiliBaby	Apple App Store	Mike Rizzo	Medical	39	iOS 10.0 or later.	Screening for Hyperbilirubinemia	Yes
Breastfeeding, Pumping Tracker	Apple App Store	LAITKHAUS, OOO Apps	Medical	65	iOS 10.0 or later.	Tracking feeding, diaper, sleep	No
da baby: newborn tracker app	Apple App Store	Yilei Yang	Medical	24.3	iOS 14.0 or later.	Tracking feeding, diaper, sleep	Yes
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?

eat sleep: simple baby tracking	Apple App Store	Make Sail, Inc.	Medical	7.2	iOS 6.1 or later.	Tracking feeding, diaper, sleep	Yes
Enfamil Family Beginnings	Apple App Store	Reckitt Benckiser Group plc	Health & Fitness	98.3	iOS 12.0 or later.	Parenting tips for each week of pregnancy	Yes
firstyear - baby feeding timer, sleep, diaper log	Apple App Store	Yi Ding	Medical	63	iOS 5.1.1 or later.	Tracking feeding, diaper, sleep	No
Growth Charts UK-WHO	Apple App Store	Incubate Ltd/Paediatrics.co.uk	Medical	7.1	iOS 8.0 or later.	Centile Calculator for weight, head, height	No
Growth: baby & child charts	Apple App Store	Clafou Ltd	Medical	8.6	iOS 7.0 or later.	Normal growth monitoring	No
Help My Baby Learn	Apple App Store	Help My Baby Learn	Utilities	21.9	iOS 11.0 or later.	Development screening	No
huckleberry: baby & child	Apple App Store	Huckleberry Labs Inc.	Medical	42.5	iOS 11.0 or later.	Tracking feeding, diaper, sleep with specific focus on sleep patterns and consultation from experts	No
kidcentric: baby tracker + log	Apple App Store	Kyle Scenna	Medical	10.4	iOS 13.0 or later.	Tracking sentimental milestones, keeping track of reminders, generic health reminders (E.g. appointments)	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Lamaze Play	Apple App Store	TOMY International	Health & Fitness	345.5	iOS 9.0 or later.	Scanning app for developmental promotion apps	No

Lansinoh Baby App 2.0	Apple App Store	Lansinoh	Health & Fitness	112	iOS 10.0 or later.	Tracking feeding, diaper, sleep, pumping, and parent water consumption	No
mammababy - breast feeding app & baby log tracker	Apple App Store	Life'n Stats	Medical	50.2	iOS 8.0 or later.	Tracking feeding, diaper, sleep, recording milestones, and tips to support milestones	No
my baby - newborn tracker	Apple App Store	Aleksei Neiman	Medical	30.2	iOS 11.0 or later.	Tracking feeding, diaper, sleep	No
mybaby milestones	Apple App Store	Tamer Abdel - Baset	Utilities	10.9	iOS 6.0 or later.	Information about milestones	No
n-born - baby feeding tracker	Apple App Store	Ivan Petrashka	Medical	60.5	iOS 11.2 or later.	Tracking feeding, diaper, sleep	No
Napper: Baby Sleep Tracker	Apple App Store	Napper AB	Lifestyle	64.3	iOS 11.0 or later.	Tracking sleep only	No
nara baby tracker	Apple App Store	Nara Organics, Inc.	Medical	21.4	iOS 11.0 or later.	Tracking feeding, diaper, sleep	No
newborn baby tracker & log	Apple App Store	ZENIA, OOO	Medical	33.4	iOS 10.0 or later.	Information about activities that promote developmental promotion	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
nursing timer	Apple App Store	Creaplay/Junhyun Cho	Health & Fitness	16.6	iOS 8.0 or later.	Tracking feeding, diaper, sleep	Yes
Onoco - Baby and Child	Apple App Store	Onoco Limited	Medical	49.4	iOS 13.0 or later.	Tracking, feeding, diaper, sleep, developmental milestone tracking, activities for developmental health promotion	No

Pathfinder Health	Apple App Store	Samar Parikh	Medical	34.2	iOS 10.0 or later.	Development screening	No
Saint Francis Baby & Me	Apple App Store	Saint Francis Hospital and Medical Center	Health & Fitness	23.5	iOS 12.0 or later.	Resources for early well-child care (includes tracking diaper, feeding)	No
Sprout Baby (Baby Tracker)	Apple App Store	Med ART Studios LLC	Health & Fitness	53.9	iOS 13.0 or later.	Tracking feeding, diaper, sleep and monthly developmental milestones, information about general parenting tips	No
Text4baby	Apple App Store	Voxiva	Health & Fitness	47.9	iOS 8.0 or later.	Vaccine tracking, general development advice, general parenting advice	No
Tryde	Apple App Store	RCJJRB LLC	Education	17.9	iOS 9.0 or later.	Development screening	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Vroom	Apple App Store	Bezos Family Foundation	Education	30.7	iOS 11.0 or later.	Activities to support development	No
webmd baby	Apple App Store	WebMD Health Corporation	Health & Fitness	65.7	iOS 10.0 or later.	Tracking feeding, diaper, sleep; random tips for parenting by week (up to 2 years old)	No
wunder - baby tracker	Apple App Store	Oya Inc	Education	82.4	iOS 12.3 or later.	Development screening	No
100 Baby Growth, Infant Care & Parenting Facts	Google Play Store	TipsBook	Parenting	16.7	Android 4.1 and up	Quiz/Trivia about child health	Yes

50 BAby & Infant Care Quiz; for new Parents	Google Play Store	Anish Nrk	Parenting	7.2	Android 4.0.3 and up	Quiz/Trivia about child health	Yes
baby + - your baby tracker	Google Play Store	Philips Consumer Lifestyle B.V. (partnership with Philips Avent)	Parenting	126	Android 5.0 and up	Tracking feeding, diaper, sleep, Provides articles about developmental milestones and timelines	Yes
baby app, baby tracker	Google Play Store	Softmint	Parenting	1.6	Android 4.0.3 and up	Tracking feeding, diaper, sleep	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
baby breastfeeding tracker	Google Play Store	Sevenlogics, INC	Parenting	25	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes
Baby Care - Feeding timer & Daily Baby Log	Google Play Store	Yalintech	Parenting	12	Android 5.1 and up	Tracking feeding, diaper, sleep	Yes
Baby Care - Newborn Feeding, Diaper, Sleep Tracker	Google Play Store	Hightech Solution	Parenting	11	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes
baby care - track baby growth	Google Play Store	Breet.Jia	Medical	9.8	Android 4.1 and up	Tracking feeding, diaper, sleep	No

baby care log & tracker	Google Play Store	Steveloper	Parenting	25	Android 4.4 and up	Tracking feeding, diaper, sleep	Yes
Baby Care Parent Guide: Birth-Newborn Development	Google Play Store	Yoanna Tech	Parenting	2.6	Android 3.0 and up	Article reading (website embedded into app) about basics of taking care of child up to age 1	Yes
Baby Care Tracker - Breastfeeding	Google Play Store	digerati.cz	Parenting	10	Android 4.4 and up	Tracking feeding, diaper, sleep	Yes
baby care week by week. tips	Google Play Store	kukipukie	Books & Reference	9.6	Android 5.0 and up	Articles about health and development up to age 3	Yes
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
baby daybook - newborn breastfeeding tracker app	Google Play Store	Baltapis	Parenting	22	Android 4.1 and up	Tracking feeding, diaper, sleep	No
baby development - growth log	Google Play Store	Steveloper	Medical	6	Android 41. and up	Tracking child weight and height only	Yes
Baby Development Guide	Google Play Store	Pregnancy and Baby Apps	Health & Fitness	4.6	Android 4.0 and up	View online "free forum" in an app, paired with articles	Yes
Baby Development Milestone: Week by Week	Google Play Store	zayn media	Parenting	5.6	Android 4.4 and up	Articles about developmental milestones and taking care of chid up to 5 years old	Yes

Baby Diary - Feeding, Sleep and Healthy tracker	Google Play Store	GTSStar	Parenting	11	Android 6.0 and up	Tracking feeding, diaper, sleep	Yes
Baby Feeding Tracker - Newborn Feeding and Care	Google Play Store	Rsky	Parenting	5.7	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
baby food chart	Google Play Store	Definicija hrane	Parenting	45	Android 4.4 and up	Tracking feeding, diaper, sleep	Yes
Baby Grow: feeding, sleep, diaper, expense tracker	Google Play Store	Apponance, Inc.	Parenting	36	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes
Baby Growth	Google Play Store	OWN-IT	Parenting	9.5	Android 5.1 and up	Quiz/Trivia about child health	No
Baby Growth & Development	Google Play Store	Dr Deepak Choudhury	Medical	3.9	Android 4.2 and up	Development screening	Yes
baby growth calculator	Google Play Store	Trusted Assets	Parenting	6.3	Android 4.0 and up	Development screening	Yes
baby growth month by month	Google Play Store	ARUNAS APPS LLP	Parenting	3.9	Android 4.1 and up	Development screening	Yes

Baby Info - Baby Tracker for feeds, sleep and more	Google Play Store	MartAndTrep	Parenting	6.2	Android 4.4 and up	Tracking feeding, diaper, sleep	Yes
baby journal: child growth, milestone book & diary	Google Play Store	Master App Solutions	Parenting	15	Android 4.1 and up	Tracking feeding, diaper, sleep, sentimental milestones	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
baby language: talking baby	Google Play Store	Pranata House & Gallery	Education	Varies with device	Android 5.0 and up	Information about 5 different baby sounds	No
baby log (stash, nurse, growth, sleep, feed)	Google Play Store	Compass Apps	Parenting	8.6	Android 6.0 and up	Tracking feeding, diaper, sleep	Yes
Baby Major Steps	Google Play Store	e-verbum	Parenting	4.2	Android 4.1 and up	Development screening	Yes
Baby Manager - Breastfeeding Log and Tracker	Google Play Store	LiveKid	Parenting	23	Android 4.3 and up	Tracking feeding, diaper, sleep	Yes
baby skills	Google Play Store	BabySkills	Lifestyle	4.4	Android 2.3 and up	Development screening	Yes
Baby Tracker - Feeding, Diaper, Activity, Sleep	Google Play Store	18K Development	Parenting	26	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes

Baby Tracker - Newborn Care from Head to Toe	Google Play Store	Doğan Bilişim ve İnternet Teknolojileri	Parenting	63	Android 5.0 and up	Information about parenting/milestones, sounds to soothe baby, games to play, blog with info about baby, growth percentile calculator, vaccine tracker	Yes

Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Baby Tracker - Newborn Feeding, Diaper, Sleep Log	Google Play Store	NIGHP SOFTWARE	Parenting	19	Android 4.4 and up	Tracking feeding, diaper, sleep	Yes
Baby tracker - newborn log (blue icon)	Google Play Store	Stay Fit With Samantha	Parenting	3.4	Android 4.4 and up	Tracking feeding, diaper, sleep	Yes
baby tracker - newborn tracker	Google Play Store	wing wing	Parenting	24	Android 4.1 and up	Tracking feeding, diaper, sleep	Yes
baby tracker - sleep, breastfeeding, food, diaper	Google Play Store	Baby Tracker App	Parenting	11	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes
Baby Tracker:Feeding,Diaper,Sleep for Newborn	Google Play Store	PM Apps 2020	Tools	6.3	Android 4.4 and up	Tracking feeding, diaper, sleep, and random parenting tips	Yes

Baby Tracker. Breastfeeding Log & Nursing - MeGrow	Google Play Store	Myamplifiers.com	Parenting	9.7	Android 4.1 and up	Tracking feeding, diaper, sleep	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Baby Words - speech and language development diary	Google Play Store	BigMeApps	Parenting	3	Android 6.0 and up	Tracking baby vocabulary/word development	Yes
Baby's Brain Development week by week	Google Play Store	MasterpieceApps	Health & Fitness	6.6	Android 4.1 and up	Information about child health and parenting tips	Yes
BabyAppy: formula feeding, sleep and diapers	Google Play Store	BigMeApps	Parenting	4.2	Android 4.4 and up	Tracking feeding, diaper, sleep	Yes
babybeats early intervention resource	Google Play Store	Advanced Bionics LLC	Education	16	Android 5.0 and up	Music and movement for babies with hearing loss	No
Babygogo PArenting - Baby Care & Pregnancy Tips	Google Play Store	Babygogo	Parenting	7.3	Android 4.1 and up	Parenting tips via forums/feed/SNS/connect with doctors/shopping	No

babygym	Google Play Store	MotorikApp ApS	Parenting	40	Android 5.0 and up	Activities to support physical/motor development and connection with parents	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Babylog (Parenting, Track & Analysis)	Google Play Store	ForestApps	Parenting	6.2	Android 4.3 and up	Quiz/Trivia about child health	Yes
bee parenting	Google Play Store	Early Childhood Development Pvt Ltd.	Parenting	56	Android 5.0 and up	Tracking feeding, diaper, sleep	No
beurer babycare	Google Play Store	Beurer GmbH	Parenting	22	Android 5.0 and up	Tracking feeding, diaper, sleep	No
Boky - Baby Diary	Google Play Store	Cuberob	Parenting	10	Android 4.4 and up	Tracking feeding, diaper, sleep	No
bonbaby - baby health tracker	Google Play Store	FEMOMETER LIMITED	Parenting	22	Android 4.3 and up	Monitor baby fever, weight, height, medications	No
Best App for Pregnancy Tracker & Baby Care	Google Play Store	Amit Kulhari	Parenting	21	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes
Breastfeeding Newborn tracker, pump and baby diary	Google Play Store	Whisper Arts	Parenting	14	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes

Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
child development - wachanga	Google Play Store	Wachanga	Parenting	29	Android 5.0 and up	Milestone diary, weekly development tips	No
Child Development 0 to 6	Google Play Store	Tibus	Education	6.8	Android 4.1 and up	Quiz/Trivia about child health	No
Child Development (hartwell)	Google Play Store	harwell mhunduru	Health & Fitness	7.2	Android 5.0 and up	Development screening	No
Child Development Milestones	Google Play Store	Academy for Professional Excellence	Books & Reference	2.8	Android 4.1 and up	Information about development and milestones (list with reading)	No
Child Development	Google Play Store	Mapri apps	Medical	2.7	Android 2.3.3 and up	Tracking feeding, diaper, sleep	No
Child Growth Diary	Google Play Store	CosTheta	Health & Fitness	2.9	Android 5.0 and up	Development screening	No
Child Growth Tracking	Google Play Store	EXRL	Parenting	21	Android 5.0 and up	Tracking head, body, weight against WHO percentiles	Yes
child learning development	Google Play Store	Success Freedom System	Education	17	Android 5.0 and up	Articles about parenting advice	Yes
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?

Continua Kids - Child Growth & Development	Google Play Store	Wayu Health	Medical	46	Android 5.0 and up	Development screening	No
your baby month by month	Google Play Store	devalip	Parenting	7.1	Android 4.1 and up	Information about child development by month	Yes
womanlog baby calendar	Google Play Store	Pro Active App SIA	Health & Fitness	21	Android 4.1 and up	Tracking feeding, diaper, sleep	Yes
Turalura Baby: Track Growth Percentile & Milestone	Google Play Store	KosmicDust	Parenting	23	Android 5.0 and up	Development screening	Yes
Talli Baby	Google Play Store	Babylogger, LLC	Medical	38	Android 5.0 and up	Tracking feeding, diaper, sleep	No
SuperMama: Breast Feeding and Baby Daybook App	Google Play Store	Lighthouse GmbH	Parenting	57	Android 6.0 and up	Tracking feeding, diaper, sleep	No
Playfully Baby Development Activities & Milestones	Google Play Store	Playfully	Parenting	9.9	Android 4.4 and up	Milestone tracking and activities to support those milestones	No
Baby Tracker, Breastfeeding, Diapering: ParentLove	Google Play Store	Baby Tracker by Coquisoft	Parenting	Varies with device	Android 4.4 and up	Tracking feeding, diaper, sleep	Yes
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?

Parent Sense: Activity & Milestones Baby Tracker	Google Play Store	Sense-IT Limited	Parenting	35	Android 5.0 and up	Tracking feeding, diaper, sleep	No
ovia parenting: baby tracker, breastfeeding timer	Google Play Store	Ovia Health	Medical	21	Android 6.0 and up	Tracking feeding, diaper, sleep; Tracking/supporting maternal wellness, developmental milestone checklist, activities to support development (in article form)	Yes
OBAby	Google Play Store	Overlake Medical Center & Clinics	Health & Fitness	30	Android 4.4 and up	Articles about newborn/pregnancy (customizable) care and tracking feeding, diaper, sleep	No
Daily Baby Tracker	Google Play Store	Ugurcan Ozkan	Parenting	8.3	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes
child growth tracker (crawling baby)	Google Play Store	ABQ App Source, LLC	Medical	8.7	Android 4.1 and up	Tracking feeding, diaper, sleep	Yes
Nuttri - Baby Food: Guide to starting solids	Google Play Store	MultiMension Inc.	Parenting	20	Android 4.4 and up	Meal Planner for Child (transition to solid foods)	Yes

Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Nod - Baby Sleep Coach & Feeding Tracker	Google Play Store	Rest Devices, Inc.	Parenting	19	Android 4.1 and up	Sleep Coaching/Tracking and Feeding Tracker	Yes

Newborn & Baby Development Guide	Google Play Store	Parenting Pets Care Tips	Parenting	4	Android 4.1 and up	Quiz/Trivia about child health	Yes
MyPreemie app	Google Play Store	Graham's Foundation	Medical	24	Android 4.4 and up	Growth tracking for premature baby, Parenting advice for premature baby	No
guide to newborn care	Google Play Store	Saleha Group	Parenting	4.4	Android 4.1 and up	Articles about caring for newborn	Yes
hatch baby - activity tracker	Google Play Store	Hatch Sleep	Health & Fitness	51	Android 4.4 and up	Tracking feeding, diaper, sleep	No
Immunization Planner	Google Play Store	NiveshNiti	Parenting	12	Android 4.0 and up	Tracking Immunizations and Developmental Milestone Checklist	Yes
Indian PRegnancy Advice, Baby Care, Parenting Tips	Google Play Store	Parentune - Parenting, Child care Growth Tracker	Parenting	13	Android 5.1 and up	Parenting advice forum (ask doctors/experts, connect with other parents, read articles, chat)	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Indigo. Smart activities.	Google Play Store	baby development app	Parenting	8.9	Android 4.4 and up	Development screening	No
Kiduga: BAby Development	Google Play Store	Kiduga Digital	Parenting	8.1	Android 7.0 and up	Tracking feeding, diaper, sleep	No
kidzgrow child development app	Google Play Store	KidzGrow Aps Pte Ltd	Education	7.3	Android 4.0 and up	Development screening	Yes

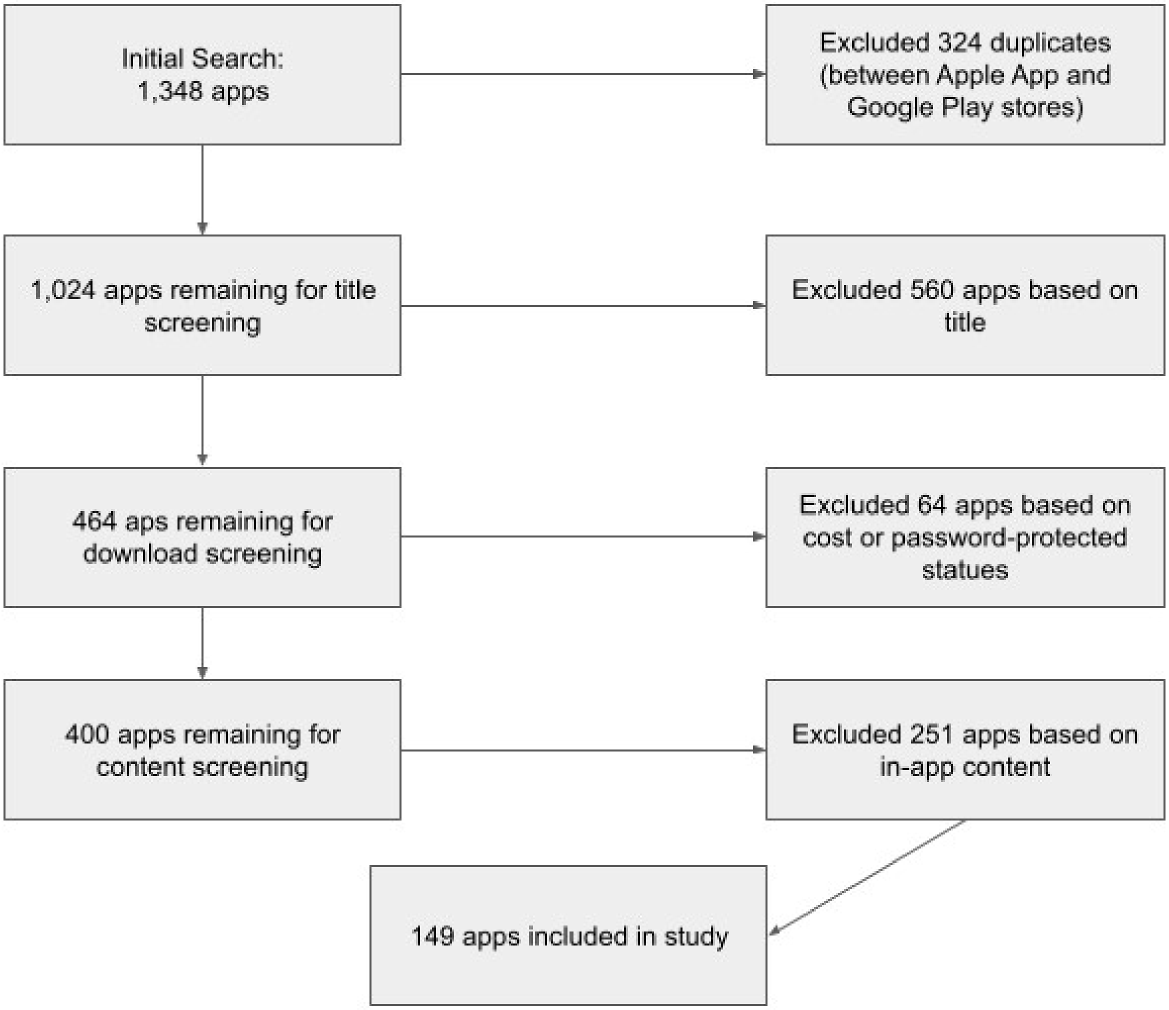
KinderPass: Baby Development, Activities & Classes	Google Play Store	KinerPass Pte Ltd.	Education	54	Android 5.0 and up	Developmental milestones checklist, general parenting advice articles, activities to support baby development	No
Little Ones tm	Google Play Store	LittleONES	Education	12	Android 4.4 and up	Parenting coaching programs, online articles, open forums for parents to communicate	No
mediclinic baby - baby	Google Play Store	Mediclinic (Pty) Ltd	Medical	35	Android 4.1 and up	Focus on pregnancy ddevelopment with month by month information about milestones and development (short paragraph)	No
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Mom And Baby - Love Baby 3000	Google Play Store	RemifasonPR	Parenting	5.4	Android 4.4 and up	Tracking feeding, diaper, sleep	No
mother & baby care	Google Play Store	ALAA Apps	Parenting	16	Android 5.0 and up	Random parenting tips articles	Yes
my baby pediatric growth	Google Play Store	Sistema Informaticos	Health & Fitness	4.1	Android 4.2 and up	Percentiles growth tracker (weight and height), recipes, first foods	Yes
my baby: development tracker app 0-12	Google Play Store	Hylal Health Apps	Parenting	3.7	Android 7.0 and up	Weight and Height Tracker, sentimental photo album, general articles about parenting/activities/tips	No

development of the child up to a year	Google Play Store	identdevelop	Parenting	15	Android 4.1 and up	Articles about parenting and child development	Yes
early child development kit guide	Google Play Store	Grow Together	Parenting	7.5	Android 4.1 and up	Random activities to do with child (not based on age)	Yes
Erby Breastfeeding tracker, pump log & baby diary	Google Play Store	Whisper Arts	Parenting	20	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes
Name of App	App Store	Developer	Category	Size (in MB)	Operating systems supported	Primary features in app	Has in-app advertisements?
Feed Baby - Baby Tracker	Google Play Store	Penguin Apps	Parenting	19	Android 4.1 and up	Tracking feeding, diaper, sleep	Yes
GLOW. Baby Tracker & Feeding, Diaper, Sleep Log	Google Play Store	Glow Inc	Parenting	34	Android 5.0 and up	Tracking feeding, diaper, sleep	Yes
Growth Chart, Development Milestones & Vaccination	Google Play Store	Growth Book	Parenting	10	Android 5.0 and up	Trackng growth, development, food, vaccines, online consultation with provider	No

Table C3: Search Strings by App Store

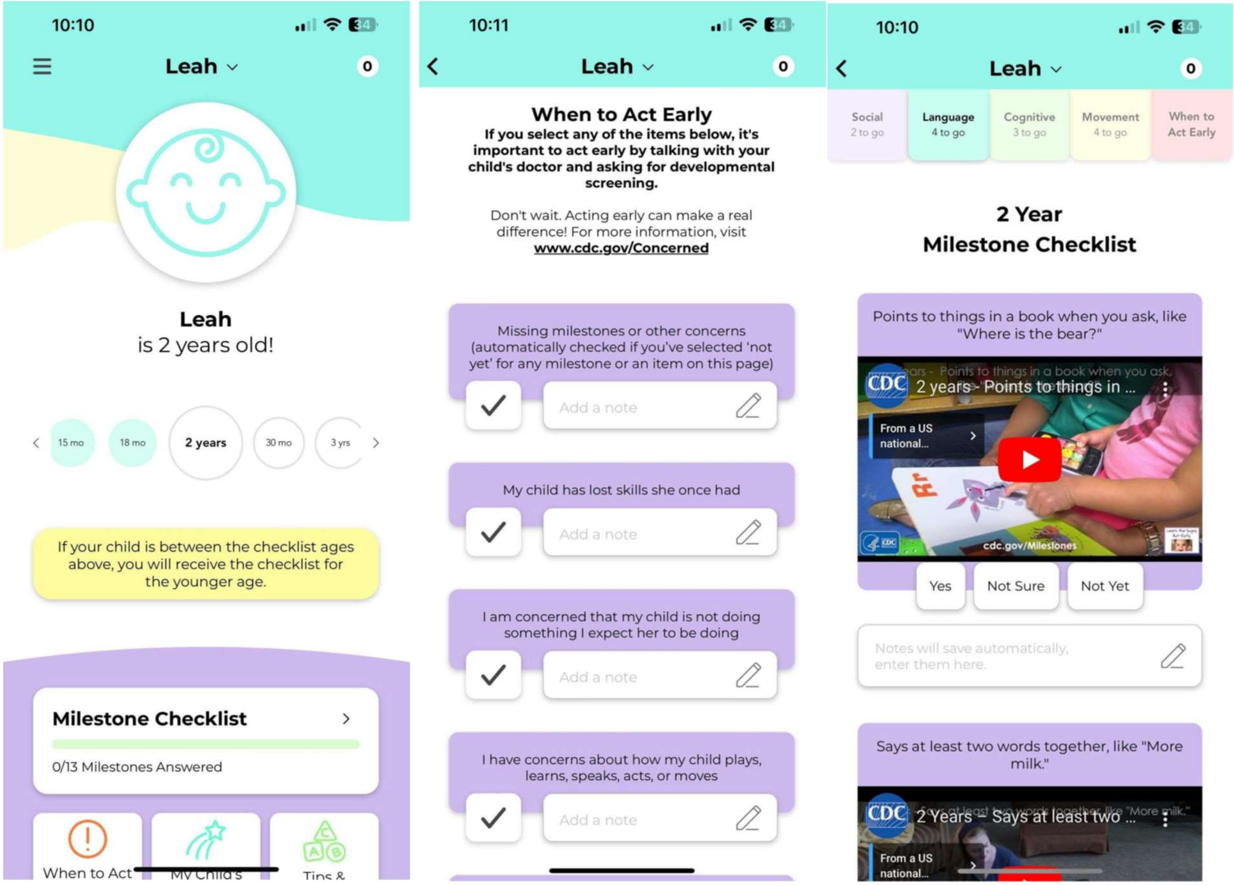
App Store	Search String
Apple App Store	Baby+health Baby+development Baby+milestone Baby+tracking Child+development Child+milestone Child+tracking Child+health
Google Play Store	Baby+health Baby+development Baby+milestone Baby+tracking Child+development Child+milestone Child+tracking Child+health

Figure: Apps Excluded in each step of the screening process



Appendix D: Images of Apps Evaluated to Compare Performance of HTP heuristics and Nielsen’s heuristics

D1: CDC Milestone Tracker



Leah
is 2 years old!

If your child is between the checklist ages above, you will receive the checklist for the younger age.

0/13 Milestones Answered

When to Act Early

If you select any of the items below, it's important to act early by talking with your child's doctor and asking for developmental screening.

Don't wait. Acting early can make a real difference! For more information, visit **www.cdc.gov/Concerned**

Missing milestones or other concerns (automatically checked if you've selected 'not yet' for any milestone or an item on this page)

My child has lost skills she once had

I am concerned that my child is not doing something I expect her to be doing

I have concerns about how my child plays, learns, speaks, acts, or moves

2 Year Milestone Checklist

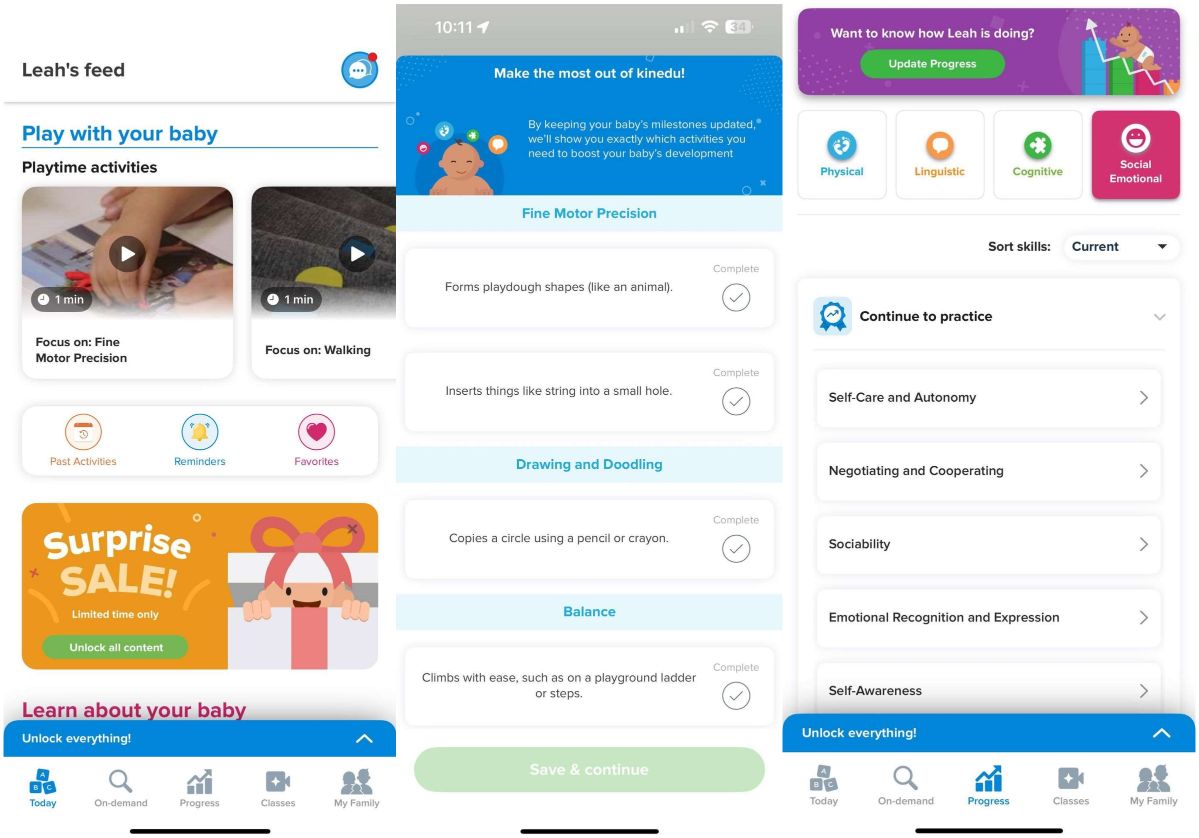
Points to things in a book when you ask, like "Where is the bear?"

Notes will save automatically, enter them here.

Says at least two words together, like "More milk."

Caption: Screenshots from the CDC Milestone Tracker App in April 2024.

D2: Kinedu - Baby Development Plan



By keeping your baby's milestones updated, we'll show you exactly which activities you need to boost your baby's development

Forms playdough shapes (like an animal).

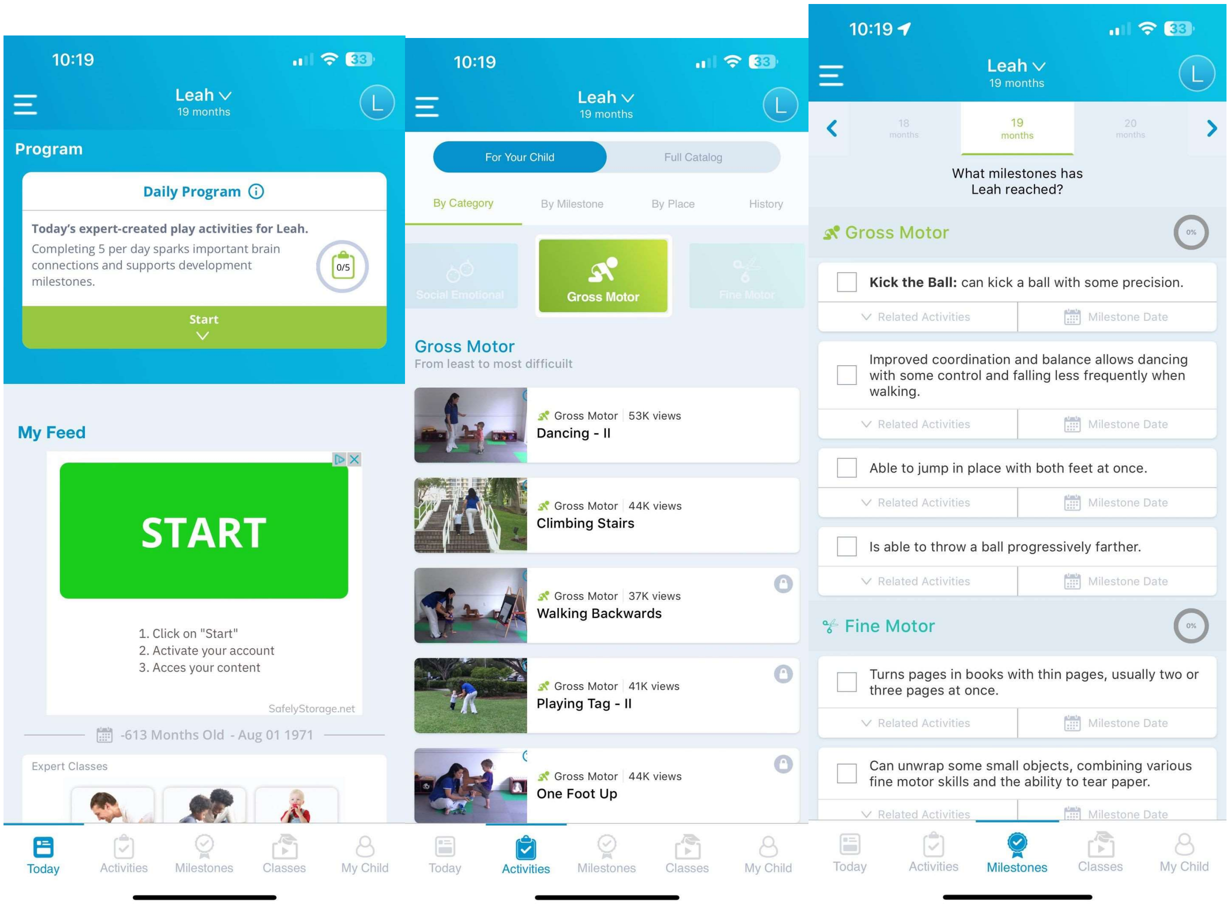
Inserts things like string into a small hole.

Copies a circle using a pencil or crayon.

Climbs with ease, such as on a playground ladder or steps.

Caption: Screenshots from the Kinedu – Baby Development Plan App in April 2024.

D3: BabySparks - Development App



Today's expert-created play activities for Leah.
Completing 5 per day sparks important brain connections and supports development milestones.

1. Click on "Start"
2. Activate your account
3. Acces your content

-613 Months Old - Aug 01 1971

Gross Motor
From least to most difficuilt

- Gross Motor | 53K views — Dancing - II
- Gross Motor | 44K views — Climbing Stairs
- Gross Motor | 37K views — Walking Backwards
- Gross Motor | 41K views — Playing Tag - II
- Gross Motor | 44K views — One Foot Up

What milestones has Leah reached?

Gross Motor

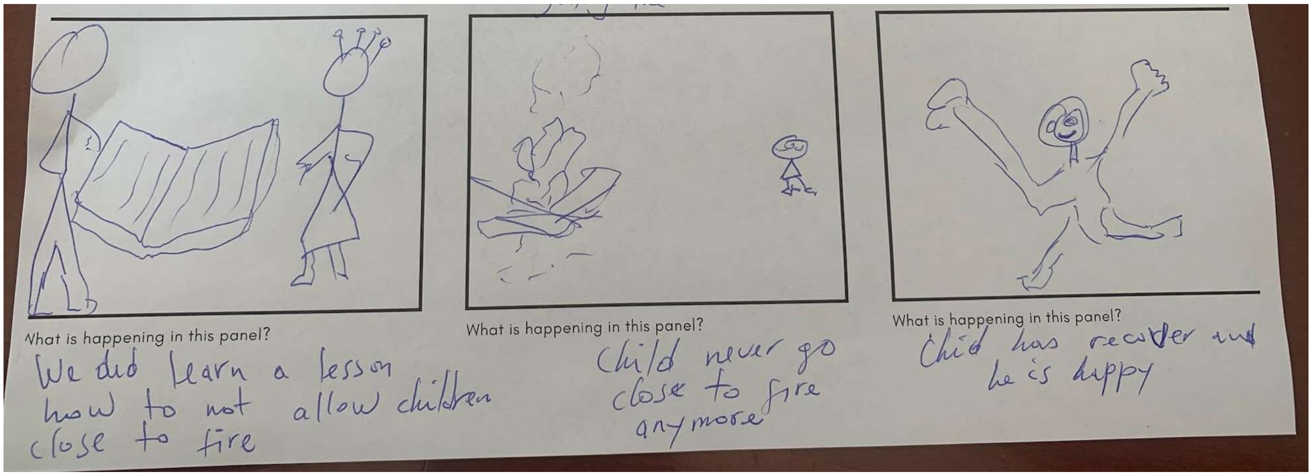
- ☐ **Kick the Ball:** can kick a ball with some precision.
- ☐ Improved coordination and balance allows dancing with some control and falling less frequently when walking.
- ☐ Able to jump in place with both feet at once.
- ☐ Is able to throw a ball progressively farther.

Fine Motor

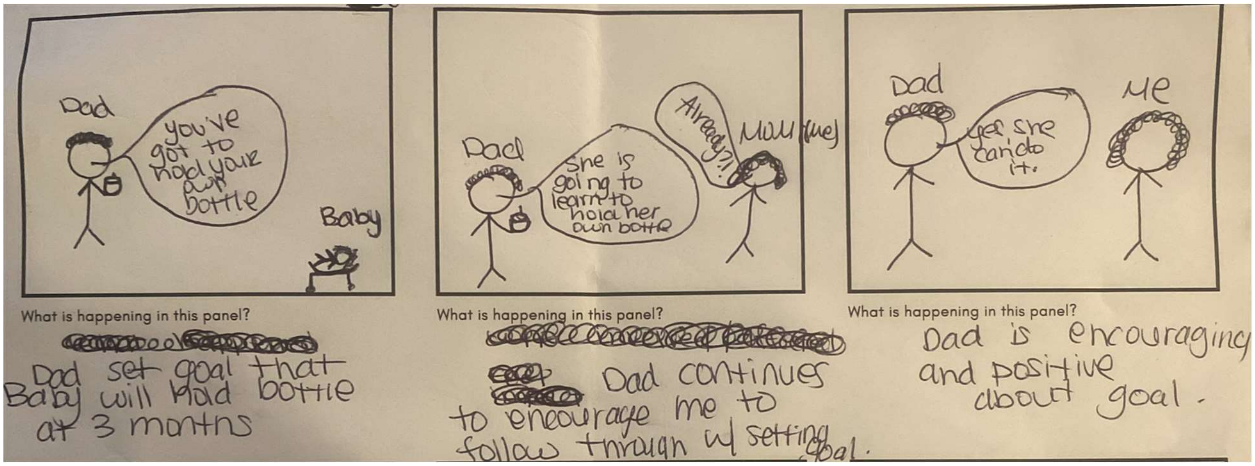
- ☐ Turns pages in books with thin pages, usually two or three pages at once.
- ☐ Can unwrap some small objects, combining various fine motor skills and the ability to tear paper.

Caption: Screenshots from the BabySparks – Development App in April 2024.

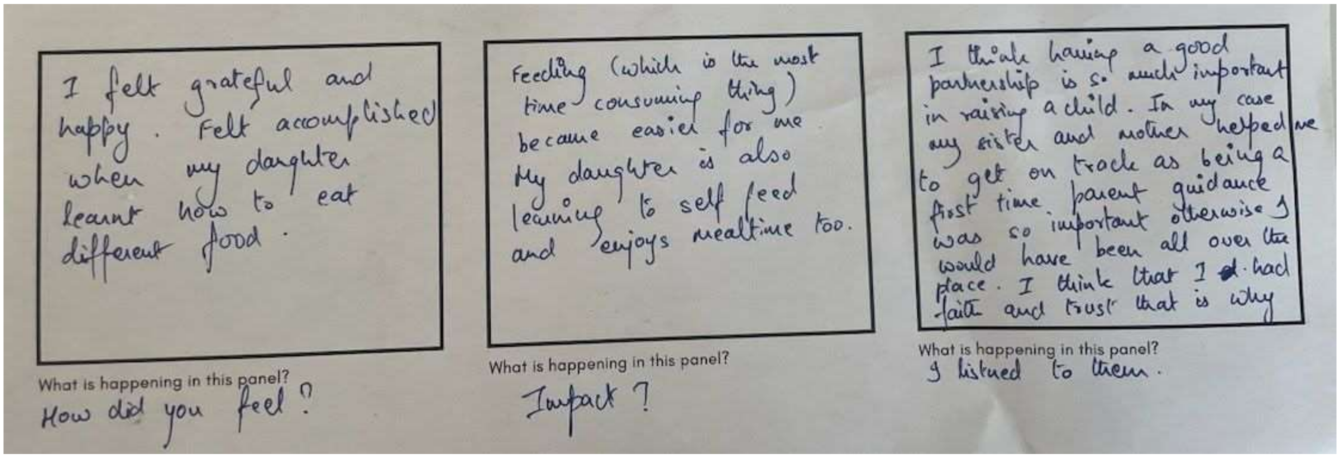
Appendix E: Images from Storyboarding Activity



Caption: A parent's storyboard is shown, where they describe an experience with teaching their child about fire safety. The panel reads, from left to right: "We did learn a lesson. How to not allow children close to fire. Child never go close to fire anymore. Child has recover and he is happy".



Caption: A parent's storyboard is shown, where they describe setting a goal for their child to hold their bottle by 3 months old. The panel reads, from left to right: "Dad set goal that Baby will hold bottle at 3 months. Dad continues to encourage me to follow through with setting goal. Dad is encouraging and positive about goal".



I felt grateful and happy. Felt accomplished when my daughter learnt how to eat different food.

What is happening in this panel?
How did you feel?

Feeding (which is the most time consuming thing) became easier for me. My daughter is also learning to self feed and enjoys mealtime too.

What is happening in this panel?
Impact?

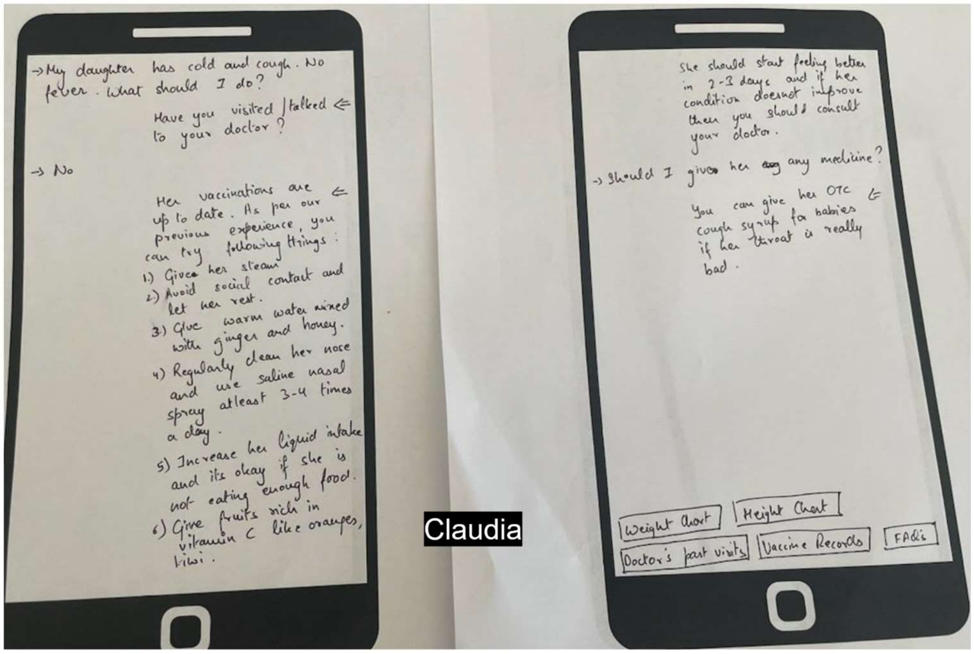
I think having a good partnership is so much important in raising a child. In my case my sister and mother helped me to get on track as being a first time parent guidance was so important otherwise I would have been all over the place. I think that I had faith and trust that is why

What is happening in this panel?
I listened to them.

Caption: A parent’s storyboard is shown, where they describe an experience with helping their child eat a bigger variety of foods. The panel reads, from left to right: “How did you feel? I felt grateful and happy. Felt accomplished when my daughter learnt how to eat different food. Impact? Feeding (which is the most time consuming thing) became easier for me. My daughter is also learning to self feed and enjoys mealtime too. I think having a good partnerships is so much important in raising a child. In my case my sister and mother helped me to get on track as being a first time parent guidance was so important otherwise I would have been all over the place. I think that I had faith and trust that is why”.

Appendix F: Co-Design Ideas Generated by Parents

Below, images illustrating the co-design ideas from each parent are shown.



→ My daughter has cold and cough. No fever. What should I do?

Have you visited / talked to your doctor? ⇐

→ No

Her vaccinations are up to date. As per our previous experience, you can try following things: ⇐

1.) Give her steam

2.) Avoid social contact and let her rest.

3.) Give warm water mixed with ginger and honey.

4.) Regularly clean her nose and use saline nasal spray atleast 3-4 times a day.

5.) Increase her liquid intake and its okay if she is not eating enough food.

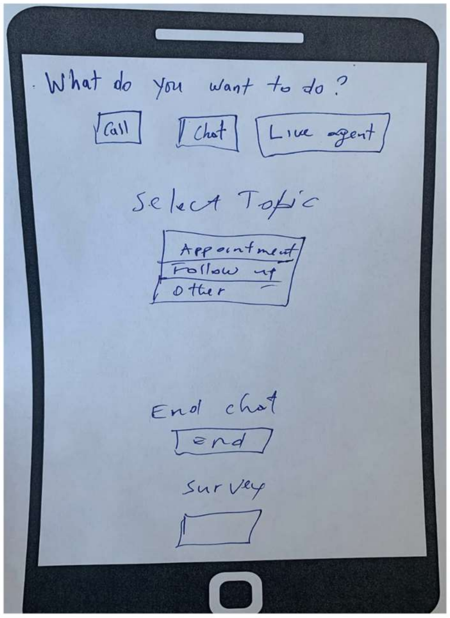
6.) Give fruits rich in vitamin C like oranges, kiwi.

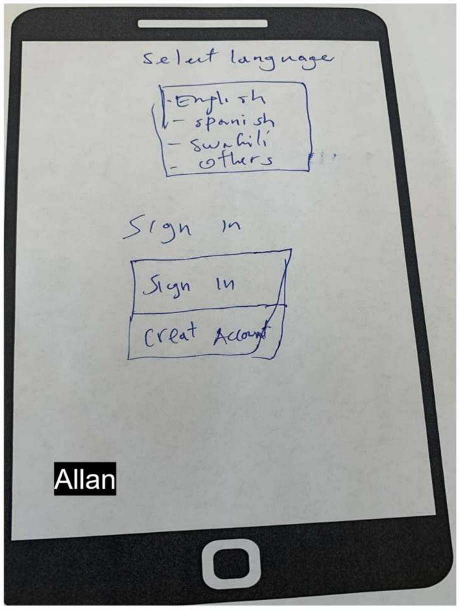
She should start feeling better in 2-3 days and if her condition doesnot improve then you should consult your doctor.

→ Should I give her any medicine?

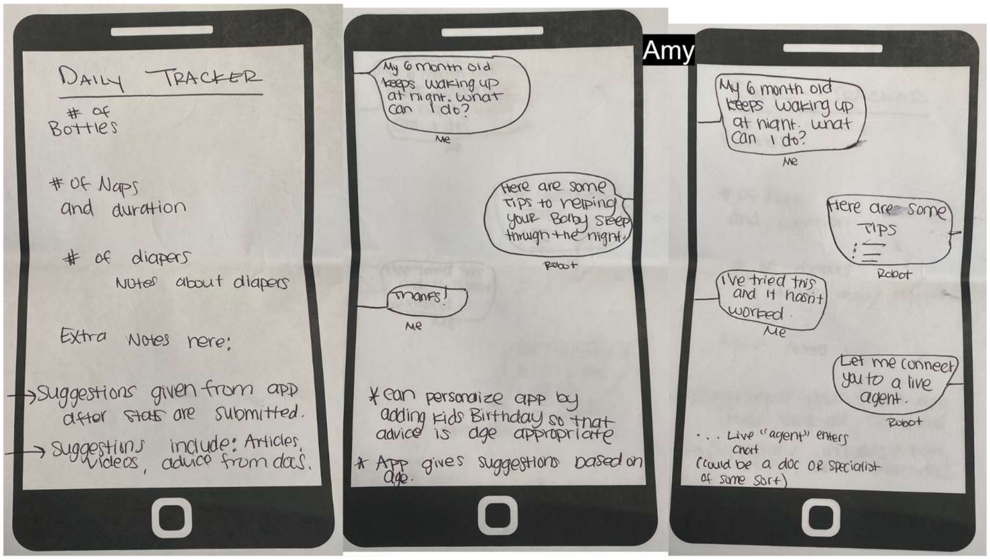
You can give her OTC cough syrup for babies if her throat is really bad. ⇐

Claudia





Allan



DAILY TRACKER

# of Bottles

# of Naps and duration

# of diapers

Notes about diapers

Extra Notes here:

→ Suggestions given from app after stats are submitted.

→ Suggestions include: Articles, videos, advice from docs.

My 6 month old keeps waking up at night. what can I do?

Me

Here are some tips to helping your Baby sleep through the night.

Robot

Thanks!

Me

* can personalize app by adding kids Birthday so that advice is age appropriate

* App gives suggestions based on age.

My 6 month old keeps waking up at night. what can I do?

Me

Here are some TIPS

Robot

I've tried this and it hasn't worked.

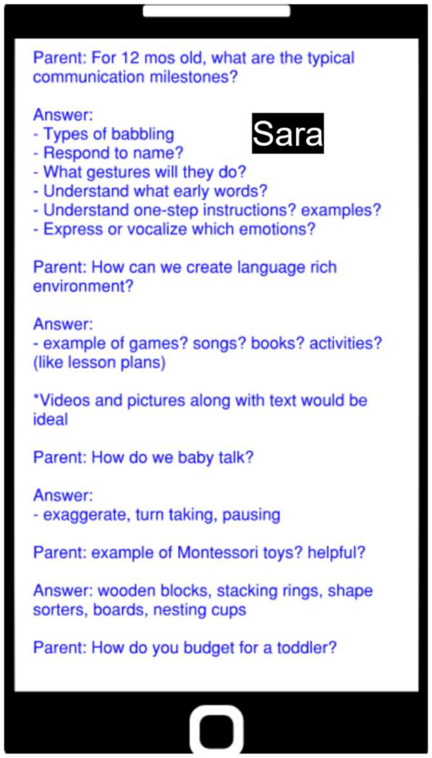
Me

Let me connect you to a live agent.

Robot

. . . Live "agent" enters chat

(could be a doc or specialist of some sort)



Parent: For 12 mos old, what are the typical communication milestones?

Answer:
- Types of babbling
- Respond to name?
- What gestures will they do?
- Understand what early words?
- Understand one-step instructions? examples?
- Express or vocalize which emotions?

Parent: How can we create language rich environment?

Answer:
- example of games? songs? books? activities? (like lesson plans)

*Videos and pictures along with text would be ideal

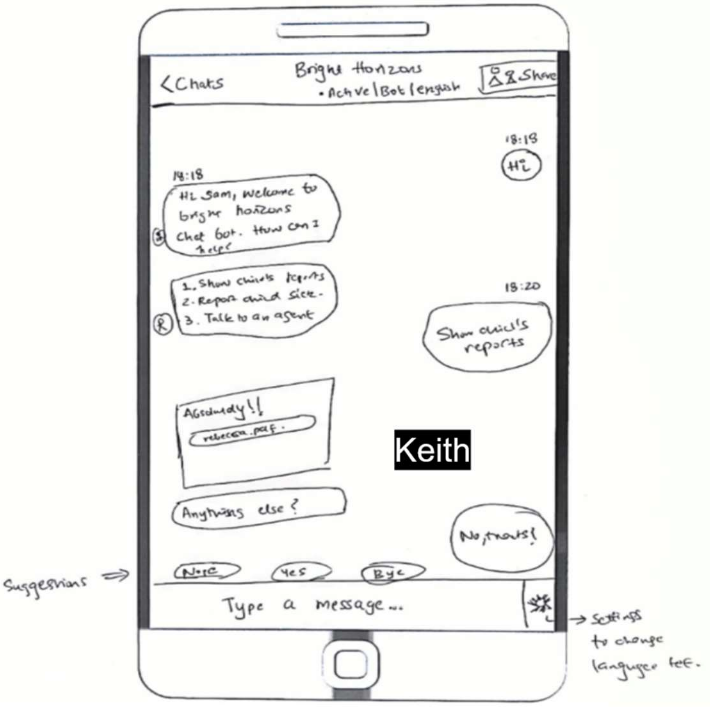
Parent: How do we baby talk?

Answer:
- exaggerate, turn taking, pausing

Parent: example of Montessori toys? helpful?

Answer: wooden blocks, stacking rings, shape sorters, boards, nesting cups

Parent: How do you budget for a toddler?



Hi

Hi Sam, welcome to bright horizons chat bot. How can I help

1. Show child's reports
2. Report child sick.
3. Talk to an agent

Show child's reports

Absolutely!!

rebecca.pdf.

Anything else?

No, thanks!

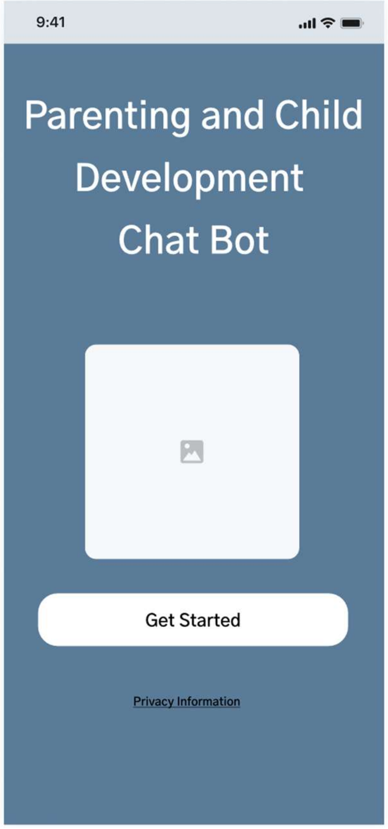
None

Yes

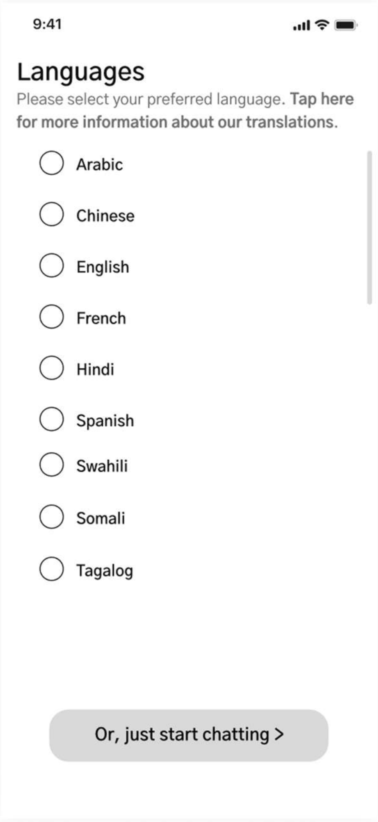
Bye

Type a message...

Appendix G: Images of Final Prototype Generated in Co-Design Study



Parenting and Child Development Chat Bot



Languages

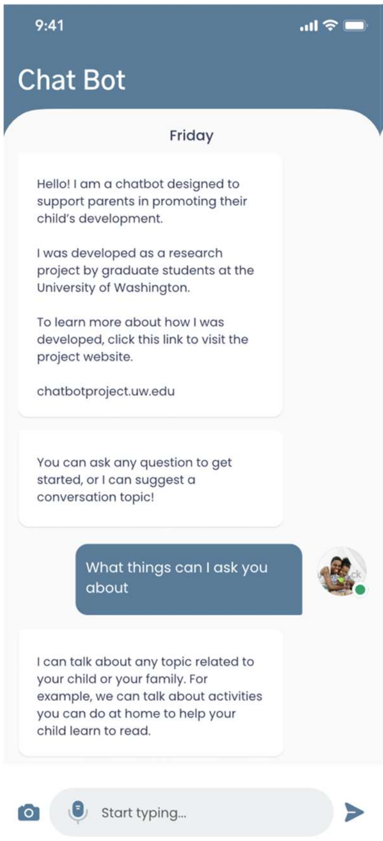
Please select your preferred language. **Tap here for more information about our translations.**

- ○ Arabic
- ○ Chinese
- ○ English
- ○ French
- ○ Hindi
- ○ Spanish
- ○ Swahili
- ○ Somali
- ○ Tagalog

Languages

Please select your preferred language. **Tap here for more information about our translations.**

- ○ Chinese
  - ○ Cantonese
  - ○ Hokkien
  - ○ Wu



Chat Bot

Friday

Hello! I am a chatbot designed to support parents in promoting their child's development.

I was developed as a research project by graduate students at the University of Washington.

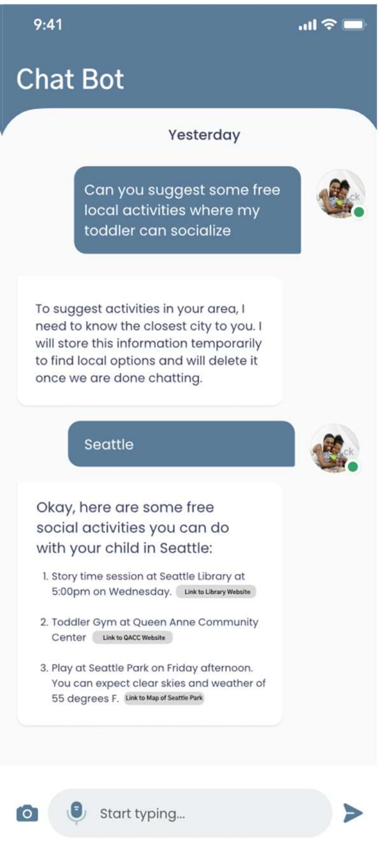
To learn more about how I was developed, click this link to visit the project website.

chatbotproject.uw.edu

You can ask any question to get started, or I can suggest a conversation topic!

What things can I ask you about

I can talk about any topic related to your child or your family. For example, we can talk about activities you can do at home to help your child learn to read.



Chat Bot

Yesterday

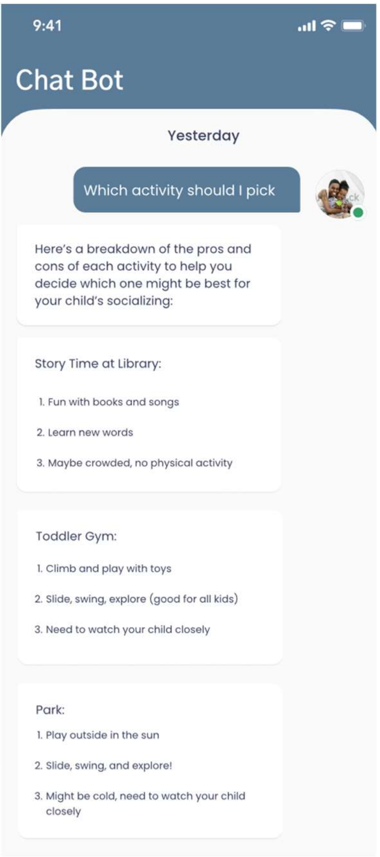
Can you suggest some free local activities where my toddler can socialize

To suggest activities in your area, I need to know the closest city to you. I will store this information temporarily to find local options and will delete it once we are done chatting.

Seattle

Okay, here are some free social activities you can do with your child in Seattle:

1. Story time session at Seattle Library at 5:00pm on Wednesday. Link to Library Website
2. Toddler Gym at Queen Anne Community Center Link to QACC Website
3. Play at Seattle Park on Friday afternoon. You can expect clear skies and weather of 55 degrees F. Link to Map of Seattle Park



Chat Bot

Yesterday

Which activity should I pick

Here's a breakdown of the pros and cons of each activity to help you decide which one might be best for your child's socializing:

Story Time at Library:

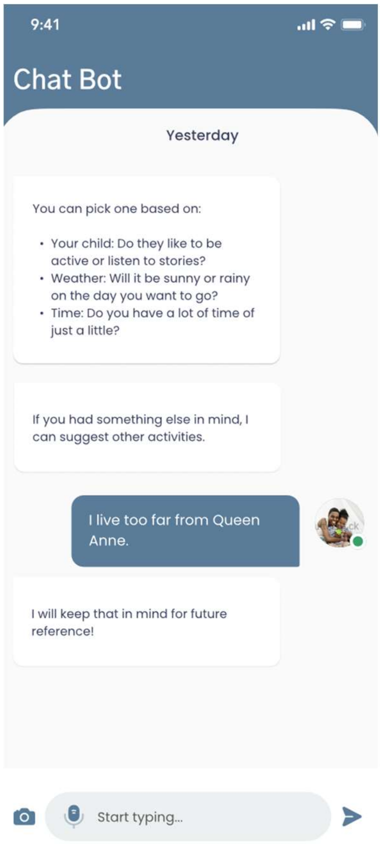
1. Fun with books and songs
2. Learn new words
3. Maybe crowded, no physical activity

Toddler Gym:

1. Climb and play with toys
2. Slide, swing, explore (good for all kids)
3. Need to watch your child closely

Park:

1. Play outside in the sun
2. Slide, swing, and explore!
3. Might be cold, need to watch your child closely



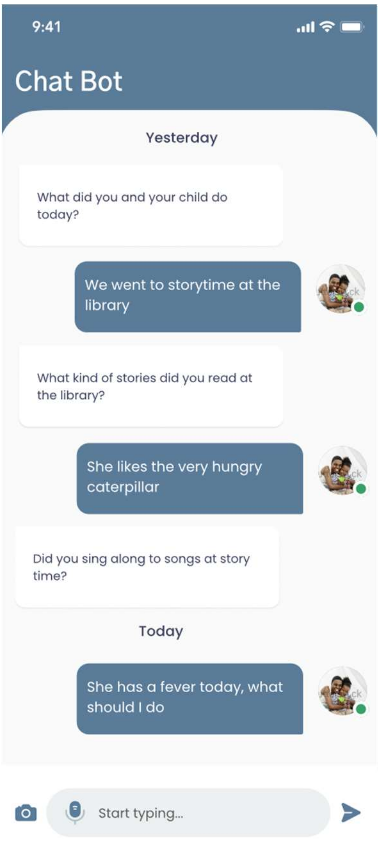
You can pick one based on:

- Your child: Do they like to be active or listen to stories?
- Weather: Will it be sunny or rainy on the day you want to go?
- Time: Do you have a lot of time of just a little?

If you had something else in mind, I can suggest other activities.

I live too far from Queen Anne.

I will keep that in mind for future reference!



What did you and your child do today?

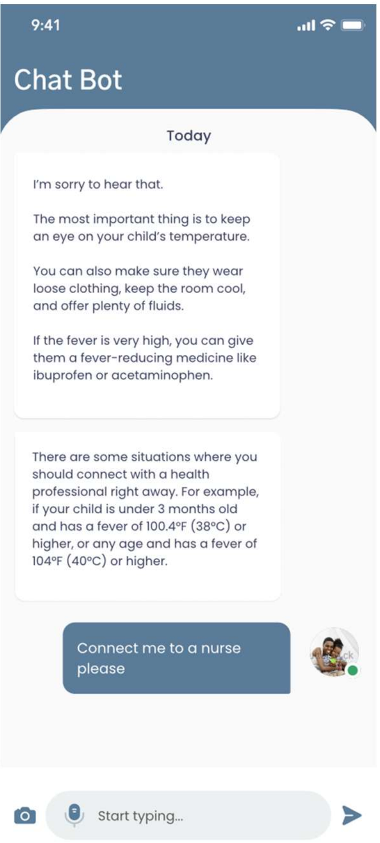
We went to storytime at the library

What kind of stories did you read at the library?

She likes the very hungry caterpillar

Did you sing along to songs at story time?

She has a fever today, what should I do



I'm sorry to hear that.

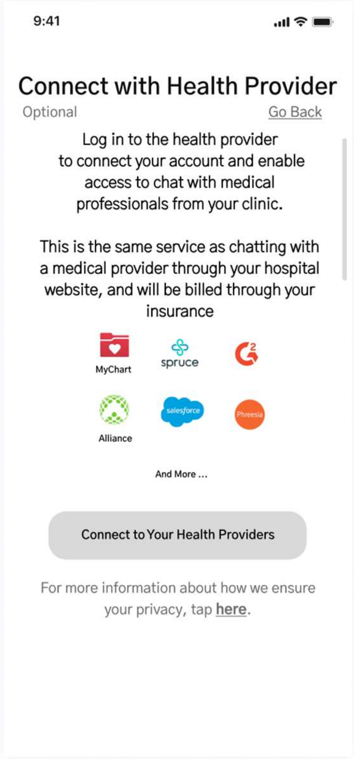
The most important thing is to keep an eye on your child's temperature.

You can also make sure they wear loose clothing, keep the room cool, and offer plenty of fluids.

If the fever is very high, you can give them a fever-reducing medicine like ibuprofen or acetaminophen.

There are some situations where you should connect with a health professional right away. For example, if your child is under 3 months old and has a fever of 100.4ºF (38ºC) or higher, or any age and has a fever of 104ºF (40ºC) or higher.

Connect me to a nurse please



Connect with Health Provider

Optional Go Back

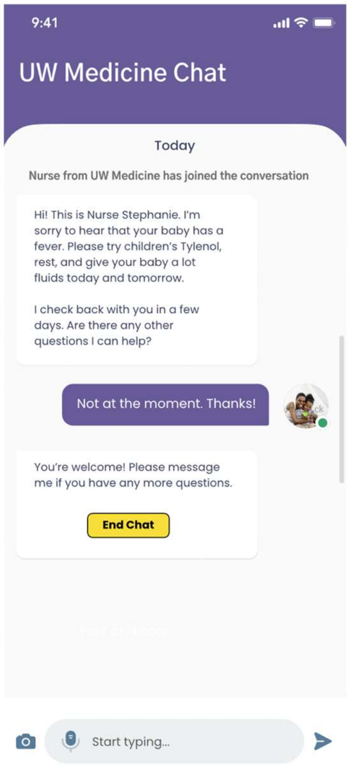
Log in to the health provider to connect your account and enable access to chat with medical professionals from your clinic.

This is the same service as chatting with a medical provider through your hospital website, and will be billed through your insurance

And More ...

Connect to Your Health Providers

For more information about how we ensure your privacy, tap here.



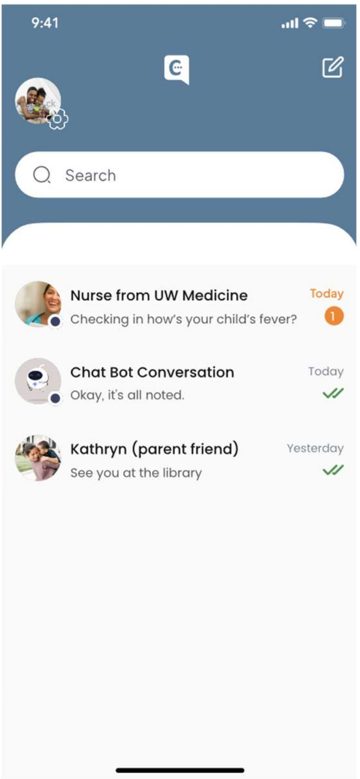
Nurse from UW Medicine has joined the conversation

Hi! This is Nurse Stephanie. I'm sorry to hear that your baby has a fever. Please try children's Tylenol, rest, and give your baby a lot fluids today and tomorrow.

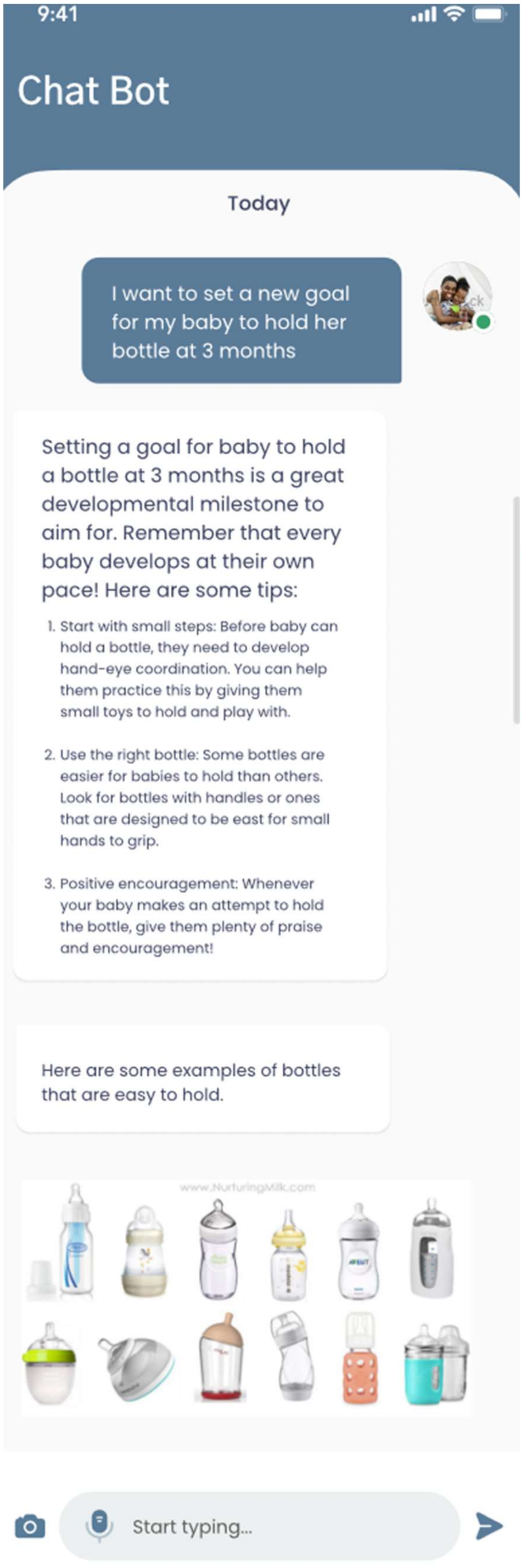
I check back with you in a few days. Are there any other questions I can help?

Not at the moment. Thanks!

You're welcome! Please message me if you have any more questions.



Nurse from UW Medicine	Checking in how's your child's fever?	Today 1
Chat Bot Conversation	Okay, it's all noted.	Today ✓✓
Kathryn (parent friend)	See you at the library	Yesterday ✓✓

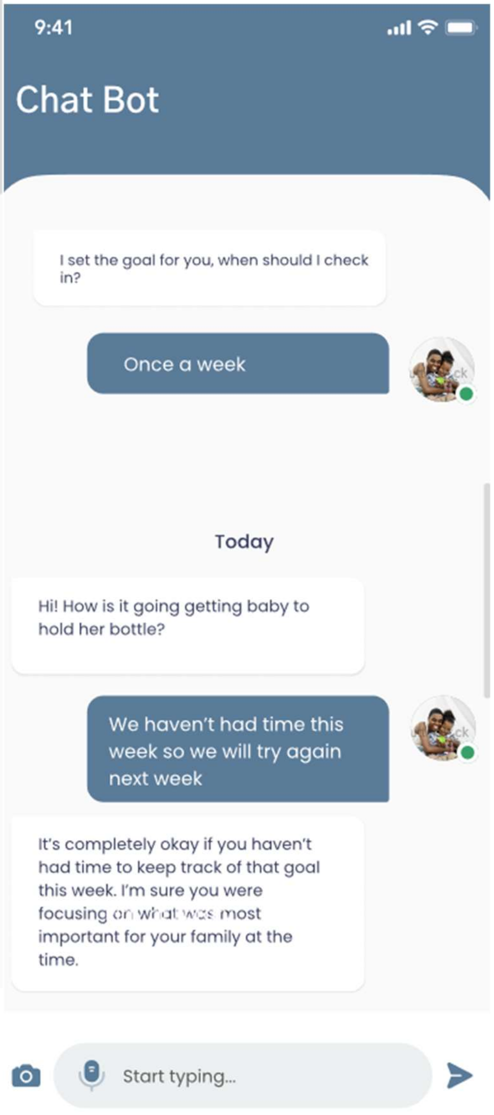


I want to set a new goal for my baby to hold her bottle at 3 months

Setting a goal for baby to hold a bottle at 3 months is a great developmental milestone to aim for. Remember that every baby develops at their own pace! Here are some tips:

1. Start with small steps: Before baby can hold a bottle, they need to develop hand-eye coordination. You can help them practice this by giving them small toys to hold and play with.
2. Use the right bottle: Some bottles are easier for babies to hold than others. Look for bottles with handles or ones that are designed to be east for small hands to grip.
3. Positive encouragement: Whenever your baby makes an attempt to hold the bottle, give them plenty of praise and encouragement!

Here are some examples of bottles that are easy to hold.



I set the goal for you, when should I check in?

Once a week

Hi! How is it going getting baby to hold her bottle?

We haven't had time this week so we will try again next week

It's completely okay if you haven't had time to keep track of that goal this week. I'm sure you were focusing on what was most important for your family at the time.

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