SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

Designing with the Extreme-user Experiences

Submitted by

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Abstract

Extreme-user experiences have a unique potential to enhance designer creativity by altering one's perception of their own designs. This shift in perception is achieved by incorporating the perspectives of extreme-users who experience the latent unmet needs among the rest of the population and have the potential to inspire design professionals. Works in the past have observed this potential (as the extreme-users) among the older adult users and users with reduced physical or cognitive abilities for the products, services, or systems (PSSs) that primarily target the mainstream general population users. While simulated experiences that emulate reduced physical and cognitive abilities are adopted to improve designers' understanding of the needs among such extreme-users, they are seldom applied beyond the realms of assistive and inclusive design solutions, especially as a tool for design creativity. Therefore, there is an opportunity to advance creativity in mainstream PSSs design by systemic adoption of extreme-user experiences. In this thesis, we empirically test the underpinnings of extreme-user experiences and simulated extreme-user experiences for design creativity. We also analyse the necessity and impact of a systematic guided approach using extreme-user inspired design methods that inform designers of the experiences that would enhance the usability of their PSSs design. We finally present a framework that proposes four stages that one could adopt to design with extreme-user experiences. Additionally, we discuss the interactions between the Design Innovation (DI) process model and the proposed Extreme-user Experience Design Framework with which we aim to stretch the frontiers of the mainstream design process.

Compliance with ethical standards

All studies performed involving human participants were in accordance with the ethical standards of either the SUTD-Instituitional Review Board (IRB Approval No: 14-053, S-19-217, 19-258) guidelines for Social, Behavioural and Educational Research (SBER) or the MIT-Committee on the Use of Humans as Experimental Subjects (COUHES Exempt ID: E-2495) guidelines for Educational Testing, Surveys, Interviews or Observation. Informed consent was obtained from all individual participants included in the studies.

List of Publications

Publications included in this Thesis

- Raviselvam, Sujithra, Shiroq Al-Megren, Kyle Keane, Katja Hölttä-Otto, Kristin L. Wood, and Maria C. Yang. "Simulation Tools for Inclusive Design Solutions." In Universal Design 2021: From Special to Mainstream Solutions, pp. 210-218. IOS Press, 2021.

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- Raviselvam Sujithra, Katja Hölttä-Otto, Kristin L. Wood, and Karupppasamy Subburaj. (2019). "An Extreme User Approach to Identify Latent Needs: Adaptation and Application in Medical Device Design." ASME 2019 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers.

- Raviselvam Sujithra, David Anderson, and Katja Hölttä-Otto. (2018). "Systematic Framework to Apply Extraordinary User Perspective to Capture Latent Needs Among Ordinary Users." ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers.

- Poster Presentation: Raviselvam, Sujithra, Karen Sng, and Kristin Wood. (2016). "Design Knowledge and Impact on Simulation Induced Creativity and Empathy." DS86: Proceedings of The Fourth International Conference on Design Creativity, Georgia Institute of Technology, Atlanta, GA, USA. **[Received Best poster award]**

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- Hölttä-Otto, Katja, and Sujithra Raviselvam. (2016). "Guidelines for Finding Lead User Like Behavior for Latent Need Discovery." DS 85-2: Proceedings of NordDesign 2016, Volume 2, Trondheim, Norway, 10th-12th August 2016.

- Raviselvam, Sujithra, Kristin L. Wood, Katja Hölttä-Otto, V. Tam, and Kamya Nagarajan. (2016). "A Lead User Approach to Universal Design-Involving Older Adults in the Design Process." Studies in health technology and informatics 229: 131. DOI 10.3233/978-1-61499-684-2-131.

- Raviselvam Sujithra, Sanaei Roozbeh, Lucienne T. Blessing, Katja Hölttä-Otto, and Kristin L. Wood. (2017). “Demographic Factors and Their Influence on Designer Creativity and Empathy Evoked through User Extreme Conditions.” ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers.

Works not included in this Thesis

- Camburn, Bradley, Ryan Arlitt, David Anderson, Roozbeh Sanaei, Sujithra Raviselam, Daniel Jensen, and Kristin L. Wood. (2020). "Computer-aided mind map generation via crowdsourcing and machine learning." Research in Engineering Design, 31: 383-409.

- Alqadi, Reem, Maryam Alhowaiti, Fatimah Almohaimeed, Mawaddah Alsabban, and Sujithra Raviselvam. (2020). "Crowdsourcing Accessibility: A Review of Platforms, Mobile Applications and Tools." In International Conference on Human-Computer Interaction, pp. 10-17. Springer, Cham..

- Camburn, Bradley, Yuejun He, Sujithra Raviselvam, Jianxi Luo, and Kristin Wood. (2020). "Machine learning-based design concept evaluation." Journal of Mechanical Design, 142, No. 3. **[Winner of the 2020 Journal of Mechanical Design Editor’s Choice Award]**

- Bradley Camburn, Yuejun He, Raviselvam Sujithra, Jianxi Luo, and Kristin L. Wood. (2019). “Evaluating Crowdsourced Design Concepts with Machine Learning” ASME 2019 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers. **[Received Best Paper Award]**.

- Sng Hui En Karen, Sujithra Raviselvam, Lucienne T. Blessing, Kristin L. Wood. (2017). “A design case study: Transferring design processes and prototyping principles into industry for rapid response and user impact." ICED17 21st International Conference on Engineering Design.

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Table of Contents

List of Figures

List of Tables

Chapter 1
Extreme-user experiences: What, why, and how.

"Universal Design is the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design."

-Ron Mace

We begin this thesis by providing an introduction to the extreme-user experiences (what?), the existing gaps, the motivation behind this thesis (why?), and the approaches we followed to addresses the gaps and develop a framework to design with the extreme-user experiences (how?).

1.1 What are extreme-user experiences?

If you like door handles that can be opened without a grip or if you enjoy the subtitles that let you appreciate movies in other languages, then you have been benefitting from products, services, or systems (PSSs) that primarily benefit users with reduced physical and hearing abilities. Similarly, there are various other PSS design solutions that were primarily designed for users with some form of physical or cognitive challenges. Recognition for such PSS led to concepts like "Universal Design," "Inclusive Design," and "Design for All" (S. Burgstahler, 2009; Mikus et al., 2020; Persson et al., 2015; University of Cambridge, 2017b). Though their origin and usage may vary, they all serve a common goal: to design products, services, systems, environments, and facilities for a diverse group of users with varying abilities (Persson et al., 2015).

Past works provide a detailed analysis on this group of users with physical challenges as lead users and demonstrated their role as innovators for universal design solutions (Conradie et al., 2014). Holmquist et al. (2004) and Liikkanen et al. (2009) applied the term "Extreme-user" to refer to users who experience needs that are realised by the rest of the population, and have the potential to inspire design professionals. Liikkanen et al., compare this quality of extreme-users to that of the "Lead users" (Conradie et al., 2014; Urban & von Hippel, 1988) who are not only ahead of the population in experiencing such needs, but also generate solutions to address those needs. While extreme-users could be anyone who is ahead of the rest of the population (Lewrick, 2020), this thesis is interested in the potential of perspectives and needs derived from reduced physical and cognitive abilities. Therefore, this thesis uses the term 'extreme-user' to refer to this user group who experience needs that are latent among the general population and have the potential to inspire design professionals (Liikkanen, 2009; Raviselvam et al., 2019).

With the term extreme-user referring to a specific user group, extreme-user experiences refers to the perspectives and needs that are inspired by the extreme-user interactions with a PSS. The difference in terminology is to distinguish that applying extreme-user experiences is different from engaging the extreme-users. The latter directly involves extreme-users but the former helps designers to design for the extremes that are not accommodated by their designs. Works by Saunders et al. (2011) and Holtta-Otto et al. (2010, 2018) identified functionality, architecture, external interactions, user interactions and cost as the five major characteristics of innovative products. Among which, innovative architecture, enhanced external interactions, and user centred interactions were the most influential. Based on these influential characteristics, we may shortlist user-interaction extremes, and other environmental and spatial extremes (external interactions), that influence user's experience with a PSS for the extreme-user experiences. In this thesis, we specifically study the impact of extreme-user experiences derived from reduced physical and cognitive abilities that influence user interactions, and briefly discuss other contextual extremes that influence the impact. Now that we have a better understanding of what they are, we will move on to why we want to use extreme-user experiences.

1.2 Why extreme-user experiences?

Awareness of concepts like inclusive design, universal design, and design for all has grown extensively over the past decade. Consequentially, nations and leading organisations are seeking to incorporate these concepts across their designs (John Clarkson & Coleman, 2015; *Microsoft Design*, 2018). To be more specific, the needs experienced by extreme-users are situationally experienced by the general population users as well (Vanderheiden, 2000). For example, a design that addresses the needs of users with reduced or no hearing ability would help the general population when they are within a noisy environment or an environment where they cannot rely on sound to capture attention. A range of products that are used by the general population derived their inspiration from the needs experienced by users with some form of physical challenges. Typewriters, Fiskars scissors that accommodate ambidextrous usage, OXO good grips (McAdams & Kostovich, 2011) that provide kitchenware that provides better grip, and recent inventions like Folks Kitchenware (*Folks Kitchenware for the Blind*, 2018) and Eatsy (Mistry, 2020) that accommodate the cooking and dining needs of users with visual impairments are a few examples of such extreme-user inspired products that are preferred among the general population users. For example, both OXO Good Grips and Fiskars were designed based on the needs experienced by a niche population, such as users with limited hand strength and users with arthritis.

To demonstrate this impact, Raviselvam et al. (2016) found that individuals from the general population would prefer products that had been altered to meet the demands of older adult users when compared to the products currently available in market. The study results showed that around 89% of general population participants and 90% of the older adult participants preferred the day-to-day products redesigned to accommodate the needs of older adult users. Surprisingly, the response was even so for the products that did not receive any design criticism among the general population users. For example, only 8% of the general population participants experienced any need to redesign the existing design of the pull tab on soda cans. Yet 100% of the general population participants preferred the redesigned soda can that provided space to position their finger below the pull tab.

With promising results that demonstrates the potential of designing for extreme-users, design science research tested the potential of simulated extreme-user experiences both as a tool to help understand extreme-users and as a tool for design creativity (Colwell, 2013; Genco et al., 2011; Lin & Seepersad, 2007). Though these perspectives are never a replacement for actual users, they add value to designers' engagement with the actual users (Kullman, 2016). Works that tested the effect of simulations and simulated scenarios demonstrated that such extreme-user experiences enabled designers to identify needs (Lin & Seepersad, 2007) and concepts (She et al., 2018) that benefitted from the extreme-user perspectives. These previous research show that the extreme-user experiences are a great resource that leverages the differences in human abilities and transfers that knowledge for a more successful design outcome. Despite this prevalence and awareness of the advantages of extreme users and simulated experiences, their applications are generally limited to assistive and inclusive design solutions. As a result, a deeper understanding of their benefits, limitations, and strategies to adapt them for mainstream design is essential.

There are various ways to leverage extreme-user perspectives and needs, such as direct user engagement, user observation, and other approaches for user need analysis (Lauff et al., 2021; Lewrick et al., 2018; Otto & Wood, 2001; Ulrich et al., 2019). Wearable simulations are one such approach, and their unique feature is that they help obtain a first person experience about ability-based constraints associated with a design. By simulation, we refer to practical experiences that impose physical and cognitive challenges and encourage design practitioners to experience a perspective that is unlike their own and potentially identify insights beyond the typical user population. Inspirational to this thesis are the works on Empathic Lead User (ELU) and Empathic Experience Design (EED). The ELU and EED approaches studied the impact of simulated extreme-user experiences with associated factors and evidence for user-need gathering (Lin & Seepersad, 2007) and concept generation (Johnson et al., 2014). Both ELU and EED impose physical restrictions that simulate the challenges experienced by extreme-users, thereby enabling the designers to experience a product, service, or system from an extreme-user perspective. These approaches provide supportive evidence on the impact of the perspectives derived from extreme-user experiences. Though past works have demonstrated that the extreme-user perspectives and simulations are capable of identifying needs that are latent among the general population users (Raviselvam et al., 2014; Raviselvam et al., 2016b). They are, however, not extensively used in mainstream design. This thesis seeks to evaluate the potential value of extreme-user experiences in mainstream design and presents a framework for incorporating them into an existing design process.

1.3 How does this thesis contribute to extreme-user experiences?

Design methods provide a systematic guidance to approach design opportunities, where they are applied according to their role along in different phases or iterations of a design process. Recent works on inclusive design look at applying the perspectives of users with different types of reduced physical abilities along the design process. For example, Microsoft has an entire toolkit that guides users to derive design insights by considering the needs of such extreme-users, including needs from situational lack of ability (*Microsoft Design*, 2018). Similarly, the works of Engineering Design Centre at the University of Cambridge have led to tools and methods that extensively support Inclusive Design (Waller et al., 2015). Some of the design methods adopted by such tools for inclusive design include user personas that comprise users with diverse abilities, scenarios that include the needs of diverse users, physical challenge simulation tools, and contextual research (Mikus et al., 2020; University of Cambridge, 2017b).

Existing design processes for inclusive design refer to the ability of these approaches to generate creative design solutions. However, adopting such extreme-user perspectives as a tool for design creativity, which reveals users' latent needs, is rarely explored. This is especially true with PSSs, which may or may not be utilised by extreme-users with reduced physical or cognitive abilities, such as medical devices handled by healthcare professionals. In this thesis, we adopt a set of design methods that aim to address this gap in adoption of extreme-user perspectives as a tool for design creativity. The empirical studies presented in this thesis strengthen the understanding of some of the approaches used for inclusive designs and how they could be adopted for mainstream design solutions. Activity Diagrams (+Journey Map), Morphological Matrix, Contextual Need Analysis (CNA), and Scenarios are the design methods adopted in this thesis to facilitate systematic application of extreme-user experiences.

The key goal of this research is to understand ways to adopt extreme-user experiences as a tool for user-centric PSS design. Figure 1-2 illustrates the structure and flow of this thesis. Chapters 2 to 6 are organised to answer five research questions that shape the extreme-user experience design framework.

We begin to answer this in Chapter 2 with two foundational studies that establish our basic understanding of extreme-user experiences. The first foundational study analysed the impact of simulated scenarios to emulate extreme-user experiences by measuring design empathy and creativity among the participants. Outcomes of this study showed that the simulated scenarios that present extreme-user experiences have a significant impact on design empathy and creativity. This outcome helped answer the first research question: **How effective are simulated extreme-user experiences at enhancing design outcomes?**

Although the results are positive and exciting, it was still unclear as to how the different types of simulated experiences could be adopted for different design opportunities. Therefore, the second foundational study tested if the type of extreme-user experience appropriate for a design should be selected based on the designer's intuition or through a systematic application approach that guides them through the process. The outcomes of this study show that a guided approach is significantly more impactful than intuition based selection of extreme-user experiences. Thereby answering our second research question: **If simulated extreme-user experiences are impactful, how might we select the extreme-user experience(s) appropriate for a specific product service or system?**

Using the foundational studies, we could understand the potential of extreme-user experiences and the advantages of having a guided approach to adopt extreme-user experiences. To be widely adopted as a tool for PSS design, the extreme-user experiences need to have a significant impact for PSS that are not essentially or exclusively designed for extreme-users. The situational demands encountered by the general population users indicate the needs that are prominent among extreme-users but latent among the general population users. Then how about extreme-user simulations that are "situational"? Would they have the same effect as extreme-user simulations that were "direct"? We analyse this difference in Chapter 3 and infer that the situational extreme-user simulations produce more inclusive design concepts when compared to the direct extreme-user simulations by answering the research question: **Do design outcomes differ between direct extreme-user experiences simulated scenarios and situational extreme-user experience scenarios? If so, how could we accommodate the differences in the extreme-user experience design framework?**

The findings from previous chapters are then used to explore methods for systematic application of extreme-user experiences to elicit design innovation and hidden insights. Two such modifications of the design methods employed for medical device design and inclusive privacy and security, respectively, are described in Chapters 4 and 5. Outcomes from both these chapters are used to answer the next research question: **How effective are the guided systematic approaches to adopt extreme-user experiences?**

In Chapter 6, we formulate the findings from our studies and finally present a framework that embeds the adopted design methods across the 4D's design process followed by the Design Innovation

(DI) team (Camburn et al., 2017; (DI) Learning Modules, 2021; Lauff et al., 2019; Lauff et al., 2021; Seow et al., 2018; Tiong et al., 2019; Tushar et al., 2020) at the Singapore University of Technology and Design (SUTD). This design process is inspired from the UK Council's 4D's model, and distinctively combines concepts and foundations from design thinking, business model innovation, design engineering, and systems thinking. Figure 1-1 shows the description for each phase of the design process. Using the framework, we answer our final research question: **How do the overall findings of this research contribute to designing with the extreme-user experiences?**

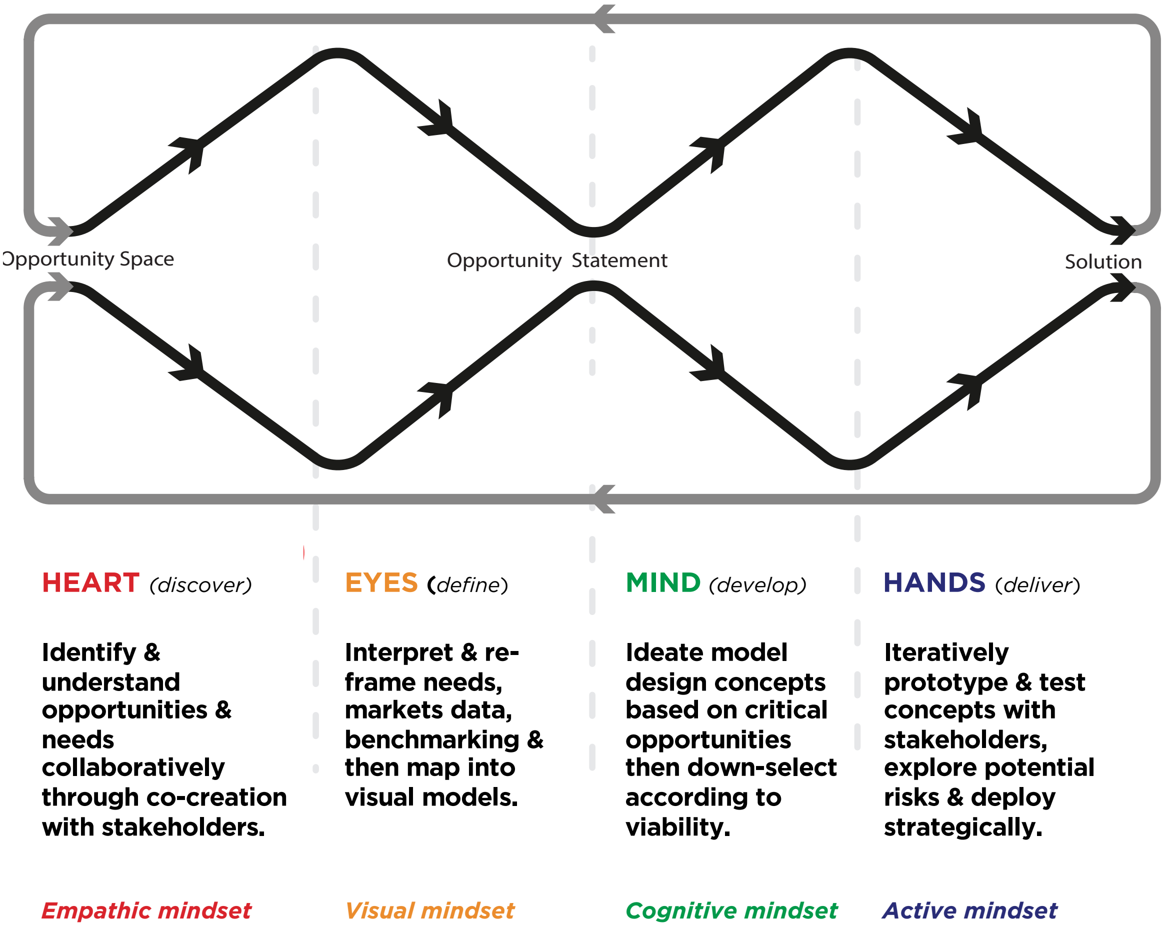


Figure 1-1 4Ds Design Process (((DI) Learning Modules, 2021; Lauff et al., 2021))

We conclude this thesis by sharing th key findings, interesting opportunities for designing with extreme-user experiences, and some limitations that are to be considered in the future.

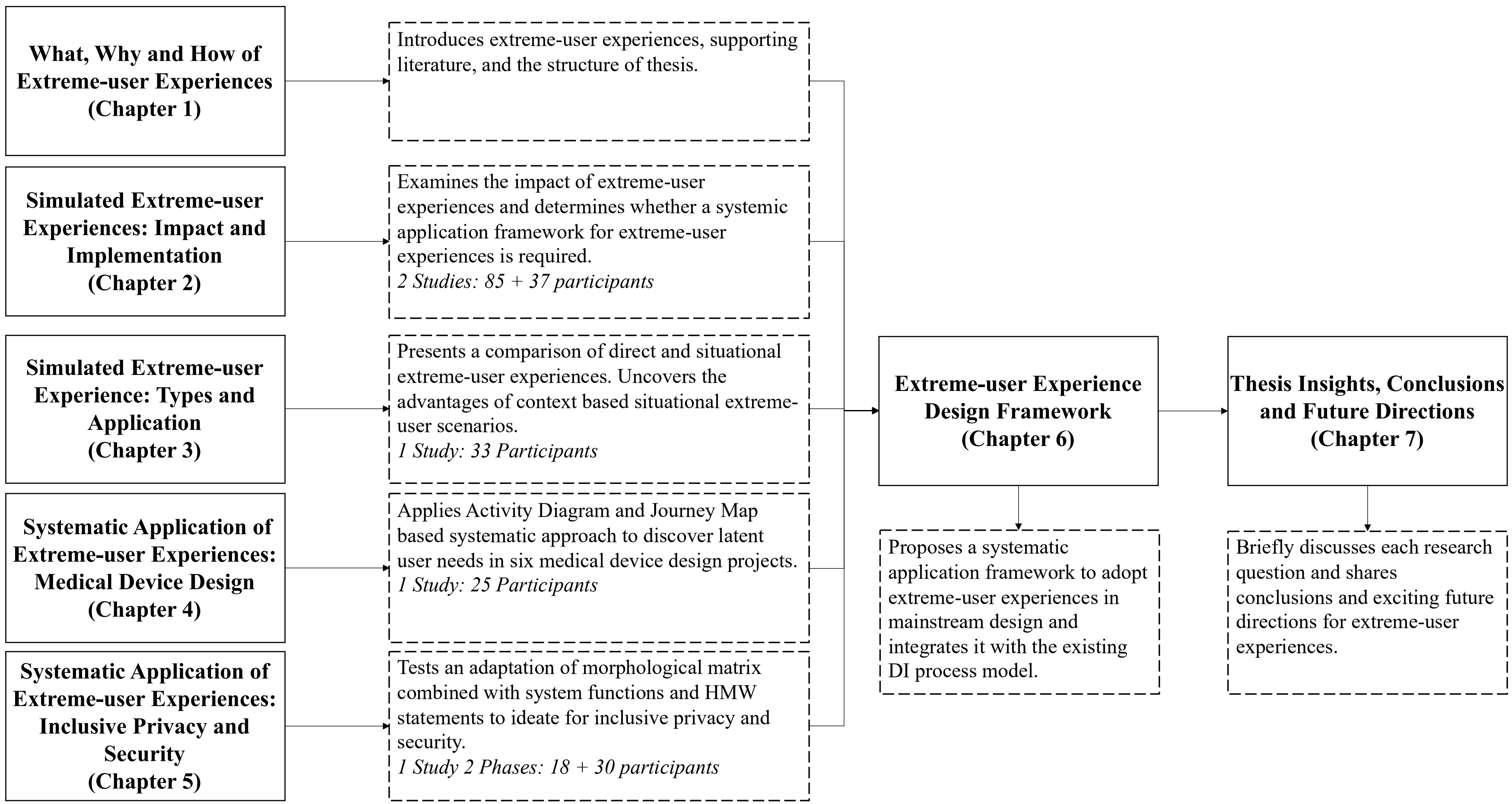


Figure 1-2 Structure of the Thesis

1.4 Key Terminologies

The literature presents us with a rich variety of terms regarding user groups and design concepts used in this research. Despite the fact that this thesis leverages the most on the perspectives of users with some form of physical or cognitive challenges, we do not want the term extreme-user experiences to be confined to user abilities alone. Some of the design methods we discuss in this thesis allow other extremes like environmental and contextual factors to complement the user ability-based extremes. Therefore, this section presents a mix of established terms combined with terms specifically adopted for this thesis.

***General-population user*:** The average majority users of a product, service, or system (PSS).

Extreme-user: Extreme-user populations comprise the group of users whose needs are different from that of the general population of users of a product, service, or system (PSS). They experience needs that are latent among the general population and have the potential to inspire design professionals (Liikkanen, 2009; Raviselvam et al., 2019). For example, the older adult users and users with reduced physical or cognitive abilities would be examples of extreme-users for a product that primarily focuses on the mainstream general population users.

Extreme-user experiences: The Cambridge English Dictionary refers to experience as the process of getting knowledge or skill from doing, seeing, or feeling things (Cambridge University Press, 2021). Extreme-user experiences refer to the process of getting knowledge or skill from doing, seeing, or feeling things inspired by adopting extreme-user perspectives.

Situational extreme-user experiences: Refers to getting knowledge or skill from doing, seeing, or feelings things inspired from instances that highlight the similarity in needs experiences by extreme-users and general population users. The term 'direct extreme-user experiences' will be used to represent extreme-user experiences when applied along with situational extreme-user experiences.

Simulation tools or Emulation tools: Devices that help experience extreme-user inspired perspectives like reduced vision, reduced physical strength, or reduced mobility.

Simulated extreme-user experiences: Refers to practical experiences that impose physical challenges and encourage design practitioners to experience a perspective that is unlike their own and potentially identify insights beyond the typical user population.

Design Methods: Systematic approaches for accomplishing specific design activities with an improved likelihood of success (Camburn et al., 2017; Cross, 2021; Jones, 1992; Otto & Wood, 2001). Design methods likewise provide a language for design to enable communication amongst designers and teams, and enable designers to create results beyond their experiences and intuition.

Design Process: A design process is "the set of activities by which designers develop and/or select the means to achieve a set of objectives, subject to constraints." (Tate & Nordlund, 1996).

PSS: Product, Service, or system.

Chapter 2
Simulating Extreme-user Experiences: Impact and Implementation

"Our need will be the real creator"

-Plato, 375 BC

Simulation tools are widely adopted in different regions of the world and in different circumstances to achieve an empathic design experience. A wide range of ideation tools and techniques are available for designers and design teams to enhance creativity (Amabile et al., 2019; Daly et al., 2012; Genco et al., 2012; IDEO, 2021; Jensen et al., 2009; Koronis et al., 2021; Lauff et al., 2021; So & Joo, 2017; White et al., 2012). Past research works have led to various tools and techniques to help designers understand specific user interactions with their designs; including wearable simulations (Battarbee et al., 2014; Goodman et al., 2008; Immel et al., 2014). A unique advantage of wearable simulations is that they could transform a designer's interaction with a design by providing a first-person experience of perspectives that are unlike their own. Thereby encouraging them to address the challenges they might have failed to visualise otherwise. This influence could be due to the increase in understanding of the challenges faced by the extreme-user population (Cardoso & Clarkson, 2012; Hosking et al., 2015). Especially, extreme-user experiences are more distil and are usually incomprehensible in a traditional design environment. Therefore, we adapted simulated extreme-user experiences as our core tool to convey extreme-user experiences.

In this chapter, we share two research works that analyse two different aspects of extreme-user experiences. The first research examines the impact of simulated extreme-user experiences as a tool for design empathy and creativity. We present a compilation of two workshops that empirically tested the impact of simulated extreme-user experience scenarios on design creativity among 72 (Study 1: 36; Study 2: 36) participants. Concepts from the workshop participants are compared with the concepts shared by 13 participants with visual impairments using a novel metric adopted from psychology to calculate empathic accuracy. We also share the impact on design empathy through self-evaluations from workshop participants.

The second study uses a pilot systematic application approach for extreme-user experiences and tests if there is a need for a systematic framework to implement them. Answering a similar question, Persad et al. (Persad et al., 2006) combined sensory, cognitive, and motor demands in their exclusion calculation approach to systematically comprehend the population of users who are not allowed to use a product. Their approach was to highlight the necessity for inclusive design, and they used user interactions that excluded extreme-users from using their design. We wanted to test if a similar approach might be used to inform on the extreme-user experiences that a PSS could accommodate. We analyse its impact on 39 (Group 1: 20; Group 2: 17) participants based on the number of latent needs that they could identify with and without adopting the extreme-user experiences.

2.1 Impact of Extreme-user Experiences

The study discussed below analyses the impact of simulated scenarios with visual impairment as an extreme-user experience. This work is under review for the International Journal of Design Creativity and Innovation (IJDCI) under the title Extreme-user Conditions to Enhance Design Creativity and Empathy- Application Using Visual Impairment. Following the SUTD policy on the inclusion of previously published work, we are including the work in its submitted form.

Co-authors include Dr Dongwook Hwang, Dr Bradley Camburn, Karen Sng, Dr Katja Hölttä-Otto, and Dr Kristin L Wood.

Raviselvam, S., Hwang, D., Camburn, B., Sng, K.H.E., Hölttä-Otto, K., Wood, K.L. (Under Review) Extreme-user Conditions to Enhance Design Creativity and Empathy- Application Using Visual Impairment. *International Journal of Design Creativity and Innovation.*

2.1.1 Abstract

Extreme-users who experience physical, sensory or cognitive challenges can help identify latent needs across a majority of the general population users. Identifying these latent needs may open doors to novel products, services, or systems. The empathic design techniques of simulation tools and scenarios allow designers to experience some extreme-user perspectives. However, research still lacks a thorough understanding of the potential impact of such techniques, especially their potential to address latent needs. This paper strengthens the understanding of simulation tools and scenarios by analysing two workshops that applied simulated scenarios to empathise with users with visual impairments and adapts an empathic similarity metric to evaluate the empathic outcomes in addition to self-evaluated empathy. In addition to empathy, creativity is also measured for the concepts shared by 36 (x2) workshop participants and 13 participants with visual impairments. Empirical analysis of the results supports the potential of simulated scenarios in evoking participant creativity and empathy while being tested under two sequences of controlled studies.

2.1.2 Introduction

Empathising with users is either a direct or indirect common goal for many need-finding and user-study techniques such as contextual need analysis, journey maps and personas (Brown, 2008; Camburn et al., 2017; Chasanidou et al., 2015; (DI) Learning Modules, 2021; Green et al., 2009, 2005, 2006, 2004; Tushar et al., 2020). Moreover, products, services, or systems that enhance end-user interactions have proved to be successful in the market (Hölttä-Otto et al., 2018; Saunders et al., 2011). Reported research in the past few years has applied empathic modelling as a methodology that encourages designers to empathise with their end-users (Johnson et al., 2014). Consequently, empathic conditions and tools have been developed to improve user interaction in a more resource-efficient way to communicate certain perspectives of the users to and with designers (Battarbee et al., 2014; Goodman et al., 2008; Immel et al., 2014), especially the perspectives of extreme-users. Extreme-users are users whose experiences are more distal to the designer and thus more difficult to capture in a traditional design context. Common examples are older adult users or users who experience any form of physical or cognitive impairment or disability (Hannukainen & Hölttä-Otto, 2006; Raviselvam et al., 2016b).

An extreme-user perspective not only helps to understand the extreme-user population, but it also helps identify latent needs among the general population users (Hannukainen & Hölttä-Otto, 2006; She et al., 2018; Vaughan et al., 2015). With the potential to identify needs that are latent among the general population users, simulating extreme-user perspectives could be one way by which designers may evaluate and design inclusive design solutions (Clarkson et al., 2013). Although an ideal case would be to actively engage extreme-users in all aspects of design development, simulated extreme-user experiences possess the potential to evoke creativity among designers (Genco et al., 2011) and co-creation with users (Frow et al., 2015; Kohler et al., 2011; Sanders & Stappers, 2008).

Simulated extreme-user experiences have thus far been applied to ideate for a specific product or a specific goal, like understanding the user needs for a rehabilitation device (Vaughan et al., 2015), or generate design concepts to improve an existing design (Hannukainen & Hölttä-Otto, 2006; Johnson et al., 2014; Lin & Seepersad, 2007). This study rather tested the impact of a set of simulated experiences and captured participants' responses via open-ended questions to understanding the diverse potential of such simulated experiences. Outcomes of this study contribute to the understanding and usage of such extreme-user perspectives, especially as a tool to address latent, otherwise unidentified, needs. This is one of the initial steps to verify if simulated extreme-user scenarios could help designers identify the needs and generate ideas that they would not consider under normal circumstances.

2.1.3 Background Literature

Extreme-users in Design

The term 'Extreme-user' is not new in literature. Holmquist et al. (2004) and Liikkanen et al. (Liikkanen, 2009) applied the term extreme-users to refer to users who experience a need that is rarely experienced by the rest of the population and has the potential to inspire design professions. Liikkanen et al. compare this quality of extreme-users to that of the "Lead users" (Conradie et al., 2014; Urban & von Hippel, 1988) who are not only ahead of the population to experiencing such needs but also generate solutions to address those needs. Conradie (Conradie et al., 2014) provided a detailed analysis on the potential of users with disabilities as lead users and demonstrated their role as innovators for universal design solutions. A similar study considered general characteristics of empathic lead users with associated factors and evidence for user-need gathering (Lin & Seepersad, 2007). Building on these works, our study recognises users who experience some form of physical or cognitive impairment(s) as extreme-users with a potential to inspire design professionals. A range of products that are used by the general population users has derived their inspiration from such extreme-users. For example, shared in Figure 2-1, both OXO good grips and Fiskars were designed based on the needs experienced by a niche population, such as users with limited hand strength and users with arthritis.

Figure 2-1. OXO Good Grips Vegetable Peeler (left) and Fiskars Scissors (right)

To further support the potential of such extreme-users, Raviselvam et al. (Raviselvam et al., 2016b) showed that a set of day-to-day products redesigned to address the needs experienced by the older adult users, primarily due to their physical challenges, was accepted with great appeal among the general population users. The study results showed that 89% of the general population participants preferred the products that were motivated by the needs shared by the older adult users, even under situations where they were satisfied with the existing design of those products. Likewise, a recent study on Kickstarter showed that an extreme-user inspired product, OneHandPlate, that allows users to consume food with a single hand was among the most highly funded from a group of 200 product launch campaigns (*Onehandplate*, 2020; Srinivasan et al., 2020). Given the potential of extreme-user perspectives in design innovation, one such extreme-user perspective is the primary focus of this in-depth study. Especially the change in creativity and empathy as they experience the simulated scenarios.

Simulating Extreme-user Experiences

By simulation, we refer to practical experiences that impose physical challenges and encourage design practitioners to experience a perspective that is unlike their own and potentially identify insights beyond the typical user population. Though simulations are never a complete substitute for real users, wearable simulations that restrict physical abilities or create situational disabilities have been tested and proven to be effective among both practitioners (Cardoso & Clarkson, 2012; Kullman, 2016; She et al., 2018) and design students in identifying contextual needs (Green et al., 2006; Lin & Seepersad, 2007) of a targeted extreme-user population. For instance, Sakamoto Aged Simulation Suit (Sakamoto Model Corporation, 2021), Adam Rouilly Age Simulation Set (Adam, Rouilly, 2021), and Ford's third age suit that simulate the challenges faced by the extreme-users (The Engineer, 2016) are exemplar cases where the simulation tools have been applied for younger adults to empathise with the older adult users. Moreover, the past two decades have seen growing research in simulation tools and their applications in inclusive design research (Langdon et al., 2010; Zitkus et al., 2013), education (Nicolle & Maguire, 2003), products (Thomas, 2013) and user-interface design (Giakoumis et al., 2014). Specifically as a means to encourage an empathic approach to understand extreme-user interactions. Kullman (Kullman, 2016) explored this potential of simulations and suggested ways to implement them as design tools that could help understand bodily complexities rather than tools that represent the experiences of users with physical challenges (extreme-users). Based on his curated case studies on wearable simulations, Kullman also highlighted the importance to understand the 'learning curves' (Latour, 2004) achieved by such wearable simulations.

Among the works that leveraged on simulated extreme-user perspectives, the Empathic Experience Design (EED) and Empathic Lead User (ELU) approaches applied the simulation tools to empathise with an extreme-user population to generate novel design concepts (Genco et al., 2011) and needs (Vaughan et al., 2015) respectively. Both EED and ELU impose physical restrictions that simulate the challenges experienced by an extreme-user population, thereby enabling the designers to experience a product, service, or system from an extreme-user perspective. The work presented in this paper is derived from the EED approach and extends to test the influence of a set of simulated scenarios over concept ideation and design empathy.

Creativity in Design

Creativity, one of the essential 21st-century skills (Geisinger, 2016; World Economic Forum, 2020), has been a key element of engineering design for decades (Cropley, 2016; White et al., 2012). The literature discusses two types of creativity for 'Innovation Design', namely the out-of-the-box creativity that leads to unconventional new ideas and the creativity that leads to breakthrough by connecting existing yet unrelated concepts (Taura & Nagai, 2017). To leverage the complete potentials of human creativity, the design research community has studied various internal and external triggers that enhance the same (Välk & Mougenot, 2019). The simulated scenarios studied in this paper were also designed as an internal trigger to help designers emotionally experience and exhibit groundbreaking, unconventional creativity. Initially associated solely with arts and aesthetics, design research in the past few decades has often strived to understand, define, and measure creativity (Gero & Milovanovic, 2020; Sarkar & Chakrabarti, 2011; Starkey et al., 2015). While creativity in designers could be influenced by factors like their interaction with a product (Bairaktarova et al., 2016) and designer's previous experiences (Hu & Reid, 2018), priming designers, especially with simulated extreme-user perspectives, proved to be effective at evoking designer creativity (She et al., 2018). Measuring creativity in engineering design, thus far, has been defined and evaluated by different means such as novelty, originality, variety, aesthetics, usefulness, and generalizability (Oman et al., 2013; Plucker et al., 2004; Sarkar & Chakrabarti, 2011; Starkey et al., 2015).

Among the factors that help measure creativity, novelty appears common across all evaluations for creativity in engineering design, and a few insist on the usefulness of a concept as well (Sarkar & Chakrabarti, 2011). With various dimensions of creativity being prominent areas of interest among design experts (IJDCI, 2013), it was important for us to define how we interpret and measure creativity while considering the limitations of a workshop based study, especially the end goal of the workshop, which was to build empathy for the targeted extreme-user population (users with visual impairments). A recent brain and behavioural study by Jung et al. (Jung et al., 2015) demonstrated the association between divergent thinking and creativity, thereby supporting the association between quantity and creativity. Since this study replicated the initial stages of ideation where divergent thinking is helpful, we focused on quantity, variety, and novelty of generated concepts as a measure of creativity. Therefore, the ideation performance of the participants of this study was evaluated based on the approach by Shah et al. (Shah et al., 2003) and Moreno et al. (Moreno et al., 2014), with minor modifications.

Empathy in Design

The term empathy is more than a century old, and its incorporation into design research has been prevalent over the past two decades. Empathy, an essential factor to enhance user-centred design, was adopted into design research from the field of psychology (Kouprie & Visser, 2009; McGinley & Dong, 2011; Nicolle & Maguire, 2003). Since then, research in phycology and cognition has contributed immensely to our current understanding of empathy in design. For example, Bairaktarova et al.(Bairaktarova et al., 2016) tested various empathic design techniques and showed that empathy in design leads to feasible design solutions that accommodated the end-user experiences. It was highlighted by Surma-aho et al. (Surma-aho et al., 2018) that such empathic perspectives, when tested among novice designers, is more likely to be adopted during the early stages of the design process during which the primary focus is entrusted on the end-users. Whereas Dalton and Kahute (Dalton &

Kahute, 2016) recommend empathy as an essential element throughout the process. They also suggest that immersing oneself to experience end-user perspective is one of the effective approaches to empathise. The definition for empathy by Cuff et al. (Cuff et al., 2016) refers to empathy as,
"an emotional response (affective), dependent upon the interaction between trait capacities and state influences… The resulting emotion is similar to one's perception (directly experienced or imagined) and understanding (cognitive empathy) of the stimulus emotion, with recognition that the source of the emotion is not one's own".

Likewise, design research states perspective and ethical empathy are recommended as the two important steps to attain empathy in design (Gasparini, 2015; Heylighen & Dong, 2019). While ethical empathy relies on the designer's personal motivation to empathise with the end-users, our work focuses on perspective empathy, where the designer physically experiences the end-user perspectives. Simulated experiences being one of the immersive ways to empathise with end-user perspectives, they have been applied to attain perspective empathy in fields like nursing(Bas-Sarmiento et al., 2019), product design (Cardoso & Clarkson, 2012), psychology (Ando et al., 2011), and user-interface design (Giakoumis et al., 2014). Ways to measure outcomes of empathy has also grown extensively. This ranges from approaches as simple as self-evaluated empathic ratings (Bas-Sarmiento et al., 2019; Gerdes et al., 2010; Hojat et al., 2018) to analysis as detailed as the physiological signals (Chang-Arana et al., 2020). Among the existing measures for empathy, the empathic accuracy scale derived from the works of William Ickes (1983), and a simple self-evaluated empathy scale was used to analyse our data.

2.1.4 Research Aims

The primary aim of this work is to highlight the as yet unknown potential of simulated extreme-user perspectives and the challenges encountered while applying them for design creativity and empathy. We conducted two workshops with students and professionals, as part of a government agency supporting and enabling persons with disabilities, that introduced participants to experience scenarios with simulated visual impairment. The workshops included a briefing session on the experiences of users with visual impairments, followed by controlled studies related to design creativity and empathy. This paper discusses the outcomes of both the workshops while answering the following research questions:

(1) How does a simulated extreme-user (visual impairment) perspective impact participant creativity and empathy?

(2) How does a Briefing (awareness, knowledge) about the extreme-user experiences influence the impact of the Simulated Scenarios (activities)? What are the combined and independent effects of a Briefing and Simulated Scenarios?

2.1.5 Research Methodology

Overview

We studied two workshops that applied a simulated extreme-user experience to understand the impact of an extreme-user perspective on participant creativity and empathy. Briefings and Simulated Scenarios on visual impairment were used to help the workshop participants understand users with visual impairments.

To capture the impact achieved throughout the workshop, data collection was executed along three different dimensions: (i) Pre-Workshop: Prior to the commencement of the workshop, (ii) Post-Briefing: Once the participants receive a Briefing on users with visual impairments, and (iii) Post-Simulation- After experiencing a series of Simulated Scenarios. During Study 1 (S1), the workshop began with a Briefing followed by the Simulated Scenarios. S1 was conducted as part of a project sponsored by a Singapore public sector agency, implemented by a Singapore based NGO- ETCH Empathy (*ETCH Empathy*, 2019). The briefings were incorporated into the S1 workshop by ETCH Empathy as an approach to provide basic knowledge on the targeted extreme-user population. Therefore, a Post-Briefing questionnaire was included with a curiosity to understand the impact of such Briefing on creativity and empathy and the specific impact of the simulated scenarios.

Due to the default structure of the workshops, S1 could not test the influence of the order in which the Briefing and simulated scenarios were presented. Hence, Study 2 (S2) was designed particularly to verify the independent and combined effect of the Simulated Scenarios and the potential influence of Briefings over the impact achieved from the Simulated Scenarios. Therefore, participants of S2 were recruited and assigned into two groups at random. Group 1 experienced the Simulated Scenarios followed by a Briefing, and Group 2 had the Briefing followed by the Simulated Scenarios. This chapter presents the findings of these two studies and discusses the impact of Simulated Scenarios in evoking creativity and empathy among the participants and the influence of Briefing in attaining the same.

Study Participants

S1 participants comprised students and professionals from the Singapore community with interest in and who volunteered for the workshop topics regarding the life challenges of people with physical disabilities and challenges and opportunities for improved inclusion. A total of 36 participants volunteered for this workshop and gave their consent to take part in the study. Participants' age group ranged from 18 to 55 with an average of 24.

As for S2, another group of 36 participants were recruited. Group 1 comprised 16 participants (Age range: 19-29; Average age: 23) and Group 2 comprised 20 participants (Age range: 19-35; Average age: 26). Participants were all graduate or undergraduate students or researchers who volunteered for the study by responding to an email that informed them about the study workshop. No monetary incentive was provided for the workshop participants to take part in the studies.

In addition to the participants in S1 and S2, 13 participants with visual impairments were interviewed to verify the empathic impact of the workshops. The interviews took place at the Singapore Association of The Visually Handicapped (SAVH) (*Singapore Association of the Visually Handicapped*, 2019). The participants with visual impairments received a gift voucher worth 5 Singapore Dollars as a token of appreciation for their time and participation. All procedures were executed as approved by the SUTD Institutional Review Board (IRB).

The Experimental Design

Figure 2-2 shows a flowchart of the research approach followed for both of the studies. Three question categories were collected to represent and understand the workshop outcomes, depending on the type of study and the corresponding workshop stages (Figure 2-2): (1) demography, (2) concept generation and (3) empathic self-evaluation. The sections that follow explain further about the corresponding workshops, the methods and the metrics used for study analysis.

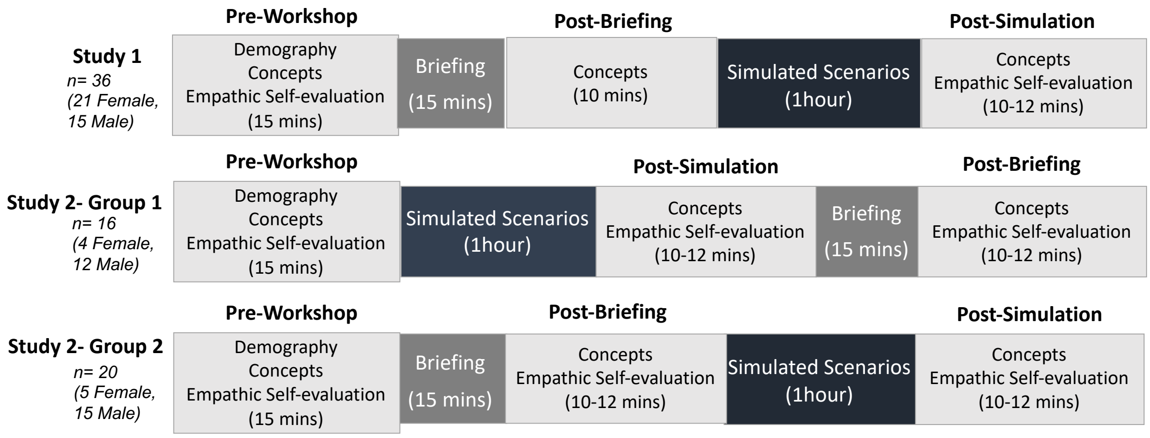


Figure 2-2 Research approach

The workshop segments commenced only after the participants gave their consent to take part in the study. As illustrated in Figure 2-2, the participants answered a set of questions presented during the Pre-Workshop, Post-Briefing and Post-Simulation stages for approximately 10-15 minutes each. These questions included exercises where participants identified issues for persons experiencing visual impairment, followed by the generation of as many concepts as possible to address the issues. Concepts generated by the participants were specific responses to the following instruction:

'Please list as many potential solutions as possible to help solve the issues you listed. (You can even sketch them if they are design solutions)'.

Similar to the workshop participants, the 13 participants with visual impairments were asked to list the issues they usually experienced and the potential solutions to help solve those issues. The Briefing segment provided a 15-minute information session on visual impairment. The Simulated Scenarios provided a one-hour simulated experience on visual impairment. The detailed procedure for each segment is explained in the sections that follow.

Briefing

During the Briefing session, participants were initially asked about their current knowledge about visual impairments, and they were then given an explanation on different types of Visual impairments, including the challenges faced by people with visual impairments. To understand the different types of impairments, the participants were given glasses that simulated those visual impairments (Figure 2-3). The glasses were used only to help participants learn about the different types of visual impairments. Participants were later introduced to CCTV (closed-circuit television) systems, used as video magnifiers by people with visual impairments for magnified viewing. Participants also participated in demonstrations about the use of a white cane that is commonly used by people with visual impairments. The only difference between the Briefing provided during S1 and S2 is that the latter used more detailed exemplar articles on the lives of people with visual impairment instead of the CCTV magnifiers introduced during the S1. Towards the end of Briefing, the participants received information on how people with visual impairments manage with their loss of sight, how they navigate from place to place, different types of visual impairments that exist, challenges associated with vision, and a few assistive devices that are currently in use.

Figure 2-3. A workshop participant viewing a computer screen using visual impairment simulation glasses

Simulated Scenario

For the Simulated Scenarios, the participants were split into five groups with six to eight participants per group. Participants experienced all the Simulated Scenarios within a dark room, where their visual abilities were inhibited. Due to the darkroom experience, the participants were led by volunteers with actual visual impairments throughout the workshop. Participants were exposed to four different scenarios: (1) a bus stop, where they attempt to board a particular bus; (2) a garden, where they attempt to identify an artificial lavender smell; (3) a fruit market, where they seek to differentiate different fruits by taste; and (4) a house, where they navigate through the entrance, living room and dining space. Each group (of participants) followed the previous group as one group moved from one scenario to the other. Figure 2-4 illustrates the layout of the simulated scenarios experienced by the workshop participants while being led by a volunteer with visual impairment.

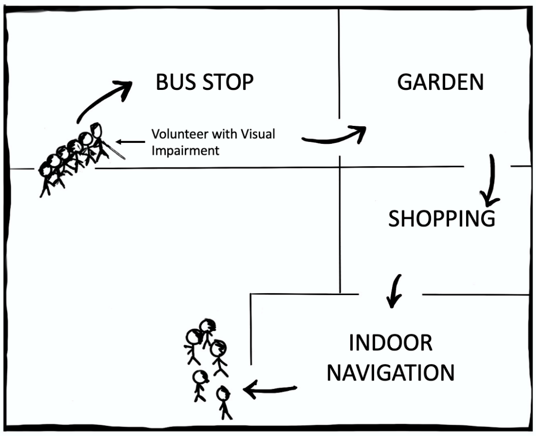


Figure 2-4. Experimental setup for the simulated experience

The ultimate goal of the Simulated Scenarios was to assist the participants in realising and experiencing the challenges faced during every day activities by a person with visual impairment. For example, during the first scenario at the bus stop, participants were asked to board a specific bus where they eventually ended missing the bus without being able to identify the bus number. Through these scenarios, participants could also apply their other senses such as taste, smell and touch so that they could relate themselves to how such senses are used by people with visual impairment. The participants also had a brief interaction with the volunteers with visual impairments to learn about their lifestyles and how they face such situations. The workshop ended with participants sharing their experiences with the rest of the participants.

2.1.6 Metrics

Creativity

The following subsections provide a detailed description of how three overall metrics were used to measure the quantity, variety, and novelty of concepts shared by the participants.

Number of Concepts: Quantity

Quantity refers to the total number of concepts that the participants generated as idea alternatives for resolving the issues faced by people with visual impairments. For this metric, *Overall* (total) and *Non-Repeated* concepts were obtained for both the studies, allowing us to differentiate the concepts that were influenced and not influenced by the workshop stage. *Overall* concepts included every concept shared by the participants along each stage, whereas the *Non-Repeated* concepts included the concepts that were specific for each stage. Equation (2.1) ,from work by Moreno et al. (Moreno et al., 2014), explains the relationship between *Overall* (Q_O) and *Non-Repeated* (Q_{NR}) concepts.

$$Q_O = \sum All\ concepts\ generated = Q_{NR} + Repeated\ concepts \quad (2.1)$$

Breadth of concepts: Categories

Following the variety metric by Shah et al. (Shah et al., 2003), the breadth of concepts was calculated based on a binning technique that seeks to cluster the concepts based on higher-level categories that they belong to. For example, the concepts such as "public education" and "public awareness on helping the population" would be grouped into one category. Similarly, if a single participant mentions two concepts related to assistive tools and technology, those two concepts will be grouped into the same category and contribute as a single entry under the breadth of concepts, while the concepts' public awareness' and 'wearable assistive technology' would not be grouped together. Two raters independently 'open coded' (Khandkar, S. H., 2009) and clustered a sample set of concepts into categories as per the metric by Shah et al. and achieved a per cent agreement of 81% upon rater training. Following this agreement, one rater continued to categorise the rest of the concepts. Appendix A shares a detailed final list of categories used to calculate the breadth of concepts. This list was used to analyse the increase in concept categories perceived along different stages of the workshop.

Uniqueness of Concepts: Novelty

Novelty is defined as the uniqueness of a concept (Shah et al., 2003). The novelty metric was calculated using the categories that were generated to capture the 'breadth of concepts.' The frequency of concepts shared under a single category determined the novelty of the concepts shared under that category. Equation (2.2) was adopted to calculate the novelty of concepts:

$$S_j = \frac{(T - C_k)}{T} \times 10 \quad (2.2)$$

where S_j refers to the novelty score for a concept, j, that falls in a specific category, k, T is the total number of concepts across all categories, and C_k is the number of concepts in k. The final value falls within a range between 0-10 once multiplied by ten (Shah et al., 2003).

The same sample set of concepts that were used to test the interrater agreement for the 'breadth of concepts' was used to check for the interrater agreement on the novelty values obtained by each concept. A linear regression analysis was performed on SPSS Statistics (Version 25.0.0.1, IBM Armonk, N.Y., USA) for the novelty values from both raters. The overall model fit was $R^2 = 0.94$ with a significance of $p<0.001$.

Empathy

Two metrics for empathy, as described in Section 2.1.3, were used to measure the empathic impact attained by the simulated scenarios: Empathic Similarity (of concepts) and Empathic Self-evaluation (by participants). A detailed description of the two metrics are as follows:

Empathic Similarity

We adapted the empathic similarity metric from the empathic accuracy rating developed by Ickes (1983). Ickes developed a measure to describe the similarity of statements using the values 0 (no similarity), 1 (in between), and 2 (evident similarity). For our work, a similarity rating was provided by comparing each concept description shared by the workshop participants against the concepts shared by 13 participants with visual impairments. A percentage index for the empathic similarity is achieved by dividing the rating by 2 (maximum accuracy rating possible) and then multiplying the resultant value by 100. As a minor modification to Ickes's metric, this study assigned '1' as the empathic similarity value if the concept was in the same category (based on the categories used for Breadth of Concepts as listed in Appendix A) but not as specific as the concept shared by participants with visual impairments. For example, if "Uses other senses (during navigation) to compensate the loss of sight" is a concept shared by a participant with visual impairments, then the concept "Infrastructural enhancements, making them more friendly for visually handicapped" would receive '1', and the concept "Alert users with visual impairments of infrastructure through their other senses" would receive '2'. This approach towards evaluating empathy enabled the rating process to be straightforward and repeatable. Equation (2.3) demonstrates the metric adopted to calculate the empathic similarity percentage for each participant.

$$E_{S_{Total}} = \frac{\sum_{i=1}^{N}\left(\frac{E_{S_i}}{2} \times 100\right)}{N} \tag{2.3}$$

where $E_{S_{Total}}$ *is the average empathic similarity percentage attained at each stage,* N *is the number of participants and* E_{S_i} *is the average empathic similarity value attained by each participant i.*

Two design researchers independently applied the empathic similarity metric to rate a subset of the concepts and attained a Pearson correlation coefficient of 0.80. Upon attaining high correlation, one of the raters continued to rate the remainder of the concepts. Table 2-1 provides the detailed key used by the researchers for the empathic similarity rating.

Table 2-1 Empathic similarity key

Empathic Similarity Score	Key Characteristics
2	The concepts from workshop participants provide solutions to issues addressed by participants with visual impairments using the same terms or terms that are synonymous with it.
1	The concepts from workshop participants provide solutions to issues addressed by participants with visual impairments at a broader level i.e., both comment belong to the same category.
0	Both content and category of concepts shared by workshop participants do not match with any concept shared by participants with visual impairments

Empathic Self-Evaluation

Empathy was also determined by empathic self-evaluation, where the participants were asked to evaluate their understanding of the issues experienced by people with visual impairments and their ability to solve those issues. Self-evaluation, a moral indicator of empathy (Bas-Sarmiento et al., 2019; Gerdes et al., 2010; Hojat et al., 2018), was used to capture participants' assessment of their understanding and ability to solve the issues faced by people with visual impairments. This evaluation used a five-point Likert scale that ranged from -2 to 2, with 0 referring to a neutral response about them being able to understand and solve the issues faced by people with visual impairments, -2 referring to strong disagreement and +2 referring to strong agreement.

2.1.7 Analysis And Results

The datasets from both studies failed the test for normality. Hence, the Wilcoxon Signed-Rank test, a non-parametric test for two related samples, was used on SPSS Statistics (Version 25.0.0.1, IBM Armonk, N.Y., USA) to compare the significance of the difference in outcomes between different stages. Given the smaller sample size, a repeated-measures ANOVA was also used to test the significance of the impact achieved from different workshop stages, with an assumption of normal distribution. Both these test results are discussed in the sections that follow.

Number of Concepts: Quantity

Table 2-2 shares a list of exemplar concepts generated by the study participants and the participants with visual impairments.

Table 2-2 Exemplar concepts shared by the participants

	Workshop Stages	Concepts
S1 Participants	Pre-Workshop	1. Infrastructural enhancements, making them more friendly for visually handicapped 2. Modification of important infrastructure 3. Education
	Post-Briefing	1. Infrastructural elements in homes, transport hubs and public places, just to name a few
	Post-Simulation	1. Help them at bus stops/train stations to lookout for the transport and board the bus/train 2. Longer time for them to cross 3. Education on visually impaired issues and assets- in community- in school- in job place 4. Inclusion in workplace Inclusiveness awareness
S2G1 Participants	Pre-Workshop	1. Utilizing their senses (hearing and touching) 2. Alert visually impaired users of infrastructure through their other senses 3. Design awareness when creating products and services
	Post-simulation	1. Some facilitation of sound/voice that explains what things are? (maybe a bus stop has a button that they can press to hear when the next buses arrive.) 2. Physical differentiation for money 3. Some method for knowing which roads to take (maybe raised slabs for major routes)
	Post- Briefing	1. Employment - use of special software for more computer-based jobs- call center 3. employment in basic jobs- waitress/ chef 2. Innovations for the masses should conceptually take consideration for people who are unable to utilize one or more of their senses 3. Workshops to explain to people to make them understand better. Devices and tools for more independence.
S2G2 Participants	Pre-Workshop	1. Guide dog 2. Braille 4. Attach RFID tags to person's belongings and have a device which is voice activated to direct person to device he wants
	Post-Briefing	1. Encourage them to wear bright clothing to make themselves more visible, prominent such that pedestrians/drivers/cyclists can notice them from after and move out of the way in time 2. Policies to level the inequality of treatment (other people's impressions of them) 3. Help patients to independently find funding (e.g. startup opportunities etc.)

Workshop Stages	Concepts
Post-Simulation	1. Automated carriages to help them move around. Inspire more public to be aware of their problems/challenges in life
	2. Include and consider more about this community in product development
	3. Design money that allows them to interpret
Participants with visual impairments	1. Bus company should alert drivers to stop and inform the bus number to the person if the person is with a cane
	2. Divide road for people and cyclists
	3. All schools to have a special needs office rather than having a separate physically challenged school
	4. Would like to see inclusive designs as technology enhances- personally believe in inclusive design
	5. Design a robotic chair that will take you to any place
	3. Public need to be aware that white cane represents visually challenged- bring awareness about condition

Table 2-3and Table 2-4 display the number of *Overall* and *Non-Repeated* concepts listed along each stage of S1 and S2. Figure 5 displays the difference in the number of concepts shared during each stage, with the number of participants, '*n*', mentioned within the brackets next to each stage. The difference in the number of concepts shared by the participants was evaluated by comparing the number of concepts shared during the Pre-Workshop and the Post-Briefing stages, the Pre-Workshop and the Post-Simulation stages, and the Post-Briefing and the Post-Simulation stages. In Figure 2-5, the horizontal bars display the *p-value* obtained from a Wilcoxon Signed Rank test between the outcomes for different workshop stages.

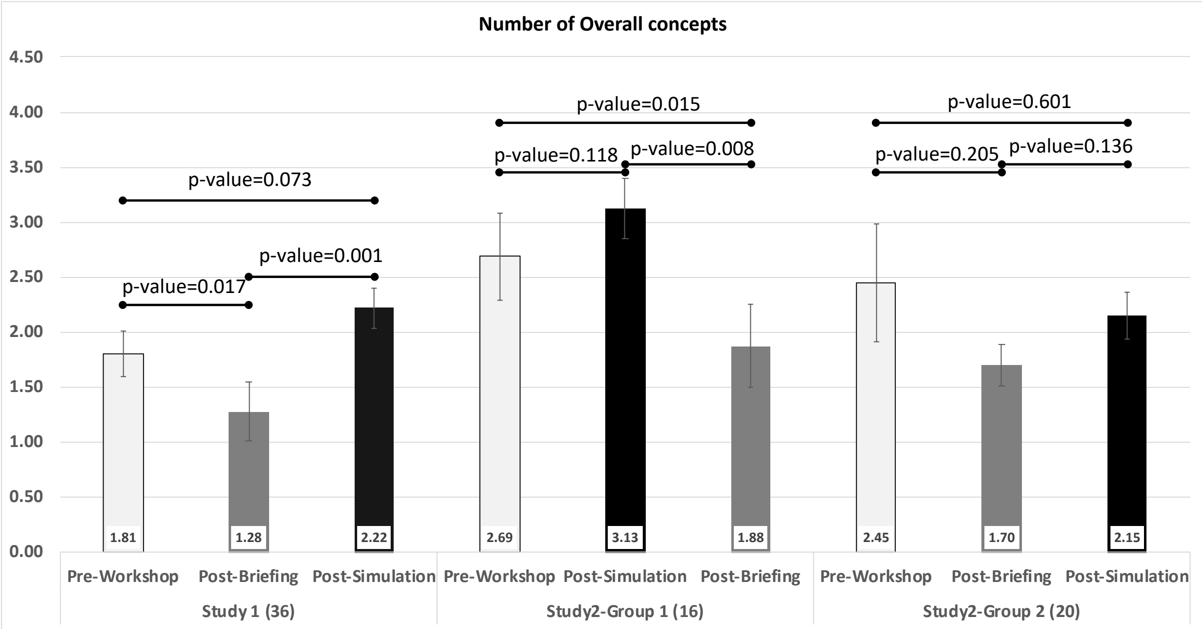


Figure 2-5 Number of overall concepts (and standard error) along all three workshop stages of the S1 and S2

Table 2-3 Quantity, breadth, and novelty of overall concepts (and standard deviation) for the post-briefing and post-workshop stages of S1 and S2 (Order for S2G1 (highlighted) should be Pre-Workshop, Post- Simulation, Post- Briefing)

Measure	Study Name	Pre-Workshop		Post-Briefing		Post-Simulation	
		Average	SD	Average	SD	Average	SD
Quantity	S1	1.81	1.14	1.28	1.28	2.22	1.10
	S2G1	2.69	1.58	1.88	1.45	3.13	1.09
	S2G2	2.45	2.14	1.70	0.80	2.15	0.93
Breadth	S1	1.72	1.09	1.17	1.16	2.17	1.03
	S2G1	2.13	0.81	1.63	1.02	2.81	0.91
	S2G2	1.95	1.79	1.55	0.69	2.00	0.92
Novelty	S1	7.38	3.37	5.86	4.23	8.93	0.50
	S2G1	8.26	0.73	8.02	2.19	8.95	0.32
	S2G2	6.66	3.95	6.57	3.94	8.97	0.36

Table 2-4 Quantity, breadth, and novelty of non-repeated concepts (and standard error) for the post-briefing and post-workshop stages of S1 and S2

Measure	Study Name	Post-Briefing		Post-Simulation		Significance
		Average	SD	Average	SD	
Quantity	S1	0.83	0.81	1.25	0.87	0.042
	S2G1	1.31	1.30	1.88	1.15	0.093
	S2G2	1.35	0.99	1.60	0.94	0.356
Breadth	S1	0.81	0.79	1.22	0.80	0.032
	S2G1	1.13	1.02	1.75	1.00	0.085
	S2G2	1.20	0.83	1.50	0.89	0.256
Novelty	S1	5.26	4.20	8.98	3.20	<0.001
	S2G1	5.78	4.08	7.69	3.06	0.121
	S2G2	6.67	3.97	8.65	1.09	0.116

The outcomes of Post-Briefing and Post-Workshop stages were alone compared for *Non-Repeated* concepts. The results of the statistical analysis obtained using Wilcoxon Signed Rank test and repeated measures ANOVA are summarised below:

- Wilcoxon Signed-Rank test results showed that the Overall number of concepts generated during the Post-Simulation stage of S1 and S2G1 were significantly higher *(p-value <0.05)* than those during the Post-Briefing stage of the workshop.
- For the Non-Repeated (NR) concepts in Table 2-4, the Wilcoxon Signed Rank Test results showed that there was a statistically significant difference in the number of concepts shared between the Post-Briefing and Post- Simulation stages of S1.
- With an assumption that the distribution is normal, repeated-measures ANOVA showed that there was a statistically significant effect of the workshop stages on the number of Overall concepts shared by the participants from both S1 *(F(2,70)= 8.485, p= 0.001)* and S2G1 *(F(2,30)= 8.862, p= 0.001).*

Breadth of Concepts: Categories

Table 2-3 and Table 2-4 share the *Overall* and *Non-Repeated* average breadth of concepts for S1 and S2. Figure 6 shows the difference in the breadth of concepts shared during each stage with the number of participants, '*n*', mentioned within the brackets. The horizontal bars share the *p-values* for the difference in means for the number of categories along the workshop stages.

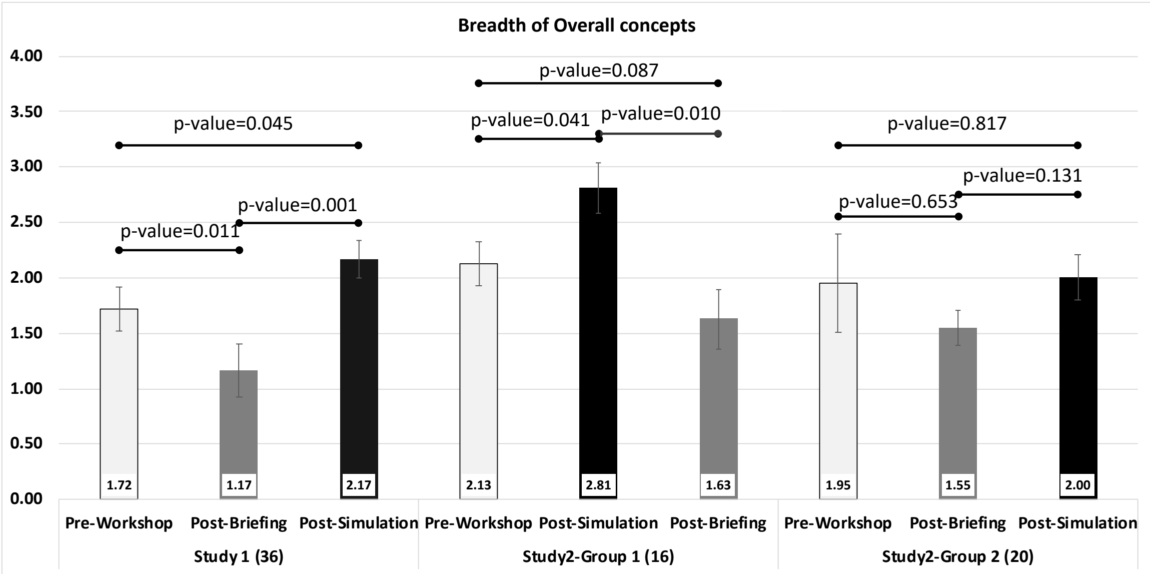


Figure 2-6 The breadth of overall concepts (and standard error) along all three workshop stages of the S1 and S2

Listed below are the results of the statistical analysis run using Wilcoxon Signed Rank test and repeated measures ANOVA:

- The results of the Wilcoxon Signed-Rank test indicated that S1 and S2G1 found a statistically significant increase *(p-value <0.05)* in the Overall number of concept categories shared between Post-Briefing and Post-Simulation stages.
- It was also found that S1 and S2G1 showed a significant increase in the breadth of concepts categories between the Pre-Workshop and Post-Simulation stages.
- For the Non-Repeated (NR) concepts shared in Table 2-4, the Wilcoxon Signed Rank Test results showed that there was a statistically significant difference in the number of concept categories shared between the Post-Briefing and Post- Simulation stages of S1.
- The repeated-measures ANOVA showed that there was a statistically significant effect of the workshop stages on the Overall concept categories shared by the participants from *S1 (F(2,70)= 10.675, p< 0.001)) and S2G1 (F(2,30)= 7.326, p= 0.003).*

Uniqueness of Concepts: Novelty

Table 2-3 and Table 2-4 display the Overall and Non-Repeated average novelty of concepts for S1 and S2. The horizontal bars in Figure 2-7 shows the *p-value* for the difference in the novelty of concepts shared during different workshop stages.

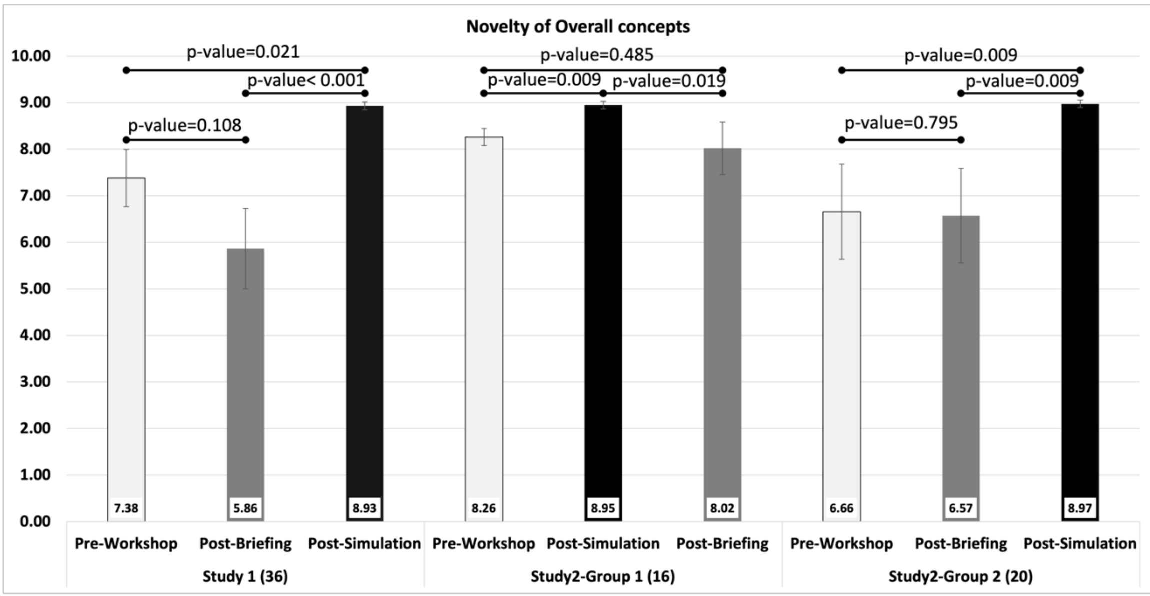


Figure 2-7 Novelty of overall concepts (and standard error) along all three workshop stages of the S1 and S2

The results of the Wilcoxon Signed-Rank test and repeated measures ANOVA are listed below:

- In contrast to the results for Quantity and Breadth, outcomes of S1 and both the groups from S2 showed a statistically significant increase *(p-value <0.05)* in the Overall novelty of the concepts shared between Post-Briefing and Post-Simulation stages.
- The increase in novelty was significant even among the Pre-Workshop and Post-Simulation stages of both the workshops.
- For S1, analysis on the Non-Repeated (NR) concepts (Table 2-4) showed a statistically significant increase in the novelty of concepts shared between the Post-Briefing and Post-Simulation, and Pre-Workshop and Post-Simulation stages of the workshop.
- Outcomes of repeated-measures ANOVA showed that there was a statistically significant effect of the workshop stages on the novelty of concepts shared by the participants from *S1 (F(2,70)= 10.452, p< 0.001))*. In contrast to the repeated measures ANOVA results for Quantity and Breadth, results of S2G1 participants did not show a significant effect *(F(2,30)= 1.935, p= 0.162), but this effect was significant on S2G2 participants (F(2,38)= 4.937, p= 0.012)*.

Empathic Similarity

Both Wilcoxon Signed Rank test and repeated measures ANOVA were used to test the statistical significance of the empathic similarity value for the concepts shared by the participants. Figure 2-8 shows the average of the empathic similarity values achieved by the participants ($E_{S_{Total}}$) along different stages of S1 and S2. A summary of the results are as follows:

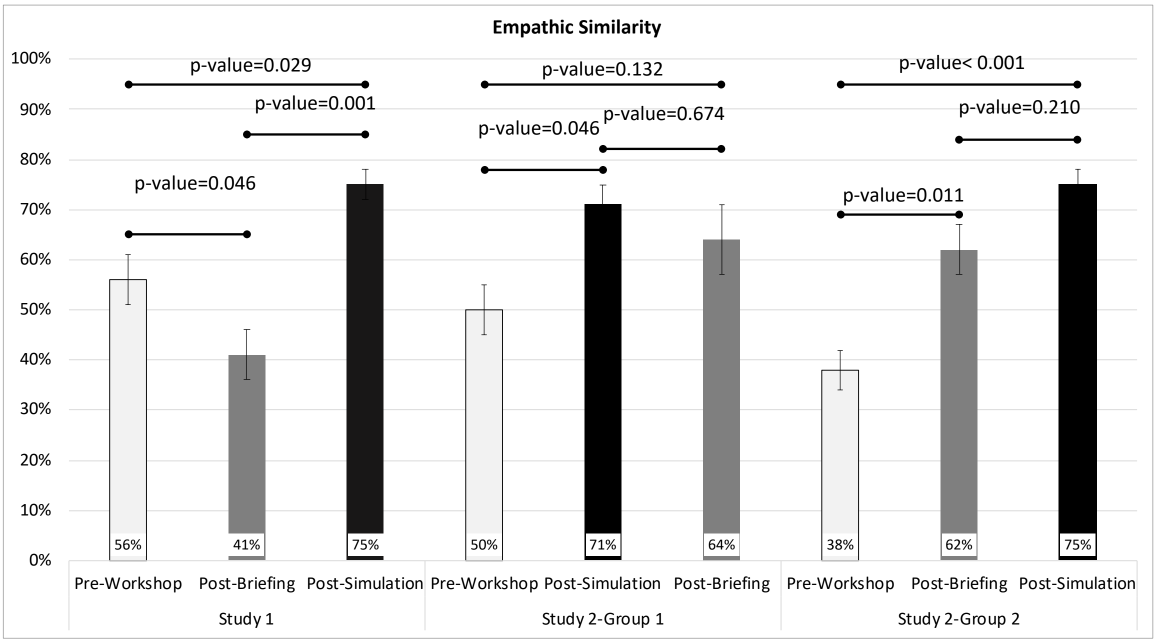


Figure 2-8 The empathic similarity between the concepts (and standard error) shared by the workshop participants and the participants with visual impairments

- The Wilcoxon Signed-Rank test results showed that S1 and both the groups from S2 showed a statistically significant increase *(p-value <0.05)* in the empathic similarity value of the concepts shared between the Post-Briefing and the Post-Simulation stages.
- The empathic similarity among the concepts was significant even among the Pre-Workshop and Post-Simulation stages of both the workshops.
- Outcomes of repeated-measures ANOVA also showed a significant effect of the workshop stages on empathic similarity for both the studies (*S1: F(2,70)= 13.751, p< 0.001; S2G1: F(2,30)= 5.222, p= 0.011; S2G2: F(2,38)= 15.079, p<0.001)*.

Empathic Self-Evaluation

Self-evaluation ratings for S1 were collected during the Pre-Workshop and Post-Simulation stages to understand the impact of the entire workshop on the participants' perception over their understanding and ability towards solving the issues faced by people with visual impairments. Whereas, S2 ratings captured the participants' self-evaluation on their empathy during all three stages and analysed both independent and combined impact of the workshop stages on empathic self-evaluation. Figure 2-9 and Figure 2-9 show the average empathic self-evaluation ratings captured for S1 and S2.

Figure 2-9 Empathic self-evaluation on the ability to understand the issues faced by people with visual impairments

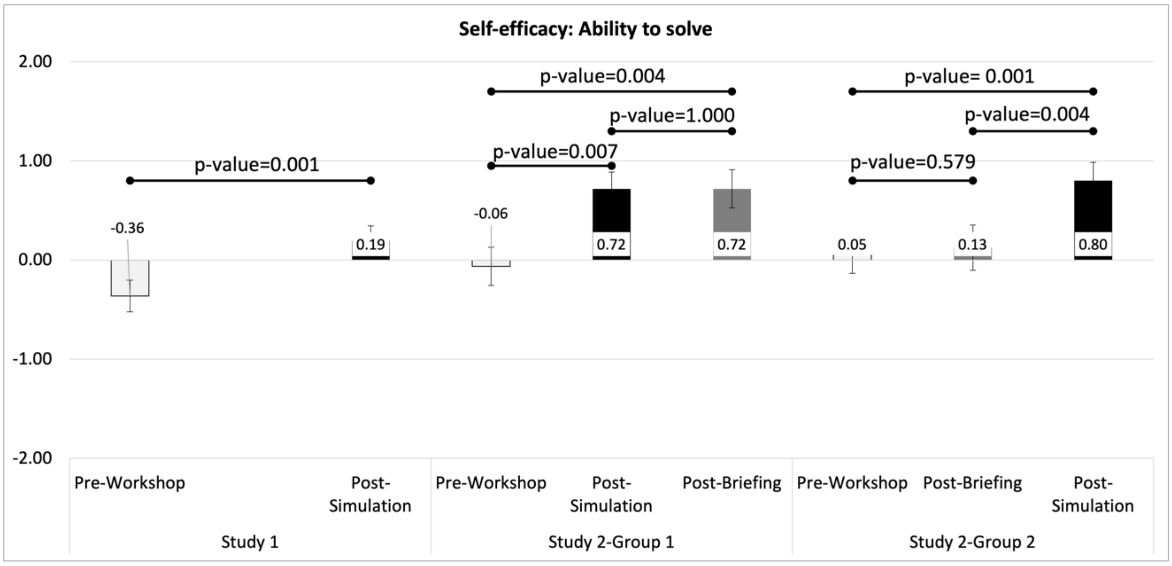


Figure 2-10 Empathic self-evaluation on the ability to solve the issues faced by people with visual impairments

Listed below is a summary of the results derived from the statistical analysis. An outcome different from that of the quantity, novelty and breadth of concepts was observed from the self-evaluated empathy ratings from S2 participants.

- For the self-evaluation on "their ability to understand (the issues faced by people with visual impairment)", the Wilcoxon Signed-Rank test results showed that there was a statistical significance between the Pre-Workshop and Post- Simulation stages.

- Similarly, ratings on their "ability to solve (the issues faced by people with visual impairments)", the outcomes were statistically significant between Pre-Workshop and Post-Simulation stages.
- Among Group 1 participants, the difference in self-evaluated empathy rating on their "ability to understand (the issues faced by people with visual impairment)" was significant between the Pre-Workshop and Post- Simulation stages. Whereas, in contrast to the results from creativity metrics, the difference in self-evaluated empathy ratings on their "ability to understand" was not statistically significant between the Post-Simulated and Post-Briefing stages.
- Similarly, the difference in self-evaluated empathy rating on their "ability to solve" was significant between the Pre- Workshop and Post-Simulation stages.
- Among Group 2 participants, the self-evaluated empathy ratings on their "ability to understand" showed a significant increase between the Pre-Workshop and the Post-Briefing stages, the Pre-Workshop and the Post-Simulation stages, and between the Post-Briefing and the Post-Simulation stages.
- The analysis showed similar results among Group 2 participants, where the self-evaluated empathy ratings were statistically significant between the Pre-Workshop and the Post-Briefing stages, the Pre-Workshop and the Post-Simulation stages, and between the Post-Briefing and the Post-Simulation stages.
- Repeated measures ANOVA results demonstrated a significant effect of the workshop stages on empathic self-efficacy achieved through both the studies. This was true for their "ability to understand" (*S2G1:* $F(2,30)= 20.828$, $p<0.001$; *S2G2:* $F(2,38)= 17.806$, $p<0.001$) and their "ability to solve" (*S2G1:* $F(2,30)= 12.755$, $p< 0.001$; *S2G2:* $F(2,38)= 12.539$, $p<0.001$).
- Both the evaluations for empathy showed no correlation to participant creativity.

2.1.8 Discussion

This section summarises the outcomes of the two workshops, executed as S1 and S2, where both the workshops introduced the participants to an extreme-user experience of visual impairment to evoke design creativity and empathy. The impact on creativity and empathy was analysed by gathering data at every stage of both workshops. Results are discussed in the context of the previously raised research questions.

1) *How does a simulated extreme-user (visual impairment) perspective impact participant creativity and empathy?*

According to the maxim 'quantity breeds quality' (Diehl & Stroebe, 1987; Jung et al., 2015; Meadow & Parnes, 1959; Parnes & Meadow, 1959), an increase in quantity and breadth of concepts after the Simulated Scenarios may indicate that the participants could generate concepts that addressed the issues that they had not realised earlier. Section 2.1.7 showed that the S1 and S2G1 outcomes concurred with this by showing a statistically significant increase in the number, breadth and empathic similarity of the concepts shared along the Post-Simulation stage when compared to the Pre-Workshop stage of the study.

Though the participants of S2G2 did not share the same outcome for number, breadth, and empathic similarity, the results for novelty support that the Simulated Scenarios encouraged the participants to generate concepts with significantly high novelty among the participants from S1 and both the groups in S2.

Given the same order of workshop sessions followed for S1 and S2G2, one possible explanation for the observed discrepancy in the results could be the background and difference in design knowledge of the participants. Similarly, S1 showed a significant difference in the impact on number, breadth, novelty and empathy achieved by Briefing and Simulated Scenarios for both Overall and Non-Repeated concepts. Such consistent impact was not observed among Group 2 participants. The limited sample size in each workshop did not support further probing into this impact, yet it provides an important insight on how the application of such Simulated Scenarios needs to be adapted based on the background and knowledge of the participants.

Nevertheless, the *Non-Repeated* concepts show both Briefing and Simulated Scenarios encouraged the participants to ideate concepts that were exclusive to each stage, and this impact was significantly high for Simulated Scenarios among a majority of the participants. Although this study does not focus on the individual differences among designers, the outcomes support that ideation through simulated scenarios could help generate new concepts despite any preconceived design fixation (Alipour et al., 2018; Linsey et al., 2010).

Results based on the outcomes of the empathic self-efficacy values support the significant effect of Simulated Scenarios on the self-evaluated empathy among the participants (Figure 2-8 and Figure 2-9). While a Briefing about a user or a situation could help understand the users, simulated experiences have the potential to evoke better empathy towards the users. Although works in past have paired empathy with creativity (Treadaway, 2007), the results of this study did not show any such correlation between the outcomes of empathy and creativity. This is in agreement with the findings from Chang-Arana et al. (Chang-Arana et al., 2020), where they showed that empathic accuracy, a quantitative measure of designer empathy, might not essentially influence the ideation outcomes or even the psychological correlation with the end-user.

2) *How does a Briefing (awareness, knowledge) about the extreme-user experiences influence the impact of the Simulated Scenarios? What are the combined and independent effects of Briefings and Simulated Scenarios?*

Results from S1 do not provide a clear insight on whether the significant effect captured after experiencing the scenarios was an independent impact of the simulations or a combined effect of the Briefings and simulations together. Whereas the results from S2, particularly the self-efficacy results, show that Briefing alone had little or no effect on the self-evaluated empathy ratings for their ability to solve. Results from S2 also show that irrespective of being independent or combined, Simulated Scenarios could enhance the ability of the participants to generate more concepts that empathise with the perspectives of people with visual impairments when compared to Briefing. Nevertheless, Figure 2-9 shows that the participants from S2G2 expressed a relatively higher increase in their understanding of the users with visual impairments when compared to the participants from S2G1.

Similarly, participants from both the studies showed a significant increase in the novelty of concepts shared, irrespective of the order in which they experienced the simulated scenarios (Figure 2-7). Based on this impact, Briefings might not be independently sufficient to have an impact on creativity but might help amplify the impact on participants' understanding towards the target users. Therefore, it would be ideal to experience the Simulated Scenarios after a brief overview of the empathised extreme-user population in order to attain an effective influence over design creativity and empathy.

2.1.9 Conclusions

Both the studies detailed in this paper aim to gain a deeper understanding of implementing simulated extreme conditions of visual impairment as a means to increase design creativity and empathy. Two different approaches are followed to test the impact of visual impairment based Simulated Scenarios. Though S1 strongly supports the impact of the Simulated Scenarios as part of need-finding conceptual design, it does not verify how this impact could be shaped by the Briefing that is provided prior to the simulated experience. S2 delves deeper to ensure if the impact is consistent among designers even when applied independently without the influence of the information provided through a Briefing.

In order to capture the independent and combined effect of Briefings and Simulated Scenarios, S2 divides the participants into two groups. One group experienced the Simulated Scenarios followed by a Briefing on visual impairment (Group 1), and the other group had a Briefing followed by the scenarios (Group 2). One difference that is observed between S1 and S2 is that the designers could produce more creative concepts right from the Pre-Workshop stage when compared to participants without a design background. This outcome among design practitioners could have been influenced by multiple contributing factors such as designer knowledge and experience, but analysis on those factors is beyond the scope of this paper. However, Simulated Scenarios did have a significant impact on participant creativity and empathy, and this could be further enhanced when Briefings are shared prior to the Simulated Scenarios.

Limitations of the work include the influence of previous experience among the workshop participants. Thirteen workshop participants who took part in S1 were connected to someone who experienced vision loss, and two of them had themselves experienced it earlier (Hu & Reid, 2018; Linsey et al., 2010). This difference, when tested, did not show a significant effect on the answers provided by the participants, but there are chances that this difference in population (Hu & Reid, 2018; Linsey et al., 2010) and cultural differences among designers could have had an influence on the concepts shared by the participants (Felgen et al., 2004; Gautam & Blessing, 2009; Tan, 2016). Based on the results from S2, a designer's experience and expertise could be an influencing factor on the extent to which the simulated experiences could create an impact. In addition, it can be inferred from Table 2-3and Table 2-4 that the current outcomes show a higher standard deviation. Therefore, better sample size and participant grouping based on their previous experience would be considerations for any potential expansion of these studies. Both the studies discussed in this paper provided supporting evidence to show the reliability of simulated experiences in evoking design creativity and empathy. With this, future work will aim to adopt these simulated extreme-user experiences not just to identify the needs among the extreme-users but also to identify the needs that are latent among the rest of the users. Future work will also focus more on a more intuitive approach to apply such extreme-user perspectives for design creativity.

2.2 Implementation of Extreme-user Experiences

The study discussed below presents a pilot systematic application approach for extreme-user experiences. Based on the results, we infer that a systematic guided approach is significantly more impactful than a pure intuition-based approach. It is to be noted that, by following previous literature (Lin & Seepersad, 2007), we use the term extraordinary users instead of extreme-users to refer to users who experience some form of physical or cognitive challenges. This work has been published in the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Following the SUTD policy on the inclusion of previously published work, we are attaching the work in its submitted form.
Co-authors include Sujithra Raviselvam, Dr David Anderson, Dr Katja Hölttä-Otto, and Dr Kristin L Wood.

Raviselvam, S., Anderson, D., Hölttä-Otto, K., & Wood, K. L. (2018, August). Systematic framework to apply extraordinary user perspective to capture latent needs among ordinary users. Proceedings of the ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 51845, p. V007T06A013). American Society of Mechanical Engineers. https://doi.org/10.1115/DETC2018-86263.

2.2.1 Abstract

This study aims to provide a systematic framework to apply emulation tools that could help designers to experience an extraordinary user perspective (users with some form of physical or cognitive impairment). Past studies have supported the impact of using tools that emulate a physically restricted scenario to evoke creativity and empathy among designers. The proposed approach for Empathic Experience Design (EED) guides designers to have better leverage emulation tools to understand the latent design needs from recommended extraordinary user perspectives. The framework combines the physical parameters involved while interacting with a product with the interaction activities associated with the product. This combination is used to select empathy tools that will provide an interactive experience by eliminating those parameters. By eliminating the identified parameters, participants tend to look at the design needs from the emulated extraordinary user perspectives. The framework was tested with a pilot study in which 37 participants (20 participants for Treatment Group 1 and 17 participants for Treatment Group 2) of ages 20-26 were asked to redesign a medical syringe. The extraordinary use cases implemented in this study are visual impairment, hearing impairment, low dexterity and single hand usage. The study not only tested the recommended systematic approach, but it also showed the application of an extraordinary user perspective to understand the general latent needs associated with medical devices that are less likely to be used by extraordinary users. The results are promising evidence that a simple systematic approach to implement empathic design tools could have

a higher impact than an unguided instinct based approach to choose the tools. The results also show that, when applied efficiently, the approach could capture a wide variety of latent needs from potential extraordinary user perspectives'.

2.2.2 Introduction

Empathic Experience Design (EED) (Genco et al., 2012) and Empathic Lead User (ELU) (Vaughan et al., 2015) techniques evolved as methods to identify novel design concepts and needs by adapting an extraordinary user perspective. The term 'extraordinary users' here refers to people who experience some form of physical or cognitive impairment, and both these methods derive their motivation from the term "lead user," coined by Von Hippel (1986), to represent users who experience a need that is still latent among the rest of the population. Though the lead user theory leveraged expert users to foresee the non-obvious needs or design modifications for an existing mainstream product, research works that followed studied the lead user characteristics that are easy to access. For example, Lai and Shu (2014) studied and showed the ability of do-it-yourselfers to be lead users without any functional fixedness while Hannukainen and Holtta-Otto (2006) demonstrated the lead user capabilities among people with both genuine and situational disabilities. Similarly, studies by Conradie et al. (2014; 2016) and few other recent works also aimed to identify the lead user abilities among the extraordinary user population (Hölttä-Otto & Raviselvam, 2016; Raviselvam et al., 2014).

There has also been extensive research on such empathy tools that emulate a situation that would help designers experience the perspective of extraordinary users like, users with visual impairment, hearing impairment (Raviselvam et al., 2017), older adult users (Raviselvam et al., 2014), etc. These tools and scenarios have not only proved to be useful in understanding the inclusive design needs with respect to the extraordinary users, but also proved to be impactful in increasing designer empathy and creativity (Raviselvam et al., 2016a).

The extraordinary user perspectives from the EED and ELU methods were achieved by imposing physical restrictions or priming that emulate some form of physical impairment (She et al., 2018). Research works have also explored the application of these empathy tools for purposes such as user interface design (Giakoumis et al., 2014; Keates, 2013; Mieczakowski et al., 2009) and automobile design, primarily to enable designers to understand the extraordinary user perspective. Another effective application of an extraordinary user perspective is to understand the percentage of users who get excluded from using a product due to their physical condition (Persad et al., 2006).

The key goal of the framework put forth in the paper is to ease the process of deciding which empathy tool or tools are appropriate to understand an extraordinary user perspective. For this, the present study applies the extraordinary user perspective to uncover the potential latent needs even for products that are not directly designed with extra ordinary users in mind.

The product domain currently studied is medical devices. Medical devices are not often designed in a user centric fashion or by taking the use context into the account (Sharples et al., 2012; Ward & Clarkson, 2004). Further, they are used by medical personnel that are aging just as the rest of the population and by ones who are often stressed by shift work or by frequent interruptions (Hull et al., 2011; Rivera & Karsh, 2010). In other words, these devices are often used in at least situationally disabled conditions.

This chapter discusses the outcome of a pilot study that explored the latent needs associated with a standard medication syringe, by answering the following research question:

Does a systematic application framework to select the "extraordinary user empathy tools", enable the designers to better leverage extraordinary user perspectives when compared to an instinct based selection of the same tools?

2.2.3 Overview of Implemented Systematic Application Approach

The systematic application approach uses activity diagrams to capture users' interactions with a product and combines them with the physical parameters associated with it. Similar to the exclusion calculation approach by Persad et al. where they implement sensory, cognitive and motor demands to understand the population of users excluded from using a product (Persad et al., 2007), the systematic application approach proposes a guideline for designers to select the appropriate empathy tool from the wide range of available options. The following section provides a detailed description of the steps involved:

Step 1: Record every step of the user interactions with the product/ system to be designed, in the form of an activity diagram. The steps can be done either through observations or by hypothesising the potential user interactions (Otto & Wood, 1998). Given the aim to ease the user experience while interacting with a product, an activity diagram serves as a better method than e.g. use of a functional diagram. Figure 2-11 shares the exemplar Activity Diagram used to demonstrate the approach to study participants.

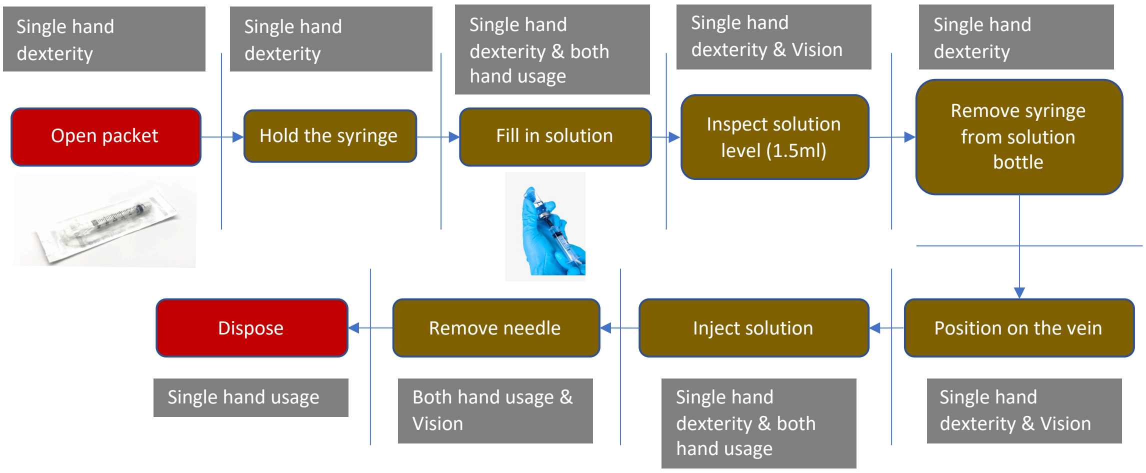


Figure 2-11 Activity Diagram of a medication needle and associated physical parameters

Step 2: Identify the physical parameters associated with every user interaction recorded in the activity diagram. displays a simple activity diagram for a medication syringe used in this study, along with the sample physical parameters involved at every stage. The physical parameters considered for this pilot study were vision, sound perception, single/ double hand usage and dexterity. Other parameters that could have been involved but were not considered for this pilot study are cognition and mobility.

Step 3: Relate the identified physical parameters to the corresponding extraordinary user empathy tools that would eliminate those parameters. Figure 2-12 displays the different types of emulation tools used for this study and Table 2-5 shows the physical parameters considered in this study along with the corresponding tools to eliminate those actions by emulating an extraordinary use case scenario.

Figure 2-12 Extraordinary User Empathy Tools used in the study: (left to right) a visual impairment emulation eye mask, a single hand use indicator band, a limited dexterity emulation glove, and a hearing impairment emulator

Table 2-5 Physical parameters and corresponding empathy tools

Identified Physical Parameter	Empathy Tool to be Applied
Vision	Eye Mask
Both hand usage	Single hand use Band
Dexterity	Low Dexterity Glove
Hearing	Noise Canceller

Step 4: Ideate design needs and opportunities to improve the user experience while emulating the absence of identified physical parameters. The participants were instructed to use the 'single hand use band' to mark the dominant hand that will not be used while emulating a physically impaired scenario. Tools can be used separately or in combination to test the interactions listed in the activity diagram. For example, the eye mask can be used along with the single hand use band to experience the perspective of visual and physical impairment together.

The proposed approach aims to enable designers to streamline and understand the application scenarios and activities for the empathy tools.

2.2.4 Research Methodology

Figure 2-13 Research illustrates the steps followed for the pilot study conducted to test the impact of systematic application of empathy tools, relative to tools being offered without any guidance.

All participants had completed their 'Introduction to Design' module during their previous year and hence were aware of many design tools and techniques. The study comprised of two phases: 1) Control phase and 2) Treatment phase.

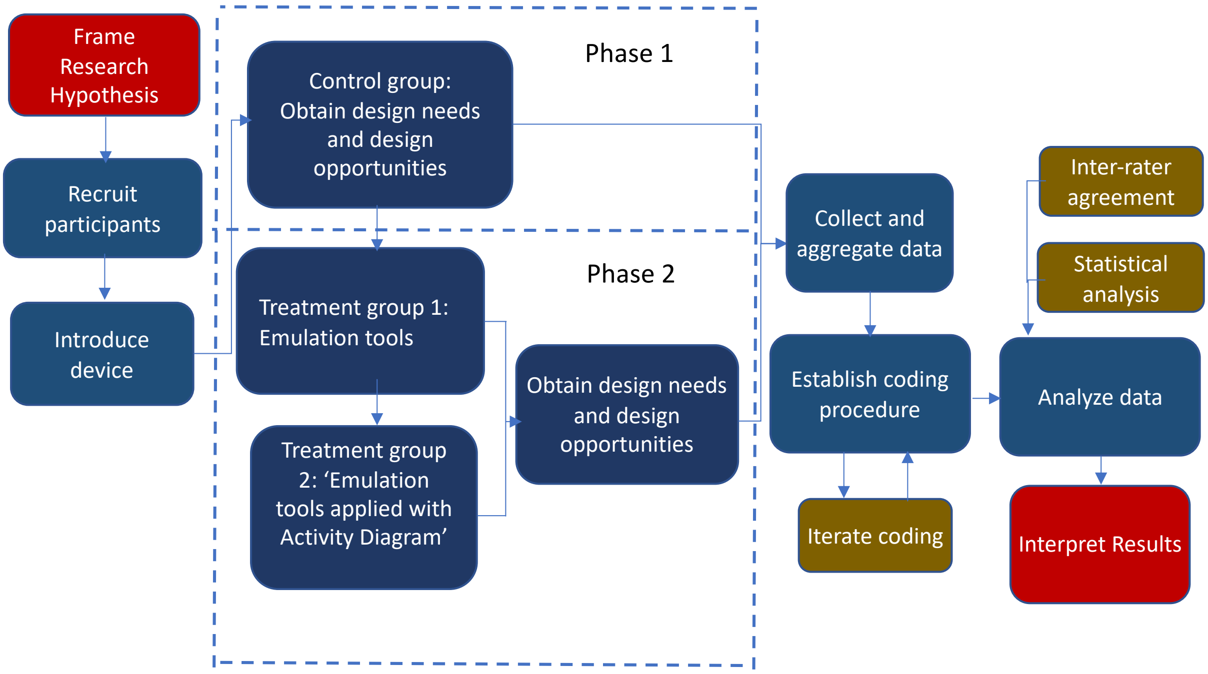


Figure 2-13 Research approach

37 participants of ages 20-26 (average: 22 years) took part in the study. There were six female participants and 26 male participants, and five participants who declined to mention their gender. Participants were students from an undergraduate module on 'Engineering Design' at Singapore University of Technology and Design.

Phase 1 started with a 10 minute briefing on the experimental flow and grouping arrangements of the participants. Participants were then introduced to the user interactions associated with a medication syringe, for a normal scenario of unpacking and administering medication. Questionnaires were then distributed to every participant, requesting them to list the specific design needs and design opportunities with respect to Size, Shape, Weight, Material, Safety, Ergonomics and other specific features associated with the given Syringe. Specific categories to capture the design needs for a medication needle was derived based from the need categories identified by Lin and Seepersad (Lin & Seepersad, 2007).

To keep the study timings within the limited class duration of one hour, participants were given a total of 15 minutes to list the specific design needs (10 minutes) and opportunities (5 minutes). They were also asked their age and gender. No identifying information was collected from the participants;

instead, they were asked to draw a symbol of their choice that they would use throughout the workshop in order to enable tracking of each individual.

Upon completion of the questionnaire for Phase 1, participants were divided into two groups during Phase 2. While both groups were provided with a treatment that aimed to test the impact of 'extraordinary user empathy tools', Group 1 tested the impact of the tools when provided without any guidance framework and Group 2 tested the impact when provided with a guidance framework to select the tools. Group 1 participants were provided with a printed description of the empathy tools and Group 2 participants were provided with printed description of the empathy tools along with the proposed guidance framework.

The participants were seated in a lecture hall and hence they were divided based on their seating arrangement, with participants seated at the first four rows categorised as Group 1 and participants seated at the last six rows categorised as Group 2. In total, the number of participants (n_p) in Group 1 was 20 (Age range: 21-26; Average: 22.8) and the number of participants in Group 2 was 17 (Age range: 20-23; Average: 21.9). The groups had enough distance in between so that the applied grouping approach prevented the Group 1 participants from being influenced by the framework provided to the Group 2 participants. The researchers approached the Group 2 participants in batches based on their seating and guided them with the given framework.

For Phase 2, all participants were given a basic introduction on the tools that were provided and the impact of such tools in evoking designer empathy and creativity while initiating inclusive design solutions. Following the introduction, participants were divided into the two groups. Empathy tools were distributed equally among both the groups but participants from Group 2 were provided with an additional guidance based on the proposed systematic application framework that guided them with selecting the appropriate empathy tool.

While both the groups were given five minutes in common to understand the empathy tools, Group 2 participants were alone given extra 5 minutes to understand the given framework. Similar to Phase 1, both groups were given 15 mins to list specific design needs and opportunities after experiencing the emulated extraordinary user interaction scenarios. Towards the end, participants were asked to reason and list the tools that they used during Phase 2. This was to understand the participants' choice of empathic design tools, when provided with and without guidance. Participants were also asked to list their previous experience with any such extraordinary user scenarios since previous connections/ experience might have a potential influence on participant response (Puccio & Grivas, 2009; Raviselvam et al., 2017).

2.2.5 Data Coding and Analysis

The effect of the proposed framework and its potential to capture the latent needs among the ordinary users was achieved using the metrics for variety, latency and quantity. This paper, due to its focus for identifying latent needs, probed into the collected need statements and ignored the generated design opportunities. Therefore, all collected need statements were coded for variety and latency by the metrics explained below.

Variety

Variety was calculated to understand the breadth of the generated design needs using the variety metric by Shah et al. (2003) Two independent raters categorised a subsection of the need statements based on their similarity. The categories were iterated and finalised upon achieving a 91% agreement between both raters. The iterated categories were thereby used to capture the major details of the generated needs while reducing the noise. For example, needs like 'syringe should be compact' and 'smaller size' are both grouped under the category' dimension'.

Latency

Latency of a need statement was calculated based on four different factors: 1) Obvious 2) Realistic 3) Impactful 4) Implicit. The four factors were used as a means to define latency. To establish this, each recorded need statement was rated by two researchers with different design expertise (design automation and medical device design) on a 5-point Likert scale with 0 being low, 4 being high and 2 being neutral. For example, statements like 'no leakage', 'easy to handle' and 'Easily exert force injection' scored "low" for latency and statements like 'Physical feedback on the plunger to indicate how much is being pulled' and 'Opening of packet must be easier to find, grasp and open' scored "high". Figure 2-14 displays the metric used by the raters to rate the generated need statements. Any generated need statement that scored above neutral for all four factors was considered to be Latent. A 77% agreement was recorded as an inter-rater agreement, upon elimination of 1-point differences.

Latency Metric				Value
Obvious	Non-realistic	Low-impact	Non-implicit	0
				1
Neutral	Neutral	Neutral	Neutral	2
				3
Non-obvious	Realistic	High-impact	Implicit	4

Figure 2-14 Latency metric used to rate the need statements

Below is the description provided for each factor:

1) Obvious- Is it an existing solution? How likely is it for you to think of this need?
2) Realistic- Is there a real need?
3) Impactful- Is it non-obvious and real?
4) Implicit- How straightforward is the need? How hard is it to visualise?

Quantity

Quantity being the total number of needs generated by the users, this study focused only on the total number of non-repeated needs generated by the participants. This was done using the equation (Equation 2.4) by Moreno et al. (Moreno et al., 2014) that shows the relationship between the repeated *(Q_{Total})* and non-repeated ideas *(Q_{NR})*.

$$Q_{Total} = \sum \textit{All Ideas Generated} = Q_{NR} + \textit{Repeated Ideas} \qquad (2.4)$$

2.2.6 Analysis

After establishing acceptable levels of inter-rater agreement, the data was analysed for differences of latency in needs generated with the provided guidance for tool selection, relative to the needs generated through designer's instinct towards tool selection. All categorised non-repeated ideas following Phase 2 (treatment phase) were analysed to compare the difference in variety of needs generated by the participants from both groups. For this, a two-sample *t*-Test for equal variance was used following a *F*-Test that confirmed the variance of two populations to be equal.

Effectiveness of Systematic Approach Framework

As expected, both treatment groups (Groups 1 and 2) were able to provide non-repeated need statements, in addition to the wide variety of needs shared during the Phase 1. Though the difference in sample means between the two groups was not significant, participants from Group 2 on average, shared more categories of needs as shown in Table 2-6.

More interesting was the variety of needs shared by the participants under the categories that were related to the four empathy tools provided during Phase 2. Among the categories listed in Table 2-6, Tactile Feedback, volume precision, audio, holding comfort, hand control, handling, automation and packaging are the bins that were directly related to the extraordinary use cases that were emulated.

Table 2-6 Categories used to group the needs

Categories Identified	
Tactile feedback	Device features
Volume precision	Device durability
Audio	Automation
Hold and comfort	Manufacturing
Hand control	Recyclability
Handling	Materials
Safety	Packaging
Toxicity/sterility	Comfort
Dimensions	

A two-sample *t*-Test on participants' outcome for the number of specific 'extraordinary user' based needs did show a significant difference in the number of categories identified by both the groups. Table 2-7 below lists the outcome of this comparison as well as the average number of all non-repeated categories and needs shared by the participants from both the groups.

Table 2-7 Two-sample *t*-Test results: Group 1 (N_P= 20) Vs Group 2 (N_P= 17) - Comparing average number of Non-Repeated Needs, Non-Repeated Categories And Non-Repeated Extraordinary Use Categories along with Std. Deviation, Std. Error and its Significance

	Non-repeated Needs		**Non-repeated categories**		**Non-repeated Extraordinary use categories**	
Group	**1**	**2**	**1**	**2**	**1**	**2**
Mean	2.2	2.53	1.95	2.2	1.45	2.07
S.D.	1.24	1.25	1.09	1.08	0.89	0.88
S.E.	0.27	0.32	0.25	0.28	0.20	0.23
p-value	0.438		0.507		0.05	
Key			Significant difference			

Need Latency

Following inter-rater agreement on the factors for latency, the percentage of ideas that scored high in latency was calculated for both the phases and compared. A Chi-Squared test on the latent needs identified by both the groups displayed a significant (*p-value:* 0.001) increase in the frequency of latent needs shared during Phase 1 and Phase 2 but, this difference was comparatively higher among the participants from Group 2.

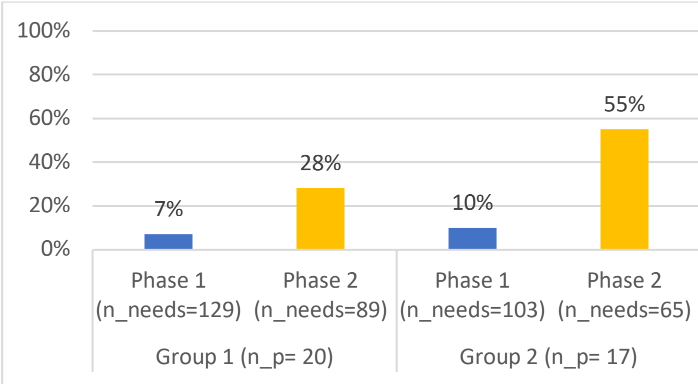


Figure 2-15 Percentage of needs that score high for latency

It is evident from Figure 2-15 that the participants with guidance on the tools (Group 2) to be used were able to realise a greater number of new latent design needs than the group without guidance. In Figure 2-15, *n_needs* denote the total number of needs shared by the participants and *n_p* represents the number of participants in each group. Table 2-8 lists few examples for regular and latent design needs classified based on the applied latency metric.

Table 2-8 Example regular and latent needs shared by the participants from both the groups

Regular needs	Latent needs
1. Non-corrosive material-not reactive to liquid (inert material) Non-toxic	1. Hand shaped, fit contours of hand
2. Need to know the amount ejected	2. Hard to falsely trigger
3. Painless	3. Easy grip of syringe (slip-proof)
4. Cannot trap air bubbles	4. Position indicator to inject
5. Sterile	5. The product is rigid and will not shift when moved
6. Needs to cater to laminar flow	6. User can push/pull fluid with one hand
7. Safe extraction of needle allowed	7. User can spin/change finger grip/ manipulate product with one hand

Empathy Tools Used

The number of empathy tools used by the participants was also captured to understand the differences in choices made by the participants while selecting the appropriate empathy tool for ideation. Participants were asked to list the number of tools they used along with their reasons for choosing those tools. The outcome shown in Figure 2-16 shows that the difference in number of empathy tools used was higher among the participants from Group 2 and this difference proved to be significant (p-value= 0.036) when tested with a two-sample t-Test.

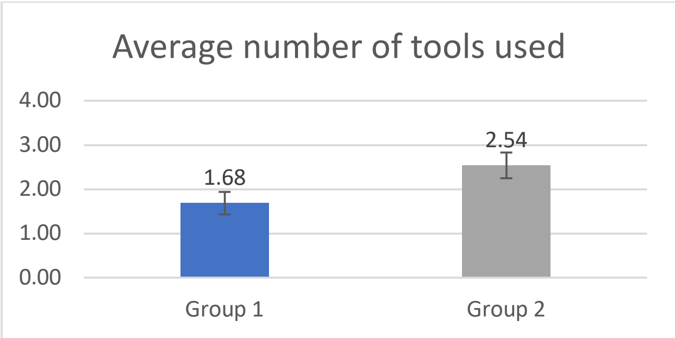


Figure 2-16 Average number of tools used with standard error

The reasons shared by the participants regarding their choice of empathy tools provided insights on how a systematic framework for selecting the empathy tools helped the designers to explore all necessary perspectives and avoid unnecessary ones. For example, participants from Group 1 picked one or two tools based on their own instinct, or used all the four tools rather than using the three tools that were most relevant to the product. Table 2-9 lists the reasons given by participants from Group 1 and Group 2 for the empathy tools they used for need-generation.

Table 2-9 Empathy Tools and Corresponding Reasons for Usage

Tools used: Group 1	**Reason**
• Low dexterity glove	• Syringes are hand operated- these are the most relevant impairments
• Eye mask	• Eyes and fluid accuracy is important in administering medicine
• Noise canceller	• To determine if hearing impairment affects usage of syringe- it doesn't
• Hand band	• Not enough grip Tests ergonomic usability with 1 hand. While possible to prime the syringe, it is difficult 1 handed. Screwing on adaptors can be tough as well
Tools used: Group 2	**Reason**
• Low dexterity glove	• To check impact of single hand dexterity on usage of syringe
• Eye mask	• To check impact of vision on usage of syringe
• Hand band	• To check performance when only one hand is in use

2.2.7 Discussion

This study evaluated the impact of a systematic approach to applying extraordinary user empathy tools in generating design needs for a standard medication syringe. An initial control study was conducted as Phase 1 to understand the baseline capability of the participants, where they were asked to share their initial need statements without the influence of any empathy tools. The participants were later divided into two treatment groups during Phase 2. During this, one group was provided with the extraordinary user empathy tools with a basic explanation of the method and inclusive design concepts. The second group was additionally given an activity diagram for the medication syringe that incorporated the physical parameters (e.g. vision, single hand usage) involved during every stage of the activity diagram. They were also guided on the corresponding empathy tools that would help them emulate a physically challenged scenario to produce the corresponding extraordinary user perspective.

The results show that the proposed framework to enhance the use of empathy tools has several major advantages over using designer instincts to decide the tools. The significant difference in participant response shared in Table 2-7 shows how it is likely that a design practitioner might miss a tool that provides a useful and relevant perspective. This is further supported by the reasons listed by the participant as shown in Table 2-9. For example, both the participants from Group 1 considered the one tool they picked to be the most relevant experience needed for a medication syringe.

Though it is natural to perceive that a greater number of tools is more advantageous in experiencing the extreme user perspectives, random selection of these tools could be an inefficient use of resources. For example, a few Group 1 participants used all four empathy tools even though hearing is not relevant while considering the interactions with a medication syringe. This was avoided among the participants who followed the systematic approach.

In addition to complementing the previous studies that proved an increased latency of design needs experienced from an extraordinary user perspective, this study also showed that a systematic approach could drastically increase the percentage (Figure 2-15) of such needs by leveraging on all possible extraordinary user perspectives that are relevant to a given product.

Based on the outcome of this study, the research question, 'Does a systematic application framework to select the "extraordinary user empathy tools", enable the designers to better leverage extraordinary user perspectives when compared to that of an instinct based selection of the same tools?' can be answered as follows: Yes, a systematic application of the framework does enable designers to better leverage the available range of empathy tools that provide an extraordinary user perspective.

2.2.8 Limitations

Being a pilot study to test the proposed approach, the study has its own limitations with regards to the sample size and other details. The shared outcomes are based on a small sample size of 37 participants divided into two groups with 20 and 17 participants respectively. External factors such as gender, age and previous experience was not considered due to this limited sample size. The sample size also prevented testing the influence of the activity diagrams alone. To compensate for this, the influence of the activity diagram was reduced by diverting the participants' focus to the identified physical parameters.

2.2.9 Conclusions and Future Work

The study results contain interesting insights about the way the empathy tools could be used when provided with and without a guiding framework regarding their association with the product that is being innovated. Below are a few key insights derived from this study:

(i) Irrespective of the application approach, extraordinary user perspectives do help designers realise new needs. Yet, providing a systematic guidance on their application helps them understand and benefit more out of such extraordinary user perspectives.

(ii) Guiding the designers towards the appropriate empathy tools has the potential to inform them about the necessary empathic lead user perspective, which in turn could result in the identification of more latent needs among the ordinary user population as well.

(iii) Moving further, the approach will be tested by expanding the sample size and by including the influence of other external factors.

(iv) The latency metric was implemented as a tool to validate the need statements and will need further revisions to ensure its reliability.

The approach was also a step towards establishing a systematic way to choose and decide on the variety of empathy tools that are available to provide an extraordinary user experience. This research aims to build a set of systematic design approaches that would incorporate such empathy tools with the current design methods. This aims to encourage and ease the implementation of extraordinary user perspectives for industries that do not necessarily target the extraordinary user population e.g. medical devices that are operated by the ordinary users.

2.3 Chapter 2: Conclusions and key findings

This chapter presents two foundational studies that analyse the impact of simulated extreme-user experiences and tested if there is a need for systematic adaptation of extreme-user experiences by answering two research questions.

How effective are simulated extreme-user experiences at enhancing design outcomes?
The extreme-user experiences presented via simulated scenarios demonstrated their capability to evoke design creativity and empathy; thereby demonstrating their potential to enhance the overall design outcomes. These results assured that adopting extreme-user experiences in a design process could significantly contribute to provoking creative new perspectives among designers. This led us to the next research question,

If simulated extreme-user experiences are impactful, how might we select the extreme-user experience(s) appropriate for a specific product, service, or system?
With a variety of extreme-user experiences that could enhance design outcomes, it is not a straightforward decision to choose extreme-user experiences appropriate for a PSS. Outcomes of the second foundational study highlighted that, without a guiding framework, participants are more likely to choose the extreme-user perspectives based on their instinct. The systematic approach provides a guided framework to leverage the right extreme-user experiences, thereby resulting in more latent needs and appropriate, resource-efficient use of extreme-use experiences.

Chapter 3
Simulated Extreme-User Experiences: Types and Application

"We can't solve problems by using the same kind of thinking we used when we created them."

-Albert Einstein

We conclude our previous chapter with the findings that supported the higher potential of systematically applied extreme-user experiences in identifying the latent design needs by evoking designer creativity and empathy. With this understanding of the impact of simulated extreme-user experiences and their implementation, this chapter tests the difference in impact attained from direct and situational extreme-user experiences. As discussed in Chapter 1, the needs experienced by extreme-users and general population users overlap during the instances where the general population users experience situational impairments (Vanderheiden, 2000). In this chapter we compare the differences in design outcomes achieved from adopting situational extreme-user experiences and direct extreme-user experiences. This work has been published in Studies in Health Technology and Informatics- Volume 282: Universal Design 2021: From Special to Mainstream Solutions under the title Simulation Tools for Inclusive Design Solutions. Following the SUTD policy on the inclusion of previously published work, we are attaching the work in its submitted form.
Co-authors include Sujithra Raviselvama, Dr Shiroq AL-Megren, Dr Kyle Keane, Katja Hölttä-Otto, Kristin L. Wood, And Maria C. Yang.

Raviselvam, S., Al-Megren, S., Keane, K., Hölttä-Otto, K., Wood, K. L., & Yang, M. C. (2021). Simulation Tools for Inclusive Design Solutions. In *Universal Design 2021: From Special to Mainstream Solutions* (pp. 210-218). IOS Press. DOI: 10.3233/SHTI210398.

3.1 Abstract

Disability has been redefined by the World Health Organization as a function of a person's interaction with the environment and not merely an innate part of a person. This redefinition highlights the need for inclusiveness in design solutions. To aid this, we apply and test the potential of different tools that restrict designers' physical abilities at deriving inclusive design perspectives among designers. Various tools and simulated conditions are often adopted in user-centered design to sup-port need-finding by

eliciting rich data on users' needs and guide designers to empathize with users. Simulation tools that restrict designers' physical abilities have been applied to understand certain perspectives of people with physical challenges, yet these tools lack the ability to evoke an inclusive design perspective among designers. Through a co-creation workshop, participants were exposed to two forms of simulations: direct and situational physical impairments. This was achieved using different tools that simulate the same physical restriction. In this study, a noise-canceller and earphones were used to simulate a reduced hearing attention. Participants were asked to generate user needs and design functions by applying both the simulation tools. The study results comprise the outcomes of 33 participants who volunteered to participate in a co-design workshop that provided a venue for them to interact and work alongside users with physical challenges. This paper analyses the inclusiveness attained through different types of simulated conditions. With a growing need to create tools and technologies that delight the user, it is necessary to equip designers with the tools that would help them with the process. The study demonstrates the application and impact of one such tool.

3.2 Introduction

Definitions for both Universal Design and Inclusive Design insists on accommodating the design needs experienced by a diverse group of users (Preiser & Ostroff, 2001; University of Cambridge, 2017b). Awareness of inclusive design practices has encouraged designers to explore various ways to understand the perspectives of such diverse user groups - particularly the older adult users and users who experience physical challenges (Cardoso & Clarkson, 2012; Raviselvam et al., 2016b). Simulating a type of physical impairment, to an extent, has enabled designers to understand the perspectives of users with physical impairments. The Third Age Suit, developed in 1990 by the Ford Motor Company (The Engineer, 2016), was one of the initial simulation tools developed to offer engineers a deeper understanding of older adult users' needs while driving. Few other simulations suits include several generations of AGNES (Age Gain Now Empathy System) age simulation suits developed by the AgeLab at MIT (AgeLab, 2019) and the GERT suit by Produkt + Projekt Design team (Groza et al., 2017).

The use of simulation tools such as AGNES and GERT have proven effective by design practitioners (Cardoso & Clarkson, 2012; Kamikubo et al., 2018), and as an educational approach to teaching design students about need-finding (Pivik et al., 2002). Nevertheless, disability simulations have been criticized due to their focus on what it would be like to newly acquire a disability without accounting forcoping mechanisms learned through life experiences (Bennett & Rosner, 2019; Colwell, 2013; French, 1992; Kamikubo et al., 2018; Kiger, 1992; Nario-Redmond et al., 2017). A meta-analysis was carried out to evaluate the impact of ten studies that assessed attitude change when simulating cognitive, visual, hearing, and orthopedic impairments (Flower et al., 2007). The review findings show that there were only small attitude changes, and, in fact, in some, the change was for the worse. Another review of ten studies that simulate visual and auditory hallucinations found participants displaying negative emotions and physical distress (Ando et al., 2011). In spite of the speculations on the application of simulation tools in impacting the attitude towards people with physical challenges, they have proven to be impactful at evoking empathy (Nario-Redmond et al., 2017) and creativity among design practitioners (Genco et al., 2012; Lin & Seepersad, 2007; Raviselvam et al., 2016a).

In addition, inclusive design studies and products support that designs that address the needs experienced by users with physical challenges, in a way address the needs that are latent among the general population users. Products such as OXO GoodGrips houseware, typewriters, Folks kitchenware for blind (Holmes, 2018; McAdams & Kostovich, 2011), StickEar (Yeo et al., 2013) and GrOpener (Sheth, 2020) are some examples of creative design solutions that were inspired from the needs experienced by people with physical challenges. Building on this, our previous work simulated different types of physical challenges to test its effect on participants' ability to apply them to identify latent user needs in medical device design (Raviselvam et al., 2018, 2019). The aim was to build medical devices that reduced physical demands when necessary and enable inclusive interfaces. Although the simulated scenarios were effective at enabling the study participants to identify latent design needs, the participants seldom viewed them as an inclusive design solution. Majority of the needs were conceptualized as a need that would specifically assist people with physical challenges and not as a need that could enable inclusive user interaction. For example, with a blindfold (simulating reduced visual attention) as the applied simulation tool, theparticipants frequently quoted '…to help users with visual challenges.'

To explore the possibilities of applying simulation tools to evoke design solutions that are more inclusive, this work studied the impact of simulating situational physical impairments and its impact on design outcomes. Situational impairments have always been insisted as a secondary reason to have more inclusive design solutions. This refersto physical challenges that are experienced due to a particular context. For example, a mother carrying a child is a single-handed user during that particular situation (Vanderheiden, 2000). Yet, simulating such situational disabilities is a less explored space for inclusive designideation. We test the impact of simulating situational disabilities by comparing them against a simulated physical impairment while answering the following research questions.

1) *Does the design outcome differ between a simulated physical challenge and a simulated situational impairment?*
2) *Does the order and type of simulation impact the inclusiveness among the derived design concepts?*

3.3 Research Methodology

This study was part of the Humanistic Co-design workshop that enabled the participants to work alongside users with physical challenges in Chennai, India. Thirty-three individuals (8 Female, 25 Male) participated in the study. Situational and direct simulation of hearing impairment was chosen as the case study. The situational hearing impairment, in this case, referred to a situation where a user has compromised hearing attention while listening to music on the earphones. To understand any potential order effects on the outcome, the participants were randomly assigned to two groups. Figure 3-1 illustrates the implemented research approach.

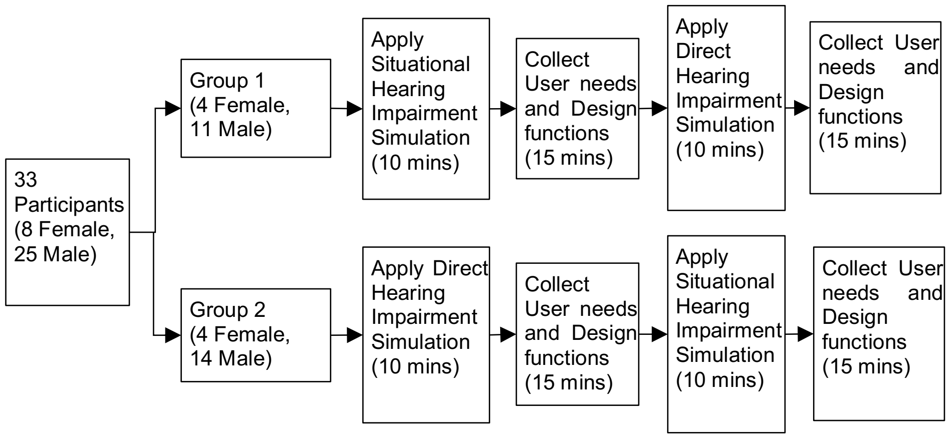


Figure 3-1 Research approach

The term 'Design functions' implied 'what must be done to the design' in order to achieve the identified user needs (Otto & Wood, 2001). The study procedures met the criteria for exemption, where an Exemption Evaluation was submitted and approved by Massachusetts Institute of Technology's Committee on the Use of Humans as Experimental Subjects (COUHES). The situational and direct simulation of hearing impairment was achieved using two conditions: 1) Noise- canceller: direct hearing impairment simulation and 2) Earphones: situational hearing impairment simulation. The order in which the participants experienced the conditions differed based on their assigned group. As illustrated in Figure 1, participants from Group 1 experienced the condition with Earphones followed by the Noise-cancellers, and Group 2 experienced the condition with Noise-cancellers followed by the Earphones.

To test the given conditions, the participants were given a scenario and were asked to place themselves in the user's perspective and engage in the simulated scenario. The simulated scenarios placed the participants at a busy train station in Chennai, India, where they intend to board a train to a particular destination. Train tickets with four varied destinations (Gao, Delhi, Mumbai, and Bangalore) were distributed amongst the participants and platform numbers (1 to 4) were placed at various locations in the study room. The noise was introduced to the room via Bluetooth speakers to replicate the ambience of a noisy station. Additionally, a number of researchers were scattered amongst the participants and were asked to imitate strangers asking for directions to a certain platform or inquiring about a departure time for a particular train. Platform announcements were carried out audibly by one of the researchers and constituted the following: "The train heading to 'CITY' will be departing from platform 'PLATFORM NUMBER' in 'MINUTES' minutes."

In the Noise-canceller condition, the scenario was presented as follows:

"*Your user is at a noisy train station in Chennai. There is an announcement being made about a rescheduled timing of their train to a particular destination. Your user is a person with hearing impairment and may not be able to hear the announcement. How would you design an announcement system that addresses this situation?*"

3M noise-cancelling headgears with additional earplugs were distributed among the participants. After reading the scenario, the participants were asked to put on the earplugs and the noise cancelling headgear to simulate hearing impairment. The simulated scenario as described above commenced as soon as all participants were in their simulation for direct hearing impairment gear. Figure 3-2 shares a scenario from the Noise-canceller condition.

Figure 3-2 Participants experiencing the noise-canceller condition using a noise-cancelling headgear

In the Earphone condition, the scenario was presented as follows:

"*Your user is at a noisy train station in Chennai. There is an announcement being made after a rescheduled timing of their train to a particular destination. You user is listening to music using noise-cancelling headphones and may not be able to hear the announcement. How would you design an announcement system that addresses this situation?*"

For this scenario, participants were asked to bring and use their own earphones. The simulated scenario commenced once the participants started to play music on their earphones. Following each scenario that lasted for 10 mins, using a google form, participants were given 15 minutes to record the user needs and design functions that are important to improve the design of the simulated announcement system. The identified design functions were used to evaluate the study outcomes.

3.4 Results and Analysis

The design functions were coded to categorize them based on the inclusiveness of the design functions shared by the participants. They were categorized into the categories:

Inclusive: *The proposed design would benefit both users with hearing impairments andthe rest of the general population users.*
Assistive: *The proposed design would benefit users with hearing impairments but would not be preferred by the rest of the general population users.*
Excluding: *The proposed design would not benefit users with hearing impairments*
Vague: *Not a clear design description*

Two researchers, one with an engineering design background and one with computer science and design background, rated a sample of the design functions sharedby the participants based on the above-mentioned categories. Upon achieving 84.2% similarity between the ratings provided by both the researchers, one researcher continued to bin the rest of the design functions. Table 3-1 lists the total number of design functions listed by the participants from both groups under each category.

Table 3-1 The number of design functions listed by the participants from Group 1 and Group 2

	Group 1 (n= 15)		**Group 2 (n= 18)**	
Categories	**Earphones**	**Noise-cancellers**	**Noise-cancellers**	**Earphones**
Inclusive	12	15	12	**12**
Assistive	0	1	8	**2**
Excluding	2	1	0	**4**
Vague	3	1	2	**1**
Total number of ideas	**17**	**18**	**22**	**19**

Results displayed in Table 3-1 shows that the Earphones condition was more impactful towards generating Inclusive design solutions among the Group 1 participants. To understand this further, Table 3-2 shares the percentage of 'Inclusive vs Only Inclusive', 'Assistive' vs 'Only Assistive' and 'Excluding' vs 'Only Excluding' design functions. While 'Inclusive' refers to the percentage of inclusive design functions identified by all participants, 'Only Inclusive' refers to the percentage of inclusive design functions listed by the participants whose 'Inclusive' category design function(s) were neither accompanied by 'Assistive' nor 'Excluding' category design functions. Similarly, 'Only

Assistive' and 'Only Excluding' refers to design functions that were not paired with either of the other two categories.

Table 3-2 Percentage of Inclusive, Assistive and Excluding design functions shared by the participants

	Group 1 (n= 15)		Group 2(n=18)	
Categories	**Earphones**	**Noise-cancellers**	**Noise-cancellers**	**Earphones**
Inclusive	86%	86%	61%	67%
Only Inclusive	64%	78%	44%	61%
Assistive	0%	7%	44%	5%
Only Assistive	0%	0%	28%	5%
Excluding	14%	7%	0%	22%
Only Excluding	7%	7%	0%	22%

A comparison between Table 3-1 and Table 3-2 shows that although the Earphones condition encouraged more inclusive solutions among both the groups, this impact was more prominent among Group 1 participants who started with the Earphones (Situational impairment) condition. Table 3-3 lists some of the ideas listed by the participants based on their categories.

Table 3-3 Exemplar design functions shared by the participants

Categories	Design functions listed by the participants
Inclusive	• We could send a message to the passengersabout the updates. • This would require a centralized displayboard. • By Placing Digital display on the platform which will be changed by getting anyresponse.
Assistive	• Adding sign language and making it visibleto everyone so Hard of hearing can understand. • A hearing aid can be given at free of cost and it can be user-friendly that is much more compatible and convenient. • A function to identify if an announcement is being made through a voice recognition system and alert the user.
Excluding	• By voice repeat announcement again.We need to design a noise filter • Automatically lower music volume.

Vague	• Should be easy to use even to kids.Getting persons attention. • Transfer of timely information.

3.5 Discussion

This study is structured with a goal to understand the impact of simulated situational impairments in generating inclusive design solutions. Two scenarios with compromised hearing abilities are simulated. While one condition directed the participants to improve the user experience of a person with hearing impairment, the other condition directed them to improve the user experience of a person listening to music over earphones. With this, we answer the two research questions introduced earlier as follows.

1) *Does the design outcome differ between a simulated physical challenge and a simulated situational impairment?*

Results observed in Table 3-1 and Table 3-2 support that the design functions identified by the participants did get influenced by each simulated condition. One interesting aspect observed among the design functions is that a majority of the assistive design functions added an additional task to the end-user. For example, a wearable that captures the sound and converts it as information thatcan be perceived by the user with hearing impairment. Whereas a majority of the inclusive design functions did not impose any additional gadget or a wearable for the user. Although both the situations expected the participants to design for a situation with compromised hearing attention, situational impairments evoked a higher percentage of inclusive design suggestions and reduced the inclination to assistive solutions.

2) *Does the order and type of simulation impact the inclusiveness among the derived design concepts?*

This could be answered from Table 3-2 where the Participants from Group 1 who experienced the simulated situational hearing impairment (Earphones) followed by simulated hearing impairment (Noise-cancellers), continued to maintain a higher numberof inclusive design functions even under a direct simulation of hearing impairment. In Group 2, while the percentage distribution was split between Inclusive and Assistive designs under the condition with Noise-cancellers, the percentage of Excluding design functions increased after experiencing the Earphones. This could be due to the possibility that the participants had already listed an inclusive or assistive design function during the previous stage and hence preferred to provide a solution more specific for the situational impairment situation. Based on the current outcomes, it would be preferable to experience a simulated situational impairment followed by direct simulation of a physical challenge. Further analysis is necessary to verify if this would be the preferable order to apply the simulations that result in more inclusive design outcomes.

3.6 Limitations and Future Work

This study is a preliminary work that explores the potential of applying a simulated situational impairment for inclusive design solutions. A small sample size that did not accommodate a rigorous statistical analysis was one of the primary limitations. Future works will focus on expanding the sample size to verify this outcome and study the impact of other potential external influencing factors, such as participant's previous experience, gender, and other demographic contexts. Following that, other types of situational impairments for vision, dexterity and single-hand usage would be tested to verify if the study outcomes hold true for other types of physical challenges.

3.7 Conclusion

A comparison between situational and direct simulation of hearing impairment was executed. The situational and direct simulation of hearing impairment was explored with two conditions: noise-canceller and earphones. Participants were randomly assigned into two groups to examine any potential order effects on the outcome (Group 1: headphones followed by noise-cancelling simulation; Group 2: noise-cancelling followed by earphones). In either condition, participants were given a scenario, which was then followed by a form to collect participants perception of user needs and design functions that are desired to improve the design of the simulated announcement system. The findings support the potential of situational impairments in evoking more inclusive design outcomes and reduced the inclination to propose assistive solutions. This impact was more prominent for the first group (Group 1) that was exposed to the situational condition followed by the direct simulation. This experiment is one of the initial attempts to study if incorporating inclusive perspectives in simulated scenarios could evoke inclusive design solutions.

3.8 Chapter 3: Conclusions and Key Findings

To answer our research question:

Do design outcomes differ between direct extreme-user experiences simulated scenarios and situational extreme-user experience scenarios? If so, how could we accommodate the differences in the extreme-user experience design framework?

The outcomes suggest that simulated situational impairments could generate more inclusive design solutions than simulated direct impairments as a standalone. Therefore, there is a difference in the type of design outcomes attained from apply situational and direct extreme-user experiences. Given that an application of extreme-user experiences in mainstream design demands more inclusive solutions than assistive solutions, it would be ideal to apply situational extreme-user experiences when designing mainstream design solutions that target a wider population of users.

With Chapters 2 and 3 focusing on simulated extreme-user experiences, their impact and implementation, Chapters 4 and 5 will test the outcomes derived from systematic application of these extreme-user experiences.

Chapter 4
Systematic Application of Extreme-user Experiences: Medical Device Design

"Research is turning the unknown into reality."

— Steven Magee

Based on the foundational and implementational understandings from Chapters 2 and 3, this section shares the preliminary results that tested the influence of the Activity Diagram (with Journey Map) on design needs and ideas generated by the students of a Medical Device Design Course at SUTD. The study applies the extreme-user experiences along the initial stages of the design process to help design students identify the latent needs of six different medical devices. Students used Activity Diagrams for a systematic application of extreme-user experiences. Six teams with a total of 25 students took part in the study. Outcomes support the potential of extreme-user experiences in capturing the latent design needs in medical device design. We apply an evolved version of the Latency metric shared in Chapter 2 to validate the identified needs and discuss the latency metric's impact in evaluating the latency of design needs.

4.1 Abstract

Extreme-user experiences refer to experiences that simulate the extremes of user abilities like reduced or no visual attention or auditory attention. Inspired by the needs experienced by the users who experience physical or cognitive challenges, extreme-user perspectives can make designers understand their designs from an inclusive design perspective and yet address the latent needs experienced by their users. This study applies the extreme-user experiences along the initial stages of the design process to help design students identify the latent needs of six different medical devices. Students used Activity Diagrams for a systematic application of extreme-user experiences. Six teams with a total of 25 students took part in the study. Outcomes support the potential of extreme-user experiences in capturing the latent design needs in medical device design. We apply a latency metric to validate the identified needs and discuss the metric's impact in evaluating the latency of design needs.

4.2 Introduction

Biomedical Engineering education has evolved significantly over the past 50 years by adapting to the trends and resources available in engineering education (Linsenmeier & Saterbak, 2020). Design-embedded education is one such adaptation (Tamsin & Bach, 2014). Consequently, design processes and corresponding design methods are gaining increased attention in Healthcare education (Cafazzo & St-Cyr, 2012; Ranger & Mantzavinou, 2018). While various adaptations of design processes are available ((DI) Learning Modules, 2021; Gericke & Blessing, 2012; IDEO, 2021; University of Cambridge, 2017b), they ultimately aim to encourage a user-centric design approach that teaches creative and innovative mindsets.

A user-centric design approach is even more important in medical devices as user interactions with medical devices form a critical part of a successful healthcare system, mainly due to multiple stakeholders who interact and experience the medical devices. In addition, medical device design demands compliance towards various other regulatory and ethical factors (Cafazzo & St-Cyr, 2012; Wass & Vimarlund, 2016). Considering these factors that influence medical device design, Lerner et al. (Lerner et al., 2006) define the role of Design in Biomedical Engineering as:

"Design in biomedical engineering means the conception, creation and/or fabrication of devices, instruments, fixtures, procedures, methods, algorithms or simulations intended to benefit health and wellness, including means to interrogate, analyze or otherwise define operating or physical parameters."

It has been a couple of decades since the release of *'To Err is Human' (Kohn et al., 2000)* which demonstrated a need for Human Factors Engineering (HFE) in healthcare design. There is currently an increase in the attention given to fix the device rather than fixing the user (Cafazzo & St-Cyr, 2012). As a result, Design processes and HFE approaches strive to ensure the efficient functioning of these devices by considering the physical and cognitive limitations in human abilities (Saidi et al., 2019; Shouhed et al., 2012). Yet, works acknowledge that this change in healthcare is still in its developing stage compared to other industry counterparts like aviation (Parker, 2015). Studies highlight that the increased weightage for error prevention imposes limited opportunities for innovation and consideration for contextual factors. For example, a device that is successful in terms of regulations might not be a real-world success. HFE adapts Design Thinking processes to complement user-centric design (Saidi et al., 2019).

Biomedical Engineering education modules allow students to develop solutions to the real-world design issues imposed by medical devices and helps them adopt a user-centric approach to address the needs shared by healthcare professionals (Hanumara et al., 2013; Linsenmeier & Saterbak, 2020; Wall et al., 2017). The study shared in this paper complements the current efforts to bring a user-centric mindset through the systematic application of extreme-user experiences. Extreme-user experiences that adapt the perspectives of users with some form of physical or cognitive challenges possess the ability to bring creative new perspectives among designers (Genco et al., 2012; Lin & Seepersad, 2007; Raviselvam et al., 2016a).

This study adapts extreme-user experiences to enable students to experience their designs under limited physical abilities. Given that healthcare professionals experience various situational challenges to their physical and cognitive abilities under high-stress scenarios (Dias et al., 2018, 2019; Kennedy-Metz et al., 2021; Ward & Clarkson, 2004; Zenati et al., 2020), a systematic adaptation of such extreme-user experiences could help designers understand the latent yet essential needs that could influence user experience.

Assistive and inclusive design research usually apply simulated extreme-user experiences to impose physical restrictions that limit the abilities of designers and students (AgeLab, 2019; Cardoso & Clarkson, 2012; Deane et al., 2008; Kullman, 2016; Ranger & Mantzavinou, 2018; Vaughan et al., 2015). While it is ideal and essential to engage actual users, these experiences can influence designers' creativity to approach a user need. Therefore, this research applies wearable simulations as a design tool that imposes situational physical limitations for creativity through extreme-user experiences and not as a replacement for actual user engagement. Our previous study (shared in Chapter 2) with undergraduate students showed that a systematic application framework that guides them through the process is more effective than an intuition-based approach to applying such perspectives (Raviselvam et al., 2018). This study shares the systematic approach followed and tested among 25 students from six different design teams who worked on six healthcare design projects proposed by the healthcare professionals in Singapore. The approach discussed in this chapter comprises a combination of Activity Diagram ((DI) Learning Modules, 2021; Otto & Wood, 2001) and extreme-user experiences. Parallel or sequential blocks connected through arrows form the Activity Diagram that helps break down user interactions with a product service or system. Through this study, we seek answers to the following research questions:

1) How do students respond to the systematic application of extreme-user perspectives in medical device design?
2) What are the specific design outcomes derived from applying the extreme-user perspectives?

4.3 Research Methodology

The Healthcare Design Course at the Singapore University of Technology and Design is a 12-week long course offered for senior year undergraduate students and graduate students as an elective for the

Engineering Product Development (EPD) Pillar (epd.sutd.edu.sg). This study engaged all 25 students from the 2019 cohort, where one was a first-year graduate student, and the remaining 24 were senior year undergraduate students. The age group of the students ranged from 21 to 26 (average 23). The researcher assured the students that their response to the study would not affect their course grades, and the study did not collect any personal identifiers from the students. All study procedures followed the regulations and approval from the SUTD International Regulatory Board (IRB).

4.3.1 Week 1 and Week 2:

During Week 1 of the course, healthcare professionals from hospitals and medical device design companies in Singapore shared their project pitches based on the design needs they experienced. Among the 12 proposed projects, students selected six projects on a first-come, first-serve basis. Following are the shortlisted projects with their description.

1) **Catheter Guidewire Safety:** As the name suggests, catheters use guidewires during a catheterization procedure. Clinicians remove the guidewires once catheter insertion is complete. There are rare instances where the guidewire gets left behind in the patient's body, leading to stringent guidelines/checklists that guide the healthcare professionals—this project aimed to prevent healthcare professionals from leaving the guidewires behind after the catheterization procedure.
2) **Biopsy Needle Stabilization:** Biopsies is a procedure that helps diagnose pathological tissue with minimal invasion. The needles used for such biopsy procedures are guided freehand to the precise tissue area, but maintaining the angle and precision required is challenging once the clinicians release the needle from their hands. This challenge leads to several iterations, tissue damage, and increased exposure to radiation—this project aimed to design a stabilizer that holds the biopsy needle in place and enhances its usability.
3) **Traction Device for Shoulder Dislocation:** A commonly dislocated joint in the human body is the glenohumeral joint at the shoulder. Relocating the dislocated joint could take an hour or two, depending on the availability of a skilled professional. This project wanted a design solution to effectively relocate the shoulder within a short duration without a need for sedation.
4) **Guidewire Introducer**: Endovascular procedures are a less invasive alternative for more complex surgical procedures. Depending on the procedure, this task demands the healthcare professional to thread the guidewires multiple times to the respective sites for intervention. This project aimed to automate the process of introducing the guidewire to increase the efficiency of the procedures.
5) **Neonatal Health Monitor:** It is crucial to monitor the independent functioning of a Newborn as the baby adapts to the conditions outside the womb. The current capacity at Singapore hospitals outnumbers nurses at the ratio of 1:140. Therefore, this project aimed to build a neonatal monitoring system that will aid nurses in monitoring Neonates' health status.

6) **Cuffless Blood Pressure Measurement:** Blood pressure is one of the primary vitals measured at hospitals. However, this demands more time and attention from the nurses, especially the positioning of the cuff. Hence, this project focused on developing a cuffless non-intrusive way to measure Blood Pressure among hospitalized patients.

During Week 2, the students started their literature reviews, benchmarking, and user interviews to strengthen their understanding of the project and user needs. Following Week 2, Week 3 and Week 4 focussed on testing the impact of the systematic application approach for extreme-user experiences. Figure 4-1 shares the step-by-step research approach followed and their time distribution during Week 3 and Week 4.

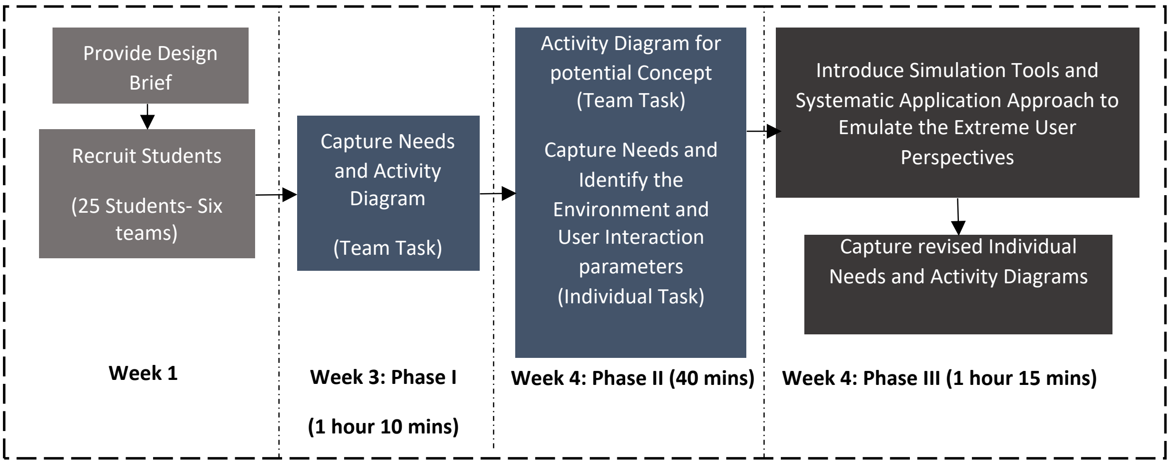


Figure 4-1 Research approach

4.3.2 Week 3- Phase I:

At the beginning of Week 3, students had their briefing on Activity Diagrams ((DI) Learning Modules, 2021; Lauff et al., 2021; Otto & Wood, 2001). Students were already aware of the Activity Diagrams from the Introduction to Design Course offered during their freshmen year. Following this, teams created an Activity Diagram for the existing medical procedure followed for their respective projects. Students recorded their responses for each phase of the study using separate questionnaires. Students listed the user needs they had captured from their user interviews and benchmarking and highlighted any additional needs they could identify from their Activity Diagram. The researcher informed the teams that every team member had to agree with the final set of needs and the Activity Diagram before submitting their questionnaire sheets.

In between Week 3 and Week 4, the Activity Diagrams and needs were verified and transcribed by a design researcher. The researcher printed the transcribed set of needs and Activity Diagrams for each student to refer to during Week 4.

4.3.3 Week 4:

Week 4 comprised two phases: Phase II and Phase III. One of the students was not present during Week 4; therefore, we had 24 students participate in Phase II and Phase III.

Phase II: Teams already had their potential design concepts ready for their respective projects by Week 4. Before proceeding to individual responses, teams again generated Activity Diagrams for their likely design concept to ensure common understanding among all teammates. Once the teams developed their Activity Diagrams, students were given individual coded questionnaire sheets along with the transcribed Activity Diagrams and needs identified during Week 3. Coded questionnaires helped differentiate individual responses without collecting personal identifiers from each student. Students did not flip through the questionnaires until they arrived at the corresponding stages. Each student had 15 minutes to revisit the initial set of needs they had identified as a team and amend them if the needs had evolved in between.

Among the questionnaires, students had a list of variables that could influence a user's experience with their medical devices. The variables included extreme-user experiences like vision, hearing, and other spatial extremes. Table 4-1 shares the list of extreme-user variables used for the study. Although this study did not apply the environmental extremes, this list helped understand the variables associated with the user's experience of respective medical devices without receiving guidance from the proposed systematic application framework. Students proceeded to the next phase once they set aside their filled questionnaires.

Table 4-1 List of user experience variables

User Demography	Ethnicity
	Gender
	Language
	Age (Older Adults above 65)
	Age (Kids)
	Height
	Physical Challenges
	None (Anyone can use my product)
	Other:
Use Environment	Temperature
	Weather
	Space required
	Height at which the product is placed
	Sound
	Other:
User Interactions	Visual
	Auditory
	Tactile (Touch)

	Spatial
	Memory
	Physical Strength
	Both hand usage
	Finger Dexterity
	Olfactory (Smell)
	Gustatory (Taste)
	Other:

Phase III: This phase involved identifying and applying wearable simulations that reduced physical abilities using the systematic application approach tested in Chapter 2. Students received a 10-minute briefing on extreme-user experiences and their potential in medical device design. Following this, they had five minutes to familiarise the given wearable simulations.

4.4 Metric Used: Latency Metric

Due to the unavailability of any published metric to calculate latency, we developed a metric for latency to understand the impact on the needs identified at each phase. We applied the initial version of this metric for the pilot study that tested the need for a systematic application framework in Chapter 2. The version shared here is modified based on the observations from the previous study. Latency refers to the needs that are important yet not obvious to the average user. The metric comprises the factors that define latency, like impact and the implicit nature of the needs. Raters used the definitions below as the key to evaluating the latency of needs. In this version, a four-scale evaluation was adapted to overcome the 'social desirability bias' (Garland, 1991) that could influence the ratings. The scale ranged from 'Strongly Agree' to 'Strongly Disagree.'

- Impactful: The need has the potential to create a real difference. This need will delight the user.
- Obvious: In all circumstances, the majority of the users will express this need. If 20 users are interviewed, the majority will share this need.
- Inefficient: This will not have a positive effect on the user experience. It is not going to improve the experience with the product, service, or system.
- Implicit: This is not a standard requirement shared by the user. Not a common requirement given to the designers.

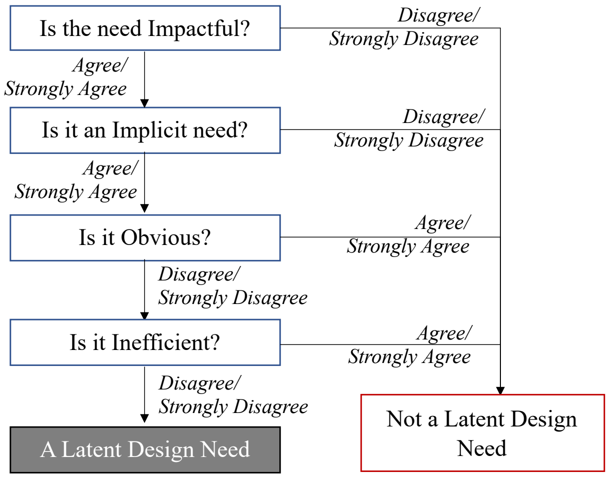


Figure 4-2 Flow followed to determine the latency of a need

Figure 4-2 illustrates the flow followed apply the four factors used to determine latency. The factors' Obvious' and 'Inefficient' were used to verify the consistency of responses received for 'Inefficient' and 'Implicit,' respectively. Table 4-2 gives an exemplar rating for the needs identified for a medical device that helps thread guidewire during the catheterization procedure (one of the projects shared in this chapter). Due to the current rudimentary structure of the metric, we categorized any need that received Strongly Agree or Agree for 'Implicit' and 'Impactful,' and Strongly Disagree or Disagree for 'Obvious' and 'Inefficient' as 'Latent needs'.

Table 4-2 Exemplar latency ratings for needs identified for a medical device

Needs	Source	Impactful	Implicit	Obvious	Inefficient
Bio-compatible	Requirements	+2	-2	+2	-2
The product needs to allow for quick and intuitive threading	User	+2	+1	+1	-1
Be integrated with the catheter	User observation	+2	+1	-1	-2
Product needs to be easily handled with one-hand	Ideation	+2	+2	-2	-2

4.5 Experimental Results

4.5.1 Latent Needs

Student outcome evaluations validated: 1) Impact on Needs: the type of design needs identified by the students during each phase of the study, and 2) Understanding of Extreme-user variables: Number of appropriate extreme-user variables students could identify.

Impact on Needs

We evaluated the impact on needs using the number of latent needs identified by the students. Table 4-3 shares an exemplar set of design needs shared by the students. Appendix B shares a detailed list of needs shared by each team. Table 4-4 highlights the total number of needs and latent needs identified by each team. It shows that the students could generate more Unique and Latent needs after applying the extreme-user experiences.

Table 4-3 Exemplar set of latent and non-latent needs identified by the participants

Exemplar Latent Needs	Exemplar Non-latent needs
• Less demand on memory • The device should be functional under single-handed use, for both left and right hand(s) • Specific to guidewire used, not easily hacked • The product needs to be less visual with its outputs	• Less demand on memory • The device should be functional under single-handed use, for both left and right hand(s) • Specific to guidewire used, not easily hacked • The product needs to be less visual with its outputs

Table 4-4 Number of needs and latent needs identified by the teams during Phase I, Phase II, and Phase III

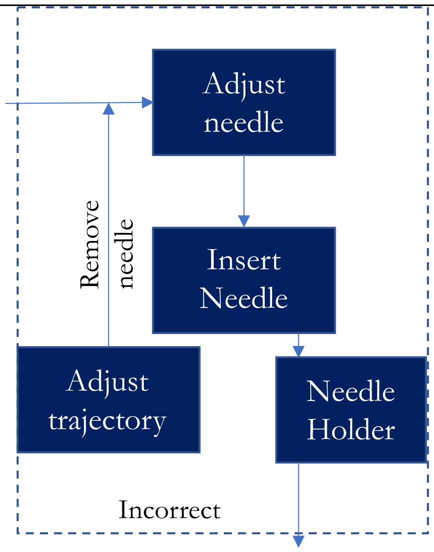
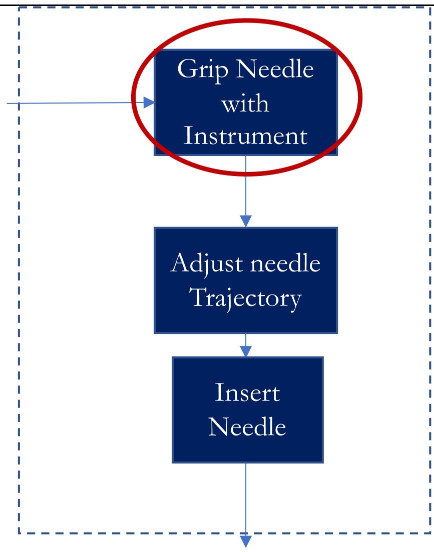
	Phase I		**Phase II**		**Phase III**	
Projects	**Needs**	**Latent Needs**	**Needs**	**Latent Needs**	**Needs**	**Latent Needs**
Project 1: Catheter Guidewire Safety	5	1	6	0	6	2
Project 2: Biopsy Needle Stabilization	8	0	4	0	17	4
Project 3: Traction Device for Shoulder Dislocation	9	0	0	0	12	2
Project 4: Guidewire Introducer	11	1	1	0	6	2
Project 5: Neonatal Health Monitor	5	1	3	0	9	5
Project 6: Cuffless Blood Pressure Measurement	5	0	0	0	9	6

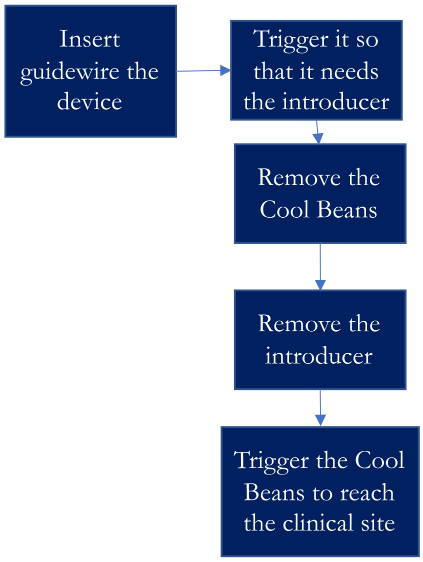
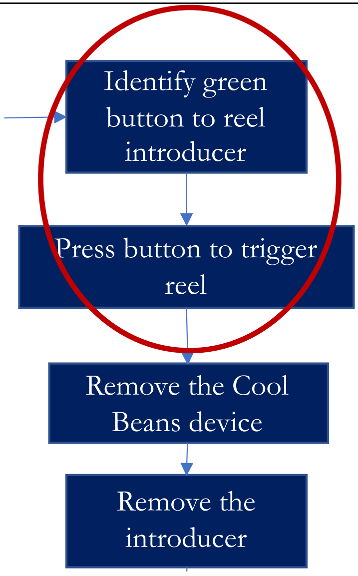
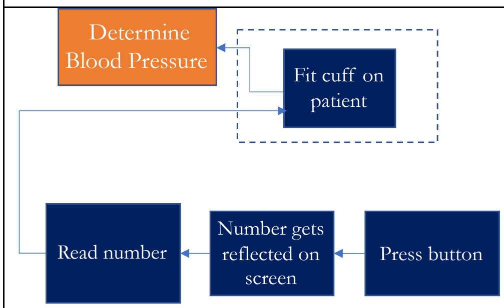
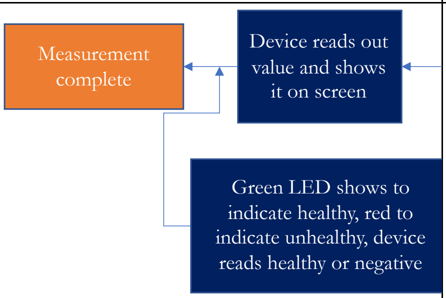
	Phase I		Phase II		Phase III	
Projects	**Needs**	**Latent Needs**	**Needs**	**Latent Needs**	**Needs**	**Latent Needs**
	43	**3**	**14**	**0**	**59**	**21**

In addition, the Activity Diagrams shared by the teams helped compare the changes implemented by the students based on the needs they identified before and after applying the extreme-user experiences. Table 4-5 shares a few notable changes observed in the Activity Diagrams illustrated by the students.

The students prominently identified needs related to the challenges that could arise due to reduced dexterity, visual attention, distractions, and single-hand usage. For example, students from Project 4 understood the need to make their device reduced-dexterity proof to ensure that the clinicians do not operate the wrong functions. They also assured that their device is ambidextrous to make it easier for their clinicians. In addition, students identified more user experience-specific needs after applying the extreme-user experiences. They could locate specific touchpoints of user interaction where their design should be more conscious of the use context, especially when there is a time constrain. For example, dexterity was a concern when the clinicians had to thread the guidewire during a procedure compared to the dexterity needed to hold a patient's arm.

Table 4-5 Notable differences in activity diagrams shared during Phase II and Phase III

<table>
<tr><th>Specific Activity Illustration-Phase II</th><th>Specific Activity Illustration-Phase III</th><th>Type of Design Change</th></tr>
<tr><td>
</td><td>
</td><td>Modifications to accommodate single hand usage when multiple tasks happened in parallel.</td></tr>
</table>

<table>
<tr>
<td>
</td>
<td>
</td>
<td>Introduced a button to avoid triggering the guidewire by accident.</td>
</tr>
<tr>
<td>
</td>
<td>
</td>
<td>Introduced an informative display to help non-experts.</td>
</tr>
</table>

4.5.2 Applying Extreme-user variables

The extreme-user variables questionnaire helped observe the impact of the proposed approach on identifying and applying extreme-user experiences that influence a user's interaction with a device. Outcomes showed that the student's ability to determine the appropriate extreme-user variables improved after using the systematic approach along their design process. This increase in similarity between Phase II and Phase III was significant when analysed using a paired sample *t*-Test ($t(22) = 3.5, p<0.005$) on SPSS Statistics (Version 25.0.0.1, IBM Armonk, N.Y., USA). Yet, we also identified gaps that proper guidance could fix while applying the extreme-user experiences. Figure 4-3 shows the similarity in extreme-user perspectives identified by the design researcher versus those identified by the students.

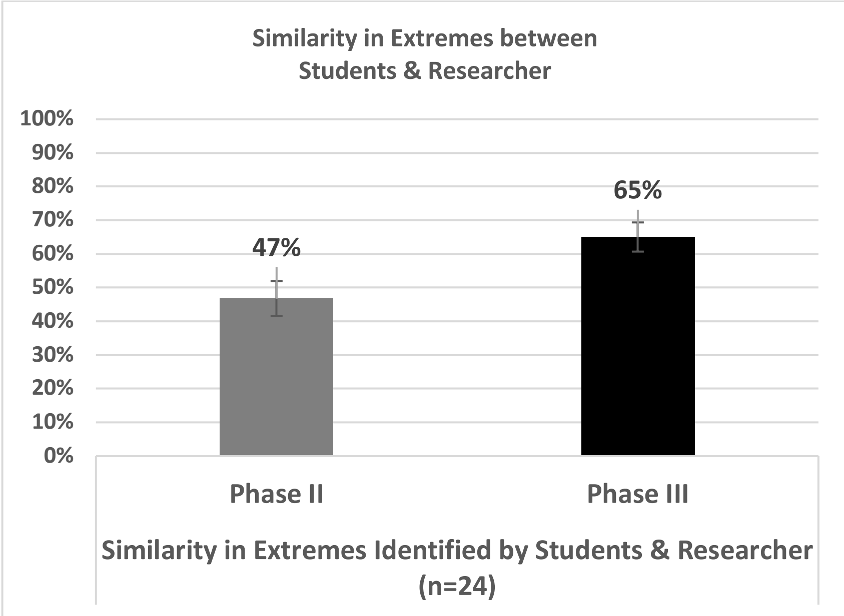


Figure 4-3 Similarity in extreme-user variables (physical parameters) identified by the researcher and the students (with standard deviation)

4.6 Discussion

The foundational study shared in Chapter 2 compared the impact achieved by guided and non-guided approaches to apply extreme-user experiences showed that a guided approach is more impactful at helping designers leverage the most from the extreme-user experiences. Research works on creativity highlight the intrinsic and extrinsic triggers for creativity, and design research has focused on various methods that contribute towards the same over the past decades. The study in this chapter shows that the simulated extreme-user perspectives served as one such extrinsic trigger for creativity.

The results showed that the students could identify a significantly higher number of latent needs after applying the extreme-user experiences. Similarly, they were able to identify a greater number of extreme-user experiences appropriate for their devices. Despite the significant increase in the similarity between the researcher and the students, the impact was not uniform.

Following are the inferences from the outcomes of this study that applied the Activity Diagrams to identify extreme-user experiences appropriate for medical device design.

There was an overall increase in the number of needs, including latent needs, generated by the students. In addition, students could identify specific user interaction-based needs that the users could experience while interacting with their designs. The type of needs listed after applying the extreme-user experiences demonstrates the specificity in the identified needs. For example, after Phase II, the needs shared (Appendix B) reflected an in-depth perception of specific interactions with their designs. Observations on student responses shared additional inferences that could help future expansions of the proposed approach:

a) The responses shared by the students showed a disparity in their understanding of certain extreme-user variables. For example, most students did not state spatial awareness as a user-experience variable that influences the user's interaction with the product. Whereas spatial awareness has a strong influence on a healthcare professional's attention, especially when dealing with surgical procedures. For example, in Project 4, the design aims to help physicians thread a guidewire during a surgical procedure that demands increased spatial attention. Yet, but none of the students from Projects 4 identified this variable.
b) Similarly, while height was associated with the need to stand while interacting with the product, students did not interpret it in such a manner. For example, the extreme-user variable questionnaire had 'Other' as an option to fill in any variable not captured in the list. Students used this option to list 'the need to stand while interacting with the product' as an extreme. These discrepancies reflect a lack of understanding of such variables. Hence, we need to provide clear definitions of the extreme-user variables before implementing the proposed approach.
c) While students identified physical factors such as vision, hearing, and hand usage as impacting extreme-user variables, only a few linked physical challenges to extreme-user variables. This understanding would be essential, especially while designing home healthcare solutions handled by a wide range of users, unlike the devices used in clinical settings. Home healthcare is one area of application where designers could use the proposed approach to evaluate the inclusiveness of specific designs. This inference is in line with the approach followed by the Cambridge Engineering Design Centre (Goodman et al., 2011; Ning et al., 2019; University of Cambridge, 2017b), where they used user activities to calculate the exclusion imposed by a device.
d) Although few students did not indicate certain associated extreme-user variables, their rationale for their needs showed the influence of such variables. For example, Student 14 from Project 4 did not identify any of the primary extreme-user variables provided in their variable list. Still, they had identified a need to address limited dexterity while interacting with the device. Therefore, the impact of applied extreme-user experiences could be even higher than reflected in the data.
e) The needs identified by a few participants focussed more on the applied extreme-user perspective than on the design aspects of the device, thereby listing accommodation for extreme-user experience as a need. For example, needs like 'support single hand interaction' or just 'dexterity'. Such needs do not share the design aspects, like which component needs to support single-hand interaction or dexterity.

The needs and Activity Diagrams shared by the students helped assess the design changes that appeared after applying the extreme-user perspectives. Detailed observations from the needs and activity diagrams generated by the students include:

a) Design modifications accommodated instances where the users would find it challenging to use both hands (refer to Table 4-5).
b) Detailed understanding of user-interaction-related needs. For example: 'Ease of use' was a common need identified before experiencing the extreme-user perspective. Whereas, after experiencing the extreme-user perspectives, students listed more specific design needs like 'Easy to adjust (strength and dexterity) and Easy to use (less demand on memory)' to ease the users' experience with their design.
c) Students had an increased awareness of the physical and cognitive abilities needed to interact with their devices. The majority of the needs shared in Appendix B, after applying the extreme-user experiences, demonstrates its association with the user's interactions with their devices.
d) Identification of instances where users will need to be informed about the device's status and how this information should not rely on visual attention alone. For example: 'Audio cue for the readings. Give readings without visuals.' shared by students from Project 6 to inform nurses of the blood pressure values (Appendix B).
e) Increase in needs that addressed any potential user-interaction-related error or mishap. For example, the students from Project 4 identified 'Clear distinction/ indication if the direction of movement- Lights/ clear indicator' to prevent the users from selecting the wrong direction of insertion for their automated Guidewire introducer.

4.7 Limitation and Future works

The main limitation of our study is the small sample size. Any future expansion of this work needs to test the effectiveness among a wider sample size. In our future work, we aim to make the proposed approach more systematic by incorporating it with the findings from cognitive load theory. Cognitive load theory states that a user's mental demand increases when multiple interactions simultaneously rely on the same resource centre or modality(Dias et al., 2018; Mousavi et al., 1995; Sepp et al., 2019). For example, spatial and visual attention are linked to the same resource centre in the brain. Therefore, a key question for future expansion of the proposed approach is

'How might we guide designers to identify appropriate interactions where extreme-user perspectives could be applied and thereby generate user-interactions that reduce the mental demand experienced by healthcare professionals?'

This study applies the latency metric that was adapted to evaluate the needs generated by the students. But this metric is still at its rudimentary state, and it will need to be validated further before any formal adaptation as a latency evaluation metric. Nevertheless, the responses received from healthcare professionals who used the latency metric helped understand their perspective over the generated needs. Therefore, future works could also look into adapting the metric to establish good communication with healthcare professionals. Another potential application of this metric could be to rank the ideas based on their latency and user preference. For example, needs that receive *Strongly Agree* for both 'Implicit' and 'Impactful,' and *Strongly Disagree for both* 'Obvious' and 'Inefficient' can be a 'High Priority Latent needs'. Needs that receive *Strongly Agree* for 'Implicit' and *Agree* for 'Impactful' or vice versa, and *Strongly Disagree for* 'Obvious' and *Disagree* for 'Inefficient' or vice versa can be 'Medium Priority Latent needs'.

Similarly, the needs that receive *Agree* for both 'Implicit' and 'Impactful', and *Disagree for both* 'Obvious' and 'Inefficient' can be a 'Low Priority Latent needs'. It is to be noted that latent needs are not necessarily the primary needs, but they add value to the users' primary, more obvious needs. This ranking of needs could help student teams to include the needs that would delight the user.

4.8 Conclusions

This chapter considers an approach for a systematic application of extreme-user perspectives to complement the design processes adapted for medical device design education. The outcomes share the impact observed on student projects that addressed six real-world medical device design opportunities proposed by clinicians who interact with the respective devices. This study is part of a larger framework that systematically applies extreme-user experiences throughout the design process. We believe the approach shared in this chapter could help medical device design professionals to have a first-person experience on the nuances of user needs that get missed in the current design process and build better designs that could prevent the mishaps associated with medical device design.

4.9 Chapter 4: Conclusions and Key Findings

The study considered in this chapter adopts a combination of Activity Diagrams and Journey Maps to systematically identify the extreme-user experiences appropriate for six medical devices and tested the impact on the needs and concepts generated by the participants. The outcomes from this study share fascinating results and demonstrate the potential of extreme-user experiences in changing designers' perceptions over their design solutions. This study applies direct extreme-user experience simulations to alter participant design perspectives. As a result, we notice that some of the identified needs directly reflect the physical challenge they encountered by adopting the extreme-user experiences. These needs are vague and without any design context. Therefore, the systematic application approach shared in the next chapter applies system functions with the morphological matrix to balance the focus on the user and device (J. M. Hirtz et al., 2001).

Chapter 5
Systematic Application of Extreme-User Experiences: Inclusive Privacy and Security

"User-centered design means understanding what your users need, how they think, and how they behave – and incorporating that understanding into every aspect of your process."

-Jesse James Garrett

Previous chapters demonstrate the benefits of extreme-user experiences and the potential of situational extreme-user experiences in guiding more inclusive design solutions. We also tested systematic application of extreme-user experiences and its impact in identifying latent user needs in medical device design. This chapter empirically tests another systematic application approach that focuses on concepts developed by applying situational extreme-user experiences. The morphological matrix method is adapted to enable concept development based on extreme-user experiences. Eighteen experts from security, human-computer interactions, and design participated in the study. This study was part of a collaboration project that focused on ensuring inclusive privacy and security in mobile phone browsers for older adult users. In comparison, the analysis shared in this thesis focuses on studying the impact of the morphological matrix as a tool to generate inclusive design solutions. We compare the outcomes with the concepts generated by applying older adult user persona and a control with no user profile. We test the concepts developed from all three methods among 30 users from different age groups (above 21).

5.1 Introduction

Inclusion in UI/UX design is well recognised and advocated by various organisations and research groups, and it has become even more critical with a growing need for usable security. Consequentially, there is an increase in recognition of the role of humans in building such cybersecurity systems. Usable security is a broad topic, and various factors determine the usability of an interface. Lennartsson et al. (2020) recently explored the key aspects of usable security based on the previous five years of research. Adaptability to a user's abilities, the time needed to ensure security, simplicity, and consistency are some of the aspects identified through their review. Alternatively, there is also a focus on providing sufficient resources that equip developers to build usable security mechanisms (Acar et al., 2016; Senarath et al., 2019; Senarath & Arachchilage, 2018). Despite such increasing interest for usable security, the existing user interface, especially on mobile phones, are becoming even more complex for extreme-users like older adults (Petrovčič et al., 2018).

Recent works highlight the necessity for better UI/UX solutions that holistically address the needs experienced by older adult users (Petrovčič et al., 2018). Even with the existing recommendations and guidelines, only a fraction of the works diligently includes them in their design (Almao & Golpayegani, 2019; Nurgalieva et al., 2019). This gap in design accommodation for diverse user groups is becoming an even more significant threat in smart cities and nations like Singapore. A whopping 82% of older adult users (above 55 years) are internet users in Singapore (*Singapore Digital Marketing Statistics 2020*, 2021), and over 56% of the older adult users are smartphone users (Han et al., 2021). Being a nation with a diverse population of users adopting smart technology, Singapore has seen a significant rise in scams over recent years. The year 2020 saw a 65.1% increase in the number of scams reported compared to 2019. Despite the efforts to bring awareness, users still fall victim to cybercrimes like e-commerce and bank phishing scams (*Singapore Police Force*, 2021). While the current steps are more around developing awareness among users, developers need to understand the role of user interfaces in delivering unusable security.

With growing awareness of the benefits of inclusive design, most works focus on the needs experienced by extreme-users like the older adult users as an assistive or specific need shared by a niche user group. While rich resources contribute to participatory design with the older adult users (Gorski et al., 2020), not many provide a systematic approach to adopt inclusive design perspectives for creative design concepts that could benefit more users (Erdtman et al., 2021; Pardo, 2018; Zeagler et al., 2018).

Chapter 2 in this thesis demonstrates the overlap in the primary and latent needs among older adult users and general population users, respectively. From Chapter 3, we understand that situational extreme-user experiences can evoke more inclusive design perspectives compared to direct extreme-user experiences. The study discussed in this chapter proposes an adaptation of morphological matrix to systematically apply situational extreme-user perspectives for design ideation. Morphological matrices are used to conceptualise and ideate new ways of tackling design opportunities. A morphological matrix comprises a set of system functions that contribute to building a complex system. Each system function receives multiple design solutions shared in rows and columns in the form of texts or figures (Fargnoli et al., 2006; J. Hirtz et al., 2002; J. M. Hirtz et al., 2001; Jensen et al., 2009). Several research works have leveraged this method to generate diverse concepts within a short duration (Bryant et al., 2009; LIU Xi-ze & LIU Xi-ze, 2012; Williams et al., 2011). Designers could ultimately have concepts that systematically combine different combinations of solutions to achieve each system function. This study applied a morphological matrix to convey the system-level adjustments that were required to accommodate the extreme-user experiences without attaching them to the extreme-user abilities or disabilities. We compare the outcomes with the ideation outcomes using older adult user personas (Camburn et al., 2017; Lauff et al., 2021) that shared direct extreme-user perspectives and a control that did not provide any extreme-user perspectives. The second half of the study tests if the design concepts from the ideation phase are preferred among the older adult users and the general population users.

Ultimately, we aim to answer the research question, *"How does the morphological matrix transform the situational extreme-user needs into inclusive design solutions?"*

5.2 Research Methodology

The study commenced by using three opportunity statements based on the needs experienced by older adult users. The needs were extracted from a study that looked into the privacy and security related challenges experienced by the older adult users in Singapore regarding mobile phone interfaces (Pakianathan, 2020). How Might We (HMW) statements were used to frame the extreme-user inspired opportunity statements ((DI) Learning Modules, 2021; Lauff et al., 2021). The three opportunity statements were:

Opportunity Statement 1: How might we redesign the detection of malicious URLs to prevent phishing?

Opportunity Statement 2: How might we improve password hygiene among users to reduce password compromise risks?

Opportunity Statement 3: How might we provide critical information on apps' data collection in a format that is easy to understand for the users?

A total of 18 experts with experience in cybersecurity, human-computer interaction, and design, participated to ideate for the three opportunity statements by adopting three methods for ideation. The acceptance for a set of concepts generated during the ideation phase was tested among 30 users who represented both the older adult users and the general population users. All study participants were smartphone users and residents of Singapore. Participants signed up for the study using the participant signup forms distributed by leveraging Singapore's design research ecosystems like social media groups and research forums. Participant distribution comprised 12 young adult users (21-54), six young-old adult users (55-64), and 12 older adult users (65 and above) (*Age*, 2019). Participants between 55-64 were grouped separately to make the age distribution distinct between the older adult users (extreme-users) and the general population users (Raviselvam et al., 2016b; Singapore Department of Statistics, 2020). Each study participant was provided with vouchers worth SGD10 as compensation for their time and effort. All study procedures followed the protocol approved by the SUTD Institutional Regulatory Board (IRB). Figure 5-1 displays the research approach followed for the study.

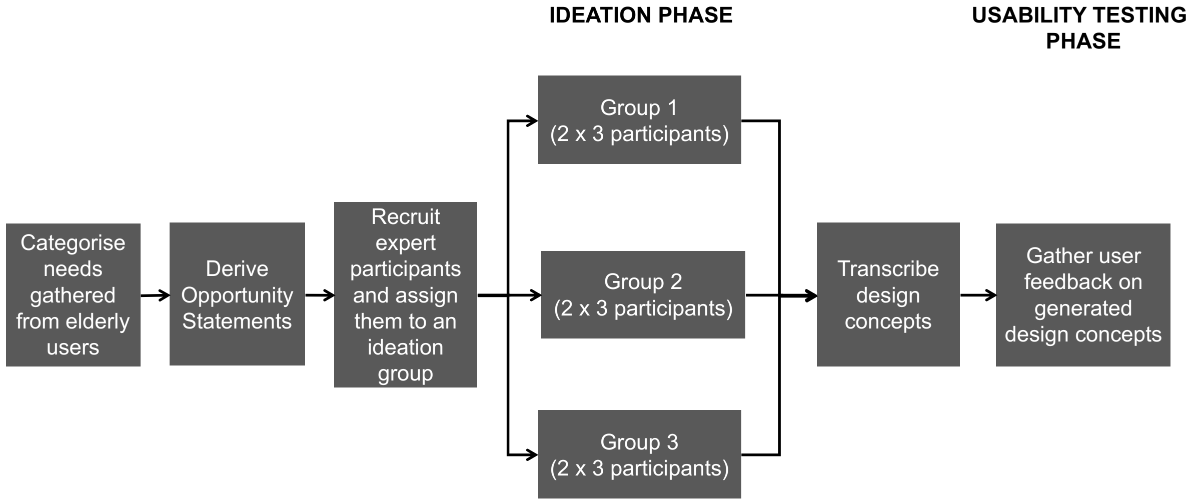


Figure 5-1 Research approach

The following section divides the research approach into two phases: 1) Ideation phase and 2) Usability testing phase.

5.2.1 Ideation Phase

This phase tested the difference in outcomes from using three different methods for ideation: control with no extreme-user prompt, morphological matrix with situational extreme-user prompt, and personas with direct extreme-user prompt. The persona method was included as a backup to produce older adult user-centric needs if the morphological matrix failed to provide the desired outcomes. The participants were divided into three groups, each of which used the three ideation methods in a different sequence to mitigate order influence. The participants applied the methods independently but provided feedback on each other's final concepts as a team. Table 5-1 shares the workshop order and corresponding opportunity statements provided for each group.

Table 5-1 Workshop order and opportunity statements shared for each group

	Group 1 (6 participants)	**Group 2 (6 participants)**	**Group 3 (6 participants)**
Phase 1: Opportunity statement 1 (15 mins)	No prompt- Individual	Morph Matrix- Individual	Older adult user Persona- Individual
Phase 2: Opportunity statement 2 (15 mins)	Morph Matrix- Individual	Older adult user Persona- Individual	No prompt- Individual

	Group 1 (6 participants)	Group 2 (6 participants)	Group 3 (6 participants)
Phase 3: Opportunity statement 3 (15 mins)	Older adult user Persona- Individual	No prompt- Individual	Morph matrix- Individual
Break			
Final stage- 1 hour	Team feedback		

We conducted a pilot study with three participants to ensure the overall approach and the timing provided were sufficient for ideation. Based on the pilot, three-person teams worked efficiently by leaving enough time for feedback. Hence, the participants were divided into three main groups with two sub-groups comprising three participants in each. This arrangement ensured that the groups had sufficient time to provide feedback on the final set of concepts. Miro (https://miro.com), a visual collaboration platform, was used for participants to share their concepts. Prompts provided for each method are as follows:

Control- No Prompt:

The control without any extreme-user prompt provided the participants with the opportunity statements alone without further information on their target users. For example, participants from Group 1 started the workshop with just the opportunity statement, "How might we redesign the detection of malicious URLs to prevent Phishing?" This method assisted us in comprehending the target users who the experts typically considered.

Situational Extreme-User Prompt:

The situational extreme-user prompt provided a scenario where the need experienced by the older adult users overlaps with the needs experienced by the general population users. The scenarios design method helps describe the context in which the PSSs are used (Fuglerud et al., 2020; Lauff et al., 2021). It provides the "how (application context)", "where (environment context)", and "who (user context)" aspects of the PSS usage.

To use the morphological matrix to convey situational extreme-user experiences, we:

1) Extracted the system functions without linking them to the extreme-users.
2) Shared situational extreme-user scenarios in which the general population users have a similar need for the systems function indicated.

Table 5-2 shares the extreme-user experiences, system functions and corresponding situational extreme-user scenarios used for each opportunity statement. One of the current measures to security, followed by the older adult users, was to verify the information with their family members or their trusted social circle.

Table 5-2 Extreme-user need and corresponding systems function and situational extreme-user scenarios

Opportunity Statements	Extreme-user need, and corresponding systems function and situational extreme-user experience scenario
Opportunity Statement 1	**User Need 1:** A social ecosystem* to quality check an unknown link/URL **Systems function:** Check unknown link/URL within a social ecosystem
	Situational extreme-user experience scenario: Less tech-savvy individuals rely on their social circle to verify if links are authentic or if a service is legitimate.
	User Need 2: Create a connection security verification mechanism **Systems function:** Verify URL
	Situational extreme-user experience scenario: Users have a misconception that the lock symbol means the site is secure, but there is an increasing number of phishing sites using SSL certs with similar-looking URLs, especially during a time-critical situation. Therefore, users need a simple and straightforward way to understand the credibility of the links.
Opportunity Statement 2	**User Need 1:** Encourage/support users to maintain good password hygiene: **Systems function:** Support maintain good password hygiene
	Situational extreme-user experience scenario: Due to Password reuse, hackers could exploit other services used by the user, not changing the password after a compromise, sharing passwords with social circles based on contexts like emergencies.
	User Need 2: Allow for co-management of passwords **Systems function:** Allow password co-management
	Situational extreme-user experience scenario: There might be certain situations/contexts where passwords might have to be shared with/needed by trusted parties (spouse/children etc.) for performing transactions. Contexts/Situations such as getting emergency help or having shared accounts for Netflix/telco bills etc.
Opportunity Statement 3	**User Need 1:** Convey critical data privacy-related information to the user **Systems function:** Convey information
	Situational extreme-user experience scenario: Very few users pay attention to the terms & conditions and app permissions required when installing an app or

Opportunity Statements	Extreme-user need, and corresponding systems function and situational extreme-user experience scenario
	subscribing to a digital service. The primary reasons being the complexity of the information and the time constraints while installing the app.
	User Need 2: A social ecosystem* to support a user in assessing critical data privacy concerns in an application: **Systems function:** provide social ecosystem to assess data privacy
	Situational extreme-user experience scenario: Individuals rely on their social circles like friends and colleagues for concerns/clarifications regarding application privacy and trustworthiness.

**Social ecosystem refers to virtual support received from reliable individuals in a social circle*

We wanted to capture the type of concepts that would arise if verification with the social circle was a system function requirement combined with situational extreme-user scenarios as shown in Table 5-2. This was combined with a systems function that listed another design need currently experienced among the older adult users, like 'connection security verification mechanism' to verify if the URLs are secure. These two system functions also allowed us to ascertain the type of concepts preferred among older adult users.

Direct Extreme-User Prompt

Personas are fictional characters developed to represent different user types (Fuglerud et al., 2020; Lauff et al., 2021; So & Joo, 2017). Goal-directed personas (Dam & Siang, 2021) that define the exact need of the users were used to provide direct extreme user prompt where the participants could link the given opportunity statement to the needs experienced by older adult users. Figure 5-2 shares an exemplar persona profile and description used with opportunity statement 1.

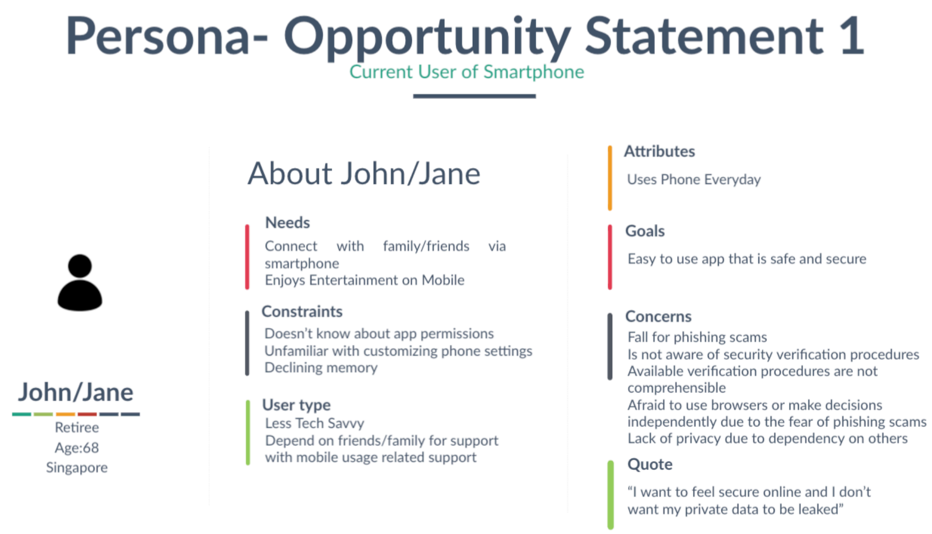


Figure 5-2 Persona profile shared for opportunity statement 1

5.2.2 Usability Testing Phase

Figure 5-3 displays the physical and digital prototypes that share the certificate information of a URL where the users could find the source information. We began the usability testing phase by capturing the user feedback for the existing interface. We also provided the participants with prototypes of two websites that are frequently used in Singapore. One of the prototypes was fake. Participants were asked to identify the fake website but using all the information, including the certificate information and URL. We proceeded with the concept testing after gathering feedback on the existing interface.

To test if the concepts from the ideation phase were preferred among the older adult users and the general population, we conducted an extensive usability testing phase. Due to time and resource constraints, we narrowed it down to a set of concepts proposed for the first opportunity statement, "How might we redesign the detection of malicious URLs to prevent Phishing?". We conducted one-on-one interviews with 12 young adult users between the age group 21-54, six young-old adult users within the age group of 55-64, and 12 older adult users above 65. The interviews lasted between 45 minutes to one hour. Both digital and paper prototypes were used to gather user feedback on the usability of the proposed concepts. The paper prototypes were used to make it easier for the users to refer back while providing their feedback. Participants rated their preference for each concept and shared the rationale behind their choice.

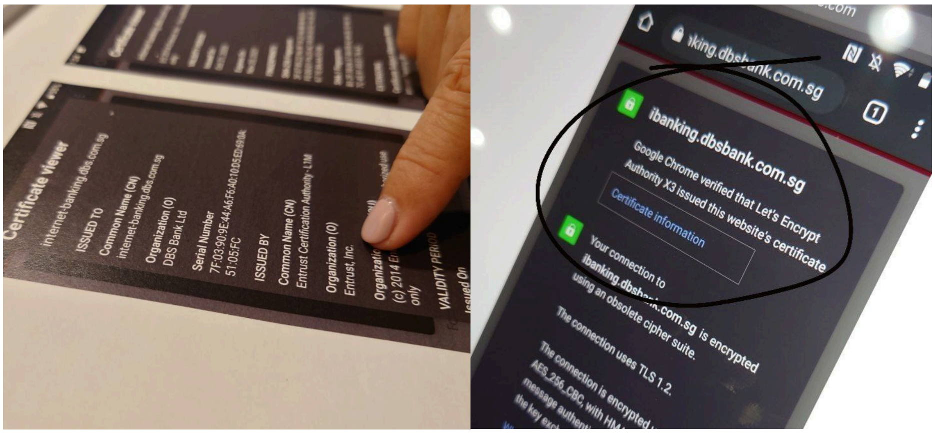


Figure 5-3 Physical and digital prototypes used for the study

5.3 Experimental Results

5.3.1 Ideation Phase

Each expert participant ideated 12 concepts: three from control, six from the morphological matrix, and three from persona. Participants were asked to pitch one concept as their final idea for each opportunity statement. Concepts derived through the morphological matrix were represented as a concept combination that addressed each systems function. Ultimately, the participants narrowed down from 216 concepts to 54 final concepts. Figure 5-4 shows Miro boards from one of the participant groups and highlights few concept examples.

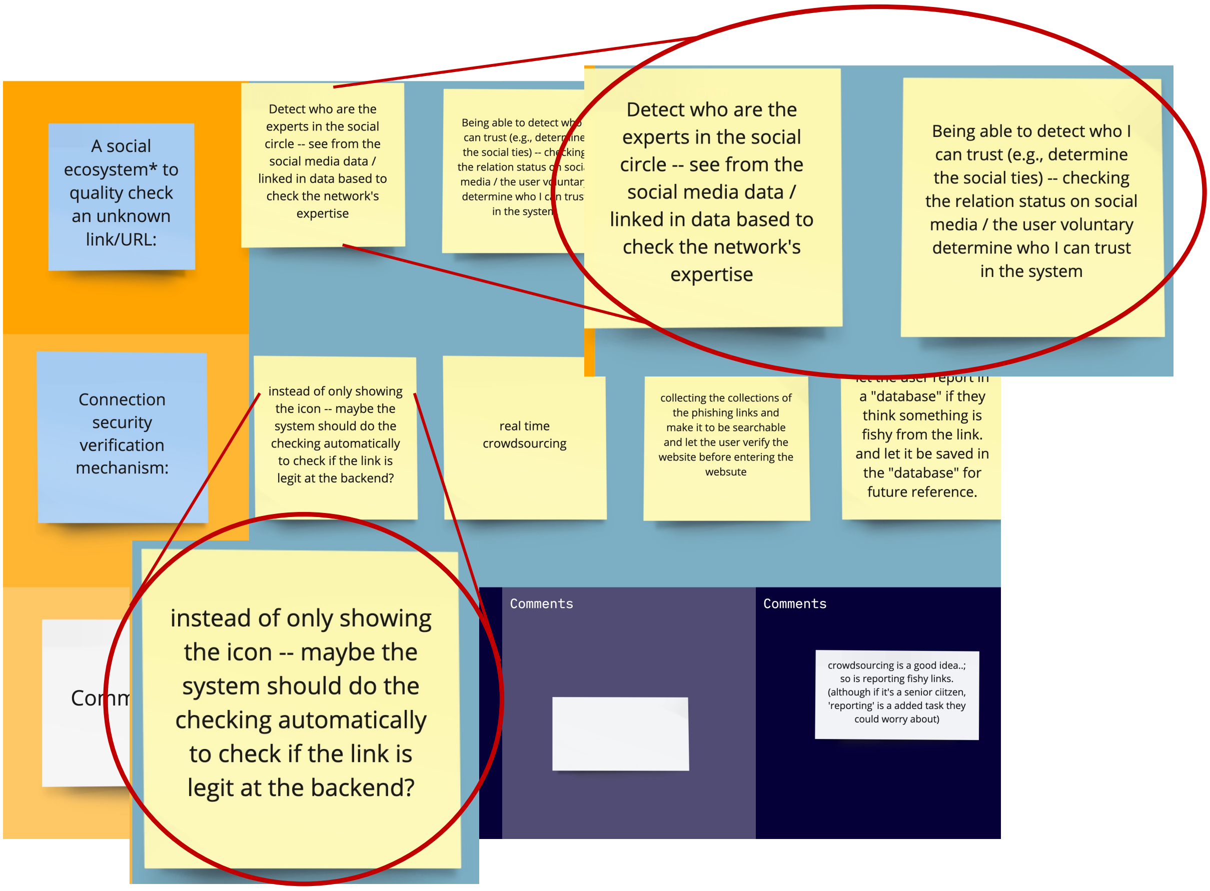


Figure 5-4 Example Miro board ideation outcomes

For analysis, two researchers coded a sample of the concepts shared by the participants. An interrater analysis using Kappa statistics was performed on SPSS Statistics (Version 25.0.0.1, IBM Armonk, N.Y., USA) to determined consistency among raters. The interrater reliability was Kappa= 0.784 ($p<0.001$), which is substantial agreement, so one rater continued to code the rest of the data. The codes were used to differentiate inclusive, excluding, and assistive concepts. Similar to the codes used in Chapter 3, the following keys were used to rate the concepts.

- **Inclusive:** The proposed design would benefit both older adult users and the rest of the general population users.
- **Assistive:** The proposed design would benefit older adult users but would not be preferred by the rest of the general population.
- **Excluding:** The proposed design would not benefit older adult users.
- **Vague:** Not a clear design description.

Figure 5-5 shares the types of concepts generated by participants based on the design method adapted for their opportunity statements. Results show that irrespective of the order of application, the morphological matrix leads to more inclusive design solutions. While the numbers of concepts are relatively small due to the small group size, it is to be noted that the participants were experts in their field. This could be significantly different for a larger user group (as observed in Chapter 3). In concurrence with the previous studies discussed in this thesis, situational extreme-user needs lead to more inclusive design outcomes when compared to direct extreme-user needs.

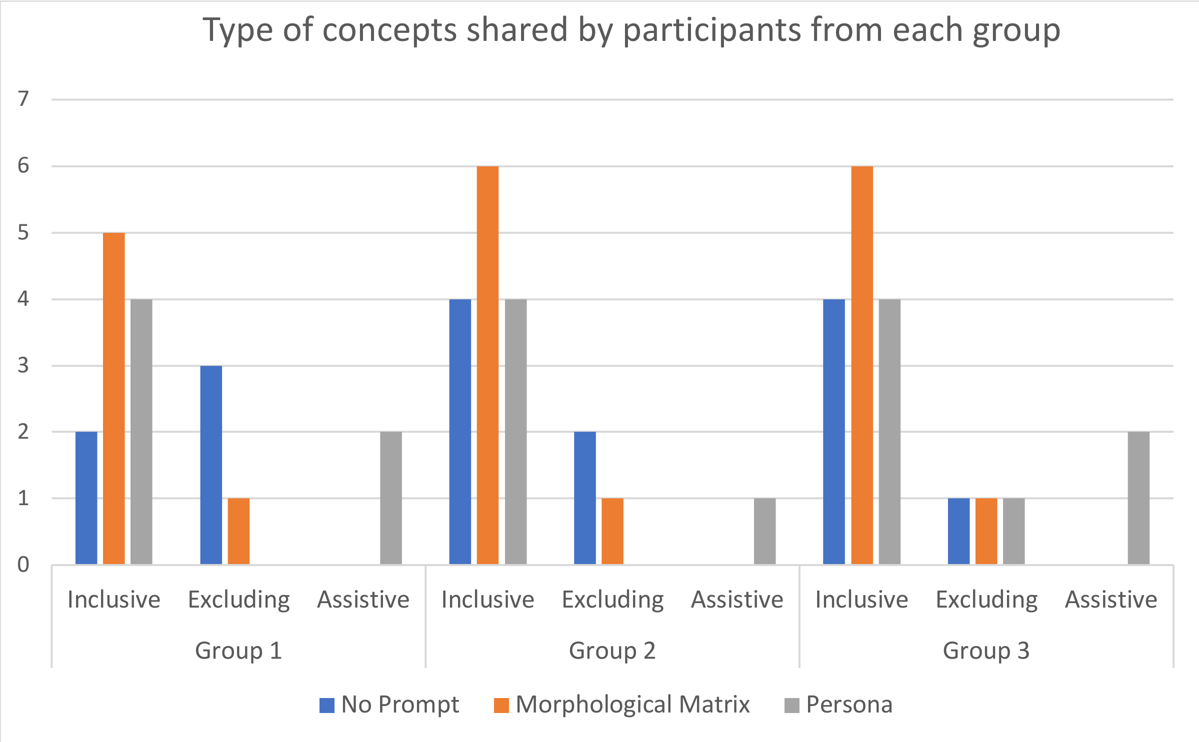


Figure 5-5 Types of concepts shared by each group for the three methods

The inclusivity of a concept was determined based on the design of the proposed interface. Table 5-3 shares the categorisation of concepts from Opportunity Statement 1, whose usability will be tested in the next phase.

Table 5-3 Types of concepts shared for opportunity statement 1

Method	Inclusive Interface	Excluding Interface	Assistive Interface
Concepts shared using control with no extreme-user prompt	Interface to share the URL info: - *Forced attention: using a colour-coded display. - *Forced attention: using a large font.	- Long press: Click and hold to see information about the URL. - Credit score: provided as a browser extension. - A dedicated application.	
Concepts shared using morphological matrix method	**Systems function:** Support maintain good password hygiene	Interface for the social ecosystem: - Engage tech-savvy peers to verify.	

Method	Inclusive Interface	Excluding Interface	Assistive Interface
	- Verify trust: Knowing who can be trusted within the social ecosystem. - Engage tech-savvy peers to verify. - Dedicated social groups: Engage admins who take down phishing links. - A Small icon to show the number of friends who trust the website. **Systems function:** Allow password co-management: - Provide visual indicators better than lock and display security scanning status. - Colour of the URL bar change depending on its credibility. - Automatic link checkers on URLs shared in chats—Colour to indicate threat level.		
Concepts shared using Persona	Interface to share the URL info: - *Display a unique icon if the URL is verified. - *Use colours to warn if an email is suspicious. - Use colours to warn if a URL is suspicious.	Interface to share the URL info: - Use logos to represent the URL's path.	To avoid phishing websites: - Avoid clicking on advertisements. - Verify sender before clicking links.
*Similar to the existing interface.			

When asked to ideate for employing situational extreme-user scenarios to create a social ecosystem, the experts' key focus was on ensuring the trustworthiness of the scenarios. In reality, the majority of the older adult users in Singapore heavily relied on their social circle due to the complexity of the current interface. Yet, there are no existing measures to build a trusted means of verifying a URL's credibility. The Usability Testing Phase shed more light on the inclusiveness of the concepts from a user perspective.

5.3.2 Usability Testing Phase

None of the 30 participants, including the young adult users, could identify the fake website from the real during the usability testing. Two young adult user participants could recognise the wrong URL after the researchers informed them of their wrong choice. Yet, the young adult user participants gave a significantly high rating on the usability of the existing approach to verify the credibility of a URL.

The usability testing phase helped understand the type of concepts preferred among different user groups despite their difference in acceptance for the existing interface. It can be inferred from Table 5-4 that seeking help from a social circle, as expected, was highly preferred among the older adult users compared to the young-old adult users and young adult users. More interestingly, participants from all age groups, including the older adult users, chose the forced attention design that helped them make their own decisions. In addition, an artificial intelligence (AI) based validation of the URLs was widely preferred among all our participants as long as they could verify the trustworthiness of the AI.

Table 5-4 Response from each user group for concepts generated from opportunity statement 1

Concept	Concept Type	Young Adult Users	Young-Old Adult Users	Older Adult Users
Submit Social Circle	Inclusive	2.58	2.50	4.08*
S.D.		1.24	1.38	1.16
Submit Outside Social Circle	Inclusive	3.17	3.17	3.00
S.D.		1.40	1.47	1.28
Submit AI	Inclusive	3.33	3.17	3.83
S.D.		1.23	1.17	0.83
Trust for Social Circle	Inclusive	3.25	2.33	4.00*
S.D.		1.29	0.82	0.85
Trust for Outside Social Circle	Inclusive	3.33	2.33	2.58
S.D.		1.23	1.21	1.24
Trust for AI	Inclusive	3.50	4.00	3.75
S.D.		1.09	1.26	0.97
Trust Score- Forced Attention	Inclusive	4.00	3.83	4.50
S.D.		1.13	1.17	0.52
Trust Score- Long Press	Excluding	2.42	3.00	3.08
S.D.		1.08	0.89	1.24

Concept	Concept Type	Young Adult Users	Young-Old Adult Users	Older Adult Users
Visual Warnings	Inclusive	4.58	4.83	4.83
S.D.		0.51	0.41	0.39
Rate Crowd workers	Inclusive	3.55	3.00	3.08
S.D.		1.13	1.22	1.31
***Significantly (p-value < 0.05) high compared to the groups highlighted in green.**				

5.4 Discussion

Among the concepts shared in Table 5-3, the persona methods' concepts were simpler and more accessible. Yet, the Experts in this study tried to make the design more straightforward and accessible for the older adult users when they applied the older adult user personas. Yet, most of the needs designed by applying situational extreme-user experiences with specific system attributes lead to more inclusive design solutions preferred by most of our participants.

Two key inferences are made from the concepts shared in Table 5-3 and the user preferences shared in Table 5-4.

1) Reassuring our findings from Chapter 2, the direct application of extreme-user perspectives has the potential to evoke concepts that a wider population would prefer—for example, visual warnings proposed by adapting extreme-user experiences. Yet, as demonstrated by the study shared in Chapter 3, there are also chances of stigmatisation that could make the design more assistive than inclusive. For example, avoid clicking on advertisements is guidance rather than a design modification.
2) The concepts from the morphological matrix show that sharing system attributes and corresponding situational extreme-user scenarios could motivate designers to identify creative yet inclusive design solutions. For example, verifying within a social circle was an informally followed way of verifying information among the older adult users in Singapore; presenting this scenario encouraged designers to address the trust concerns among the older adult users. In addition, our expert participants also recommended automated link checkers, which was one of the preferred solutions among the all three participant groups. The majority of our user participants from the testing phase conveyed that they would rather be independent than depend on others.
3) While the participants in the no prompt group also recommended forced warning, they also shared a greater number of excluding concepts when compared to the remaining two groups. This might not be an ideal outcome if we want to cater to a wider population of users.

To answer our research question:

> How does the morphological matrix transform the situational extreme-user needs into inclusive design solutions?

The morphological matrix design method is adopted as a practical approach for ideation by researchers in various fields of design due to its focus on the functional aspects of a solution (Gherardini et al., 2020; Nagel et al., 2008; Suzianti et al., 2019). This focus on functional aspects was the rationale behind adopting the morphological matrix to apply extreme-user perspectives systematically. The HMW statements used for the opportunity statements also helped to guide the ideation process. Although tested with a small sample size, the system functions and situational extreme-user scenarios enabled the expert participants to generate more inclusive solutions than assistive solutions. While the specific system functions highlighted the design need at a systems level, the situational extreme-user scenarios conveyed the necessity to address the need. This combination makes this adapted version of the morphological matrix an effective tool to apply situational extreme-user experiences for design ideation.

5.5 Limitations and Future Directions

Due to the COVID-19 situation, the Ideation phase had to be conducted online; hence we could not apply the simulated scenarios. Research studies show that the personal connection to an extreme-user population could, to an extent, attain similar impacts in the absence of simulated scenarios (Raviselvam et al., 2017). Since our extreme-user population and the situational extreme-user scenarios were not distal to the participants, we implemented the study in the absence of simulated scenarios. Any future expansion of the work could test if a simulated experience of the same would lead to concepts that address unique aspects of inclusive privacy and security. Although the study engaged 18 domain experts in an insightful ideation session, the small sample size was another limitation to this study. Future works can focus on observing the impact at a larger scale and explore opportunities to adapt the methods for complex systems where different systems interact with each other.

5.6 Chapter 5: Conclusion and Key Findings

This study is one of the first to systematically apply situational extreme-user perspectives using a morphological matrix for design ideation and empirically test user responses. While works in the past have adapted the morphological matrix design method to convey user needs for assistive design and inclusive design (O'Rourke, 2015), this would be the first attempt to apply them with situational extreme-user scenarios that lead to inclusive design outcomes. We leveraged the morphological matrix's focus on functions to convey extreme-user needs for inclusive usable privacy and security and studied the acceptance of the concepts generated among the users. This study involved two existing design methods to develop design concepts: morphological matrix and persona. While we did not modify the Persona method, we modified the morphological matrix to systematically convey situational extreme-user scenarios. HMW statements were also adopted to convey the extreme-user inspired needs to our expert participants. This combination of HMW statements with system functions served as an effective approach to guide an extreme-user experience inspired ideation. We also compared the concepts generated by applying two other approaches and discussed the different types of concepts generated using each approach. We believe this adaptation of the morphological matrix would encourage more extreme-user inspired innovation during the ideation phase of the design process.

Based on the study results from Chapters 4 and 5, we answer the research question **How effective are the guided systematic approaches to adopt extreme-user experiences?**

Outcomes from Chapters 4 and 5 demonstrated the advantages of a guided approach to adopt extreme-user experiences. We systematically adapted design methods like Activity Diagrams, Journey Maps, Contextual Need Analysis, Scenarios, HMW statements, Systems function, and Morphological Matrix to leverage the extreme-user experiences. This approach to applying extreme-user experiences enabled our study participants to:

1) Identify specific points of user interactions where adopting an extreme-user experience would benefit the most.
2) Identify PSS specific latent needs that would delight their users.
3) Derive systems function associated with the extreme-user inspired needs and transform them into inclusive design concepts that cater to a wider population.
4) Avoid potential stigmatisations that could occur from associating a need with a specific extreme-user population rather than focusing on the larger impact.
5) Ultimately, adopt PSS appropriate extreme-user perspectives throughout the design process.

Chapter 6
Extreme-User Experience Design Framework

"The method of science is tried and true. It is not perfect, it's just the best we have, And to abandon it, with its skeptical protocols, is the pathway to a dark age."

-Carl Sagan

Previous chapters of this thesis demonstrates the impact of extreme-user experiences and empirically tested a set of design methods that systematically implement extreme-user experiences to attain specific design goals. Various works advocate extreme-user perspectives as part of their design framework. For example, Microsoft has their inclusive design framework where they recommend applying extreme-user perspectives for inclusive design (*Microsoft Design*, 2018). Similarly, the Cambridge Engineering Centre has a whole suite of methods and process for inclusive design (University of Cambridge, 2017b). Universal design, on the other hand, has a set of principles and frameworks for the structuring of environments that aim to address the needs of extreme-users with some form of physical or cognitive challenges (S. E. Burgstahler & Cory, 2010; Connell et al., 2001; National Disability Authority, 2020; Singh & Tandon, 2018). While concepts like inclusive design and universal design have been studied for decades, design researchers have recently started to recognise the potential of extreme-user needs in designing products, services, or systems (PSSs) that address the latent needs in general population users.

With growing interest in extreme-user inspired design concepts and creative perspectives inspired by extreme-user experiences, there is a need to develop tools that make their adoption more intuitive and systemic. Systematic guidance that enables designers and creators to leverage extreme-user experiences could transform how they perceive their design impact, especially in improving the quality of users' lives and thereby enabling economic transformation (Silva et al., 2021). This chapter provides a systematic application framework for adopting extreme-user experiences and highlights its contribution to the SUTD-MIT International Design Centre's Design Innovation (DI) process model (Camburn et al., 2017; Lauff et al., 2021). Before we move on to the framework, however, we must review the theories that underpin it.

Design methods and processes form the core of the proposed framework. The Cambridge Dictionary defines a method as "a particular way of doing something." Like scientific methods, design methods are not rigid, but they provide a systematic approach to support design practices (Cross, 1993; Göransdotter, 2020). Design methods have been around for more than half a century. They have grown in importance to the extent that they can be found in various disciplines like sustainability, inclusion, healthcare, additive manufacturing, and automation (Cooper, 2019). This multi- and cross-disciplinary applicability have encouraged design researchers to adopt existing design methods and processes to accommodate the demands of specific disciplines (Inglesis Barcellos & Botura, 2018). For example, the Design Innovation with Additive Manufacturing (DIwAM) approach by Perez et al. (2019) presents an adaptation of design methods and principles to accommodate growing opportunities in additive manufacturing. Similarly, Anderson et al. (2018) presented an adaptation of a design process that integrates computation to accommodate the unique needs of design automation.

A design process is "the set of activities by which designers develop and/or select the means to achieve a set of objectives, subject to constraints" (Tate & Nordlund, 1996). The objectives are met using a set of goal-appropriate design methods throughout the design process. Some well-known design process models include the works by Pahl and Beitz (Pahl & Beitz, 1988), Otto and Wood (Otto & Wood, 2001), Dym (Dym, 1994), Pugh(1991), and Ulrich et al. (Ulrich et al., 2019). The recent DI process model adapted in this thesis (Camburn et al., 2017) provides a framework through the interplay and flexibility of design processes, methods, and principles that benefit designers. The framework inspired by this thesis proposes four stages to implement extreme-user experiences along the design process, and each stage aligns with the Discover, Define, Develop, and Define phases of the DI process. The four stages include:

1) Identify: To leverage the extreme-user experiences appropriate for a PSS.
2) Derive: To focus on impact evoking user interactions.
3) Ideate: To transform extreme-user inspired needs into exceptional design outcomes.
4) User Testing: To verify the impact of resulting ideas.

Ultimately, we provide an extreme-user experience design framework with a set of empirically tested design methods that guide through Discover, Define, Develop, and Deliver phases, as illustrated in Figure 6-1. From this point of the thesis, the term 'framework' will only be used to refer to the extreme-user experience design framework.

DI Process	Extreme-user Experience Design Framework	Corresponding Design Methods
Discover	Identify: To leverage the extreme-user experiences appropriate for a PSS.	• Extreme-user Simulated Scenarios • Contextual Need Analysis (CNA) • Activity Journey Map
Define	Derive: To focus on impact evoking user interactions.	• Extreme-user Simulated Scenarios • Systems function • How Might We Statements
Develop	Ideate: To transform extreme-user inspired needs into exceptional design outcomes.	• Extreme-user Simulated Scenarios • Systems function • Morphological Matrix
Deliver	User testing: To verify the impact of resulting ideas.	• Extreme-user Simulated Scenarios • Activity Journey Map

Figure 6-1 Extreme-user Experience Design Framework

The extreme-user experience design framework comprises a core method and adaptations from existing methods like Activity Journey Map, Contextual Need Analysis, How Might We (HMW) statements, Systems function, and Morphological matrix. The final part of this section will discuss the integration of the framework with the existing DI process model.

6.1 Design Methods for Extreme-User Experiences

We will first share the adaptations of the existing five design methods and then proceed to the core design method of this framework, the extreme-user simulated scenario. We will introduce each design method, its implementation protocol, and expected outcomes.

6.1.1 Activity Journey Map

Activity Journey Map is conceived as a combination of the Activity Diagrams and the Journey Mapping methods adopted for the study shared in Chapter 4. Activity Diagrams use sequential and parallel block diagrams to capture user activities that allow users to interact with a PSS (Otto & Wood, 2001). The user activities highlight the steps that complicate a user's interactions with a PSS, allowing the designer to associate problematic steps with the physical abilities needed for that specific interaction. In comparison, Journey Mapping visualises user interactions and user emotions while interacting with a PSS focusing on the touchpoints and channels for interaction. While touchpoints are similar to the user interactions (activities) in an Activity Diagram, channels refer to the mediums through which the users interact with a PSS (Salazar, 2016). Journey Mapping captures the user's likes, dislikes, and interactions, leading to frustration or joy across their overall interactions with a PSS over time (Howard, 2014). Both these methods are proven ways to understand a user's interaction with a PSS (Camburn et al., 2017; Lauff et al., 2021); while one focuses on the design, the other concentrates on the user. The emotions captured using Journey Maps help identify the specific interactions that are unpleasant or physically challenging for the user. Combining Activity Diagrams with Journey Maps allows us to visualise the physical demands and emotions they incur and systematically identify if we could eliminate a physical demand by applying appropriate extreme-user experiences.

We briefly discussed implementing this combination of Activity Diagram and Journey Mapping in our second foundational study discussed in Chapter 2 and empirically tested its impact with six medical device design projects shared in Chapter 4. Here, we present Activity Journey Map as a method to accommodate extreme-user experiences.

Method Implementation

The goal of the Activity Journey Map is to systematically identify the extreme-user experiences that could benefit a PSS design. Table 6-1 shares the steps involved in adopting the Activity Journey Map, and Figure 6-2 shares a template to implement them.

Table 6-1 Step-by-step guidance to adapt the Activity Journey Map

Steps	Description
Step 1	Depict the user interactions with a PSS as actions and verbs using an Activity Diagram. For example, activities like 'open package' or 'track progress'.
Step 2	Indicate user emotions during each interaction. For example, happy, frustrated, indifferent, sad.
Step 3	Determine the physical abilities (demand) needed to execute each interaction. For example, open package- both hand usage; track progress- vision.
Step 4	Use wearable simulations* that eliminate specific physical demands.
Step 5	Use user emotions to identify critical points for improvement. List the user needs that, when addressed, would accommodate the absence of the identified physical demand. The latency metric from Chapter 4 can be used to prioritise the needs.
Step 6	Test with users and share experiences. Check how similar or different are they from what you anticipated.
*The direct or situational extreme-user simulations can be applied depending on the desired outcomes. Refer to the Extreme-User Simulated Scenarios method for further information on adapting direct and situational extreme-user experiences.	

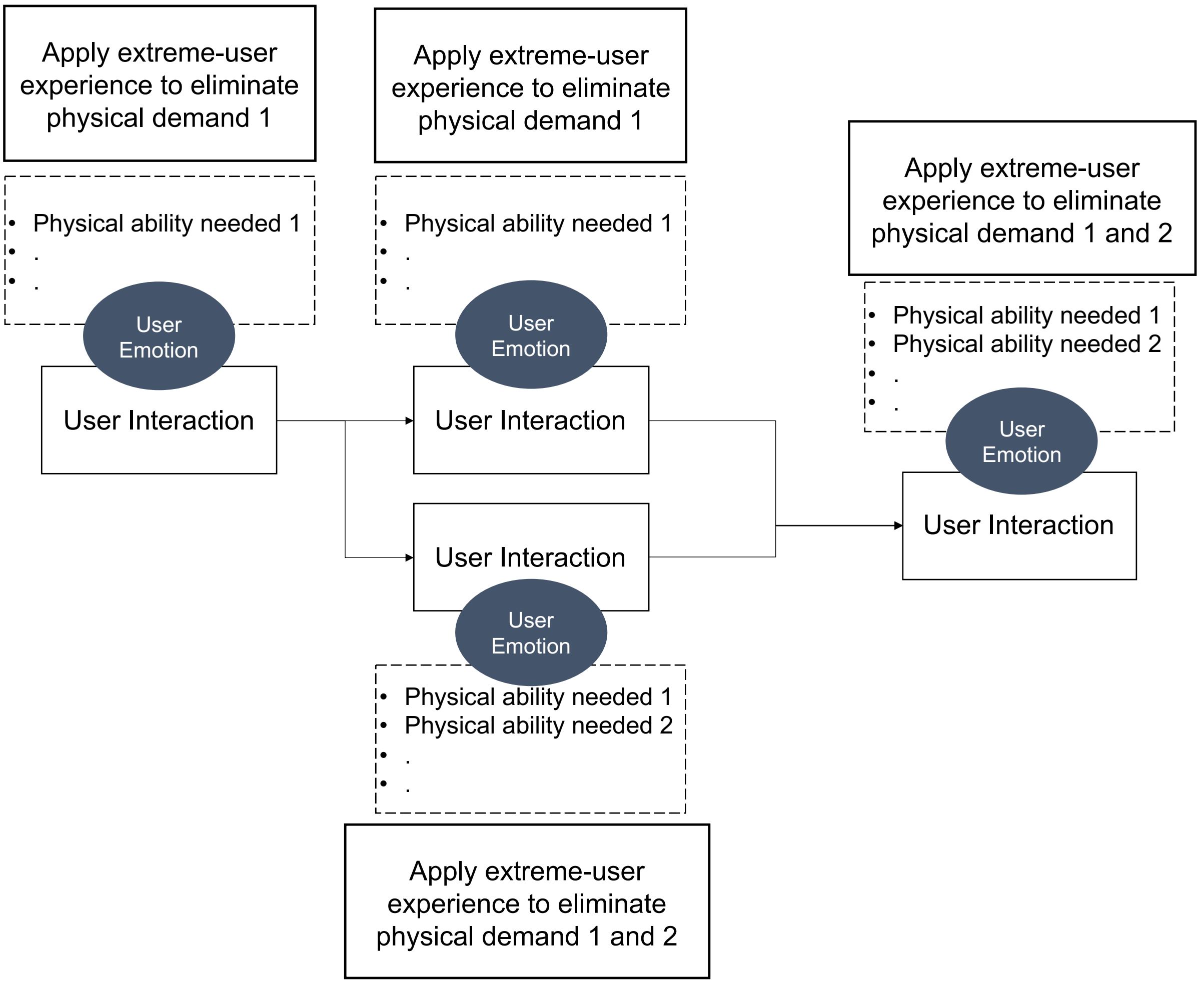


Figure 6-2 Template to apply extreme-user experiences using Activity Journey Map

Potential Outcomes:

- Identify PSS-appropriate extreme-user experiences
- Uncover creative design perspectives
- Identify latent user needs
- Develop inclusive design solutions
- Test usability of final design outcomes

6.1.2 Contextual Need Analysis

Contextual enquiry is a vital part of any user-centric design process, especially as a tool to gather user satisfaction with any PSS. Contextual Need Analysis (CNA) helps understand how users' interaction with a PSS would vary according to the use conditions or circumstances (Green, 2005; Green et al., 2009, 2008; Lauff et al., 2021). This quality makes CNA an ideal tool for extreme-user experiences since the contexts of use can enable or disable users. A circular doorknob (University of Cambridge, 2017a), for example, poses a challenge under circumstances where the user needs both hands to carry a heavy object or a laptop and a coffee cup, like our user in Figure 6-3.

Figure 6-3 Exemplar context where a circular doorknob hinders user interaction

Various domains of design research have leveraged CNA to understand different facets of user interaction with a PSS. For example, Tushar et al.(2020) used CNA to understand user's interactions with buildings to develop smart energy systems. One can find similar applications of CNA in domains like additive manufacturing (Perez et al., 2019), medical device design (Surma-aho et al., 2021), assistive technology (Walker & Sangelkar, 2017) and many more. In addition, contexts identified using CNA could help predict unique scenarios that impact users' experience with PSSs (Camburn et al., 2017). The purpose of using CNA with extreme-user experiences is to identify the scenarios that would challenge a user's ability to interact with a PSS. CNA encourages designers to focus on the how (application context), where (environmental context), who (user context), and why and when (use context) aspects that influence a design. Contexts identified with a PSS help build different scenarios for users' interactions.

Method Implementation

In our framework, CNA works alongside the Activity Journey Map, where they both gain information from each other. Environmental context (where) and user context (who) extremes for a PSS helps identify the extreme-user contexts. For example:

- Environmental extremes: This can include outdoor and indoor extremes like weather extremes, surroundings, noise level, dust, other users, etc.
- User extremes: Extremes of user abilities like the absence of visual and auditory attention, lack of physical strength, absence of mobility, etc.

Table 6-2 shares the step-by-step procedure to adapt CNA to accommodate extreme-user experiences.

Table 6-2 Step-by-step guidance to adapt the Contextual Need Analysis

Steps	Description
Step 1	List different extreme-user contexts of usage for the selected PSS. For example: Environmental extremes: This can include outdoor and indoor extremes like weather extremes, surroundings, noise level, dust, other users, etc. User extremes: Extremes of user abilities like the absence of visual and auditory attention, lack of physical strength, absence of mobility, etc.
Step 2	Use Activity Diagrams to find basic abilities needed to interact with the PSS under the listed extreme-user contexts.
Step 3	Build scenarios by applying extreme-user demands identified using Activity Diagrams.
Step 4	Test the usability of the PSS under selected scenarios*.
Step 5	Discover a diverse set of extreme-user experience-based needs.

*While scenarios usually help test user interactions in different contexts, simulated scenarios enable the designers to experience the contexts. An example template to incorporate CNA for extreme-user experience would be:

{Extreme-user demand} + {Extreme-user} = Extreme-user Experience Scenario

User with {Extreme-user demand}, interacting with {product/service/system} {Environmental/ Spatial extremes}

Potential Outcomes

- Uncover creative design perspectives
- Identify latent user needs
- Understand overlap in needs among extreme-users and general population users.

6.1.3 Systems Function

The systems function represent the desired actions from a PSS. The most common type of functional model in engineering design is the flow-based functional model (function structure) derived from the Pahl and Beitz method (J. Hirtz et al., 2002; Otto & Wood, 2001; Pahl & Beitz, 1988; Stone & Wood, 2000; Tomko et al., 2017). A black box model and a sub-functional model are the two levels of abstractions for functional models. While the black box models are stand-alone and represent high-level transformations based on the design requirements for a PSS, the sub-function model breaks the black-box model into specific flow transformations of materials, energies, and signals. Stone and Wood (2000) introduced this as the functional basis for design, where a function is typically stated in 'verb-object' form that refers to 'what must be done' to address an identified need. The functional basis was developed as a formal taxonomy for function representation in order to enhance and simplify information communication among scholars (Hirtz et al., 2001; Kurfman et al., 2001). Systems function provide a simple yet efficient approach to transform user actions into desired functionality of the design (Otto & Wood, 1998). The systems function express descriptors to represent the operations that are to be accommodated by the PSS in the form of function and flow (Hirtz et al., 2001). Many design experts have formulated ways to interpret design functions (Sangelkar & McAdams, 2013; V. Srinivasan et al., 2012). For example, Rosenman and Gero (1998) emphasised the need for functional reasoning as a vital component of the design process' life cycle. Systems function gained added attention and were represented in different variants with the adoption of mechanical engineering approaches in systems design (Stone & Chakrabarti, 2005). Example systems function would be 'verify URL' and 'provide non-visual feedback' where 'verify' and 'provide' refer to the functions.

An issue we encountered while testing the extreme-user experiences was that the participants might list the extreme-user demand as a need. For example, single had usage would be listed as a need, which could lead to ability-based stigmatisation in the final design (Bichard et al., 2007; Dankl, 2013; Hersh, 2013). A functional basic representation would eliminate this issue by focusing on the device functions rather than the user functions (Hirtz et al., 2001), thereby leading to non-stigmatised design solutions for the given PSS. Lauff et al. (Lauff et al., 2021) provide an even evolved form of representing systems function that integrates users' emotion by providing a "verb + (noun + elaboration) + adverb/adjectives" form of structuring systems function. For example, "Monitor + (baby + when unattended) + constantly". This form of capturing systems function can be an efficient way to add extreme-user experience inspired need by avoiding stigmatisation. For example, 'provide + (non-visual feedback+ when a user is visually distracted) + without hindering actions' adds context-relevant information to the systems function. Hence this form of evolved systems function representation is adapted to the framework.

Method Implementation

The systems function can be generated based on the needs identified from the CNA or Activity Journey Maps. This method did not have specific adaptations to accommodate extreme-user experiences, but they played a key role in streamlining the needs generated by applying the extreme-user experiences. Table 6-3 shares the step-by-step procedure to adapt the systems function to accommodate the extreme-user experiences.

Table 6-3 Step-by-step guidance to adapt the Systems function

Steps	Description
Step 1	Derive systems function* that corresponds to the critical points for improvements identified using extreme-user experience with Activity Journey Map.
Step 2	List them as function-flow pairs that represent the design transformations required to ease user interaction. For example, capture user attention, provide feedback.
Step 3	Extract sub-functions that contribute to the identified system function.
Step 4	Use the sub-functions to guide ideation.
*Systems function could be an efficient approach to understanding extreme-user experiences' outcomes among novice designers like students (Chapter 5). They can be combined with extreme-user experience to guide the ideation process as implemented in Chapter 5.	

Potential Outcomes:

- A better representation of extreme-user experience inspired outcomes

6.1.4 How Might We Statements (Opportunity Statements)

How Might We (HMW) statements are a simple, widely adopted approach to form opportunity statements (IDEO, 2021; Lauff et al., 2021; Odell Keller, 2019). They make it easier to decide on the impact and feasibility of addressing the identified needs ((DI) Learning Modules, 2021). In this study, the HMW statements were used to narrow down the identified systems function for ideation.

Method Implementation

The HMW statements are combined with the systems function as shared in the template below for implementation. Table 6-4 shares the step-by-step procedure to adapt the HMW statements to accommodate extreme-user experiences.

"How might we {extreme-user experience inspired system function} to {what we want to achieve}?"

For example, below is a HMW statement generated based on the needs experienced by the older adult users

How might we {improve password hygiene among users} to {reduce password compromise risks}?

Table 6-4 Step-by-step guidance to adapt the HMW statements

Steps	Description
Step 1	Generate HMW statements for the critical systems function and frame the extreme-user inspired HMW Statements*.
Step 2	Use the HMW statements to guide Ideation.
* It is to be noted that other existing design methods like Affinity Diagram (Camburn et al., 2017; (DI) Learning Modules, 2021; Lauff et al., 2021) could be used to narrow down the systems function.	

Potential Outcomes:

- Guide ideation during the Develop Phase of the design process.

6.1.5 Morphological Matrix

Morphological matrices are widely used to envision and brainstorm novel approaches to design challenges. The morphological matrix is comprised of necessary sub-systems functions that contribute to building a complex system. Each sub-system function receives multiple design solutions shared in rows and columns in the form of texts or figures (Fargnoli et al., 2006; Jensen et al., 2009). Several research works have leveraged this method to generate diverse concepts within a short duration (Bryant et al., 2009; Liu et al., 2012; Williams et al., 2011). Designers could ultimately have multiple concepts that systematically combine different combinations of solutions that contribute to each sub-system function. The morphological matrix served as one of the ideal methods to accommodate the extreme-user inspired systems function. Table 6-5 lists the steps involved to adopt a morphological matrix for extreme-user experiences, and Table 6-6 Template to adopt the Morphological matrixTable 6-6 shares a template we followed to adapt the morphological matrix for extreme-user experiences.

Table 6-5 Step-by-step guidance to adapt the Morphological matrix

Steps	Description
Step 1	List the sub-functional requirements to address the selected system function shared in the HMW statement(s).
Step 2	Add the extreme-user inspired design functions to the morphological matrix shared in Table 6-6.
Step 3	Include the extreme-user inspired need that will be satisfied by addressing the listed sub-functional requirements.
Step 4	Ideate* concepts to address each sub- functional requirement.

*Share both situational and direct extreme-user needs if ideating for assistive or inclusive design solutions. The selected concepts could be tested by applying the Activity Journey Map method.

Table 6-6 Template to adopt the Morphological matrix

"How might we *{extreme-user experience inspired system function}* to *{what we want to achieve}?*"			
Design sub- functional requirements	**Concept 1**	**Concept 2**	**Concept 3**
System Sub-function 1 (Corresponding situational extreme-user experience inspired need)	Concept to address the sub-function.	Concept to address the sub-function.	…
System Sub- function 2 (Corresponding situational extreme-user experience inspired need)	Concept to address the sub-function.	Concept to address the sub-function.	…
…	…	…	…

Ultimately, in our adaptation for extreme-user experiences, the morphological matrix inspired multiple creative design concepts.

Potential Outcomes

- Generate inclusive design solutions
- Adopt creative design perspectives for ideation

6.1.6 Extreme-User Simulated Scenarios

The Extreme-user Simulated Scenarios method is extracted from the empirical study shared in Chapters 2 and 3. The goal of this method is to provide procedural guidance to apply extreme-user simulations. As discussed in the two chapters, simulated extreme-user scenarios are often adapted for design innovation and creativity. Design processes and methods, at their core, aim to integrate rational and analytical skills with human intuitive abilities for efficient and functional design outcomes (R. Dam & Siang, 2018). The adoption of extreme-user perspectives, on the other hand, is heavily reliant on intuition. While they could be widely adopted to understand the needs experienced by an extreme-user population (Adam, Rouilly, 2021; AgeLab, 2019; Cardoso & Clarkson, 2012; Goodman et al., 2008), they are seldom leveraged for design creativity. The ELU approach by Hannukainen & Hölttä-Otto (2006) was one of the initial works that tested the potential of extreme-user perspectives in identifying latent needs in general population users. Kullman (2016), in his review on extreme-user simulations, advised that such tools be viewed as a means of changing designers' perceptions rather than as a representation of extreme-user experiences. The extreme-user simulated scenarios are designed to be a tool that helps designers to interact with their designs from a perspective unlike their own. This method also enables the designers to foresee the overlap in needs experienced among the extreme-users and general population users (Vanderheiden, 2000) by applying direct and situational extreme-user scenarios. Scenarios, in general, help represent the context in which PSSs are used. With extreme use cases being a recommended part of the Scenarios method (Lauff et al., 2021), systematic adoption of direct and situational extreme-user scenarios guided through this framework could transform the insights gathered from scenarios.

A paper for universal usability by Vanderheiden (2000) was one of the initial works to discuss situational constraints. These situational constraints are even applied as design considerations in various works (Chourasia et al., 2014; Sarsenbayeva et al., 2017; Tigwell et al., 2018; Vanderheiden et al., 2020; Wobbrock, 2019). An example set of direct extreme-user experiences and corresponding situational extreme-user experiences for the ones applied in this thesis are listed in Table 6-7.

Table 6-7 Example direct and situational extreme-user experiences

Direct Extreme-user Experiences	Situational Extreme-user Experiences
Visual Impairments	Visual Distractions while using a mobile phone or communicating with another person
Hearing Impairments	Listening to music or being in a noisy environment
Physical Impairments on one hand	Carrying a bag or a child on one hand
Physical Impairments on both hands	User carrying heavy objects on both hands or users executing tasks that require both hands.
Reduced finger dexterity	Users wearing gloves and cold temperatures (Chen et al., 2010)

Method Implementation

Table 6-8 shares the step-by-step guidance to adopt simulated extreme-user experiences and the intended outcomes depending on the design phase during which it is used.

Table 6-8 Step-by-step guidance to adapt extreme-user experiences into the design process

Steps	Description
Select	Choose a design phase appropriate method(s) from The framework. For example, Activity Journey Map and Morphological Matrix.

Apply	Adopt the design method to systematically identify the extreme-user demands that impact users' interaction with the PSS. These are the extreme-user perspectives appropriate for the selected PSS.
Simulate	Engage in simulated scenarios that present situational extreme-user experiences*, with or without accompanied by direct extreme-user experiences.
Test	Test the usability of the existing or new PSS while experiencing the simulated scenarios. Are the user interactions accommodating the extreme-user demands?
Transform	Attain extreme-user experience inspired design outcomes that are appropriate for each design phase.
Design Phase Specific Final Step	
Discover: Identify	List the needs that, if addressed, would accommodate the extreme-user demands. Are they latent?
Define: Derive	Build opportunity statements by using the identified latent needs. Down select and list the design functions required to satisfy the identified latent needs.
Develop: Ideate	Generate design concepts that would accommodate the necessary design functions.

*Situational extreme-user experiences are more impactful if the primary goal is design creativity. Situational extreme-user demands followed by direct extreme-user demands are more impactful if the end goal is to present the overlap in needs experienced by extreme-users and general population users.

Potential outcomes:

- Effectively adopt simulated extreme-user experiences.
- Discover latent user needs.
- Design creativity.
- Design inclusion.

Figure 6-4 illustrates the Extreme-user Simulated Scenarios as a method card highlighting the steps to follow, potential outcomes, and the role of situational and direct extreme-user experiences. Figure 6-5,Figure 6-6,Figure 6-7, and Figure 6-8 shares the incorporation of each of the five methods and the Extreme-user Simulated Scenarios across the three stages of the proposed framework.

Extreme-user Simulated Scenarios

To provide procedural guidance to apply extreme-user simulations.

Procedure:

Select:
Choose a design phase appropriate method(s) from Framework. For example, Activity Journey Map and Morphological Matrix.

Apply:
Adopt a phase appropriate design method to systematically identify the extreme-user demands that impact users' interaction with the PSS.

Simulate:
Engage in simulated scenarios that present situational extreme-user experiences, with or without accompanied by direct extreme-user experiences.

Test:
Test the usability of the existing or new PSS while experiencing the simulated scenarios. Are the user interactions accommodating the extreme-user demands?

Design:
Attain extreme-user experience inspired design outcomes that are appropriate for each design phase.

Extreme-user Simulated Scenarios

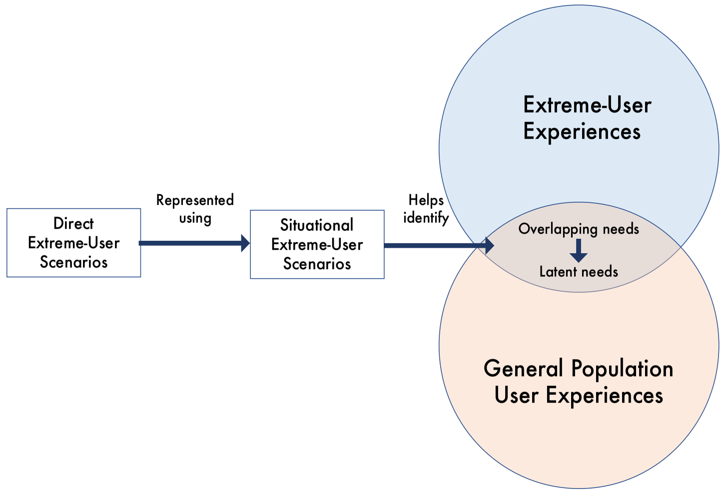
To provide procedural guidance to apply extreme-user simulations.

Expected Phase Specific Outcomes:

Identify: Needs that, if addressed, would accommodate the extreme-user demands.

Derive: Opportunity statements by using the identified latent needs.

Ideate: Design concepts that would accommodate the required design functions.



Role of Situational and Direct Extreme-User Scenarios

Figure 6-4 Extreme-user simulated scenario

IDENTIFY

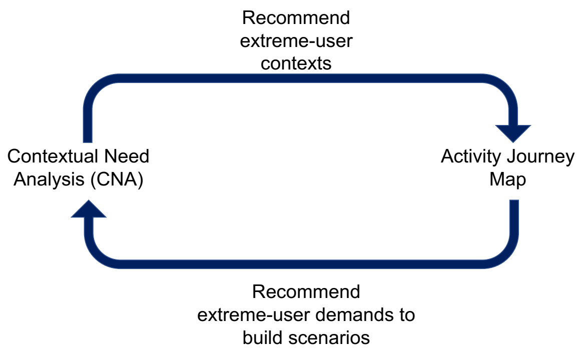
To leverage the extreme-user experiences appropriate for a PSS.

Framework Methods: Extreme-user Simulated Scenarios, CNA, Activity Journey Map.

Extreme-user Simulated Scenarios

Activity Journey Map

- Depict the user interactions with a PSS as actions and verbs using an Activity Diagram.
- Indicate user emotions during each interaction. For example, happy, frustrated, indifferent, sad.
- Determine the physical abilities (demand) needed to execute each interaction.
- Use wearable simulations that eliminate specific physical demands.
- Use user emotions to identify critical points for improvement. List the user needs that, when addressed, would accommodate the absence of the identified physical demand. Latency metric from User Testing stage can be used to discuss the latency of the needs.
- Test with users and discuss experiences. Check how similar or different are they from what you anticipated.



Contextual Need Analysis

- List different extreme-user contexts of usage for the selected PSS.
- Use Activity Diagrams to find basic abilities needed to interact with the PSS under the listed extreme-user contexts.
- Build scenarios by applying extreme-user demands identified using Activity Diagrams.
- Test the usability of the PSS under selected scenarios.
- Discover a diverse set of extreme-user experience-based needs.

Figure 6-5 Design methods that contribute to the Identify stage of the framework

DERIVE

To focus on impact evoking user interactions.
Framework Methods: Extreme-user Simulated Scenarios, Systems Function, How Might We Statements.

Extreme-user Simulated Scenarios

Systems Function

- Derive system functions that correspond to the critical points (needs) for improvements identified using Activity Journey Map.
- List them as function-flow pairs that represent the design transformations required to ease user interaction. For example, capture user attention, provide feedback.
- Extract sub-functions that contribute to the identified system function.
- Use the sub-functions to guide ideation.

How Might We (HMW) Statements

- Combine HMW statements with the design functional requirements to frame extreme-user inspired HMW Statements.

  "How might we {extreme-user experience inspired design functional requirement} to {what we want to achieve}?"

  For example, below is an HMW statement generated based on the needs experienced by elderly users

  How might we {improve password hygiene among users} to {reduce password compromise risks}?

- Use the HMW statements to guide Ideation.

Figure 6-6 Design methods that a contribute to the derive stage of the framework

IDEATE

To transform extreme-user inspired needs into exceptional design outcomes.
Framework Methods: Extreme-user Simulated Scenarios, Systems Function, How Might We Statements, Morphological Matrix.

Extreme-user Simulated Scenarios

Morphological Matrix

- List the sub-functional requirements to address the selected extreme-user inspired design functional requirement shared in the HMW statement(s).
- Add the sub-functional requirements to the morphological matrix.
- Include the situational extreme-user inspired needs that will be satisfied by addressing the listed sub-functional requirements.
- Develop concepts to address each sub-functional requirement.

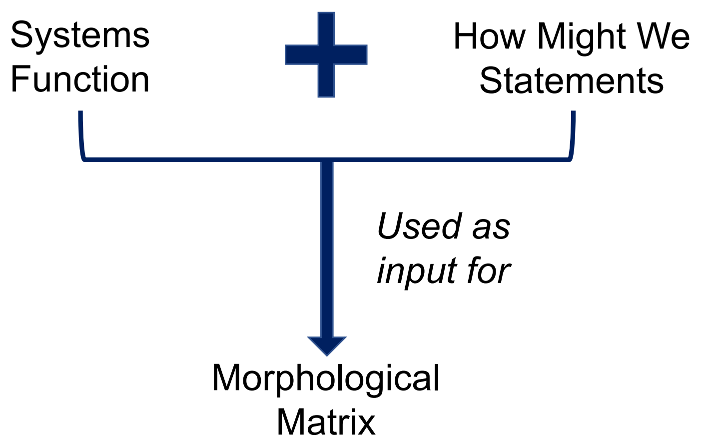


Figure 6-7 Design methods that a contribute to the ideate stage of the framework

USER TESTING

To verify the impact of resulting concepts.

Framework Methods: Extreme-user Simulated Scenarios, Activity Journey Map.

Extreme-user Simulated Scenarios

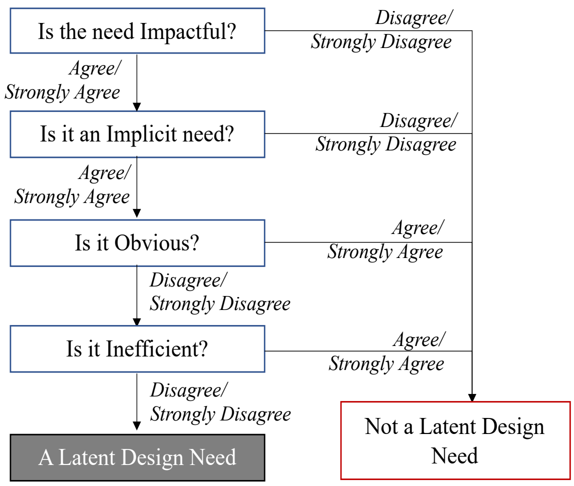
Activity Journey Map

- Depict the user interactions with the new PSS design as actions and verbs using an Activity Diagram.
- Indicate anticipated user emotions during each interaction. For example, happy, frustrated, indifferent, sad.
- Determine the physical abilities (demand) needed to execute each interaction.
- Discuss how the new design eliminates specific physical demands.
- List the number of latent needs addressed by the new design. Use the Latency metric given below to discuss the latency of each addressed need.
- Test with users and discuss experiences. Check how similar or different are they from what you anticipated.

Latency Metric

Impactful: The need has the potential to create a real difference. This need will delight the user.

Obvious: In all circumstances, the majority of the users will express this need. If 20 users are interviewed, the majority will share this need.



Inefficient: This will not have a positive effect on the user experience. It is not going to improve the experience with the product, service, or system.

Implicit: This is not a standard requirement shared by the user. Not a common requirement given to the designers.

Figure 6-8 Design Methods that contribute to the user testing stage of the framework

6.2 Proposed Framework and the DI Process Model

We thus far summarise the design methods adopted to apply extreme-user experiences throughout the design process. Every method, its implementation approach, potential outcomes, and observations were derived based on our empirical study results. While this thesis focuses on a selected set of methods, we believe they can be utilised in conjunction with the DI process model. This framework brings substantial value to the overall DI process model by improving the process, method, and people elements in ways that follow.

6.2.1 Process:

As illustrated in Figure 6-9, each method in the Framework can work alongside or feed information to the DI process model. We also believe that the Activity Journey Map from the "Identify" stage of the framework could be applied to test the usability of the prototypes and iterate during the Deliver phase of the DI process.

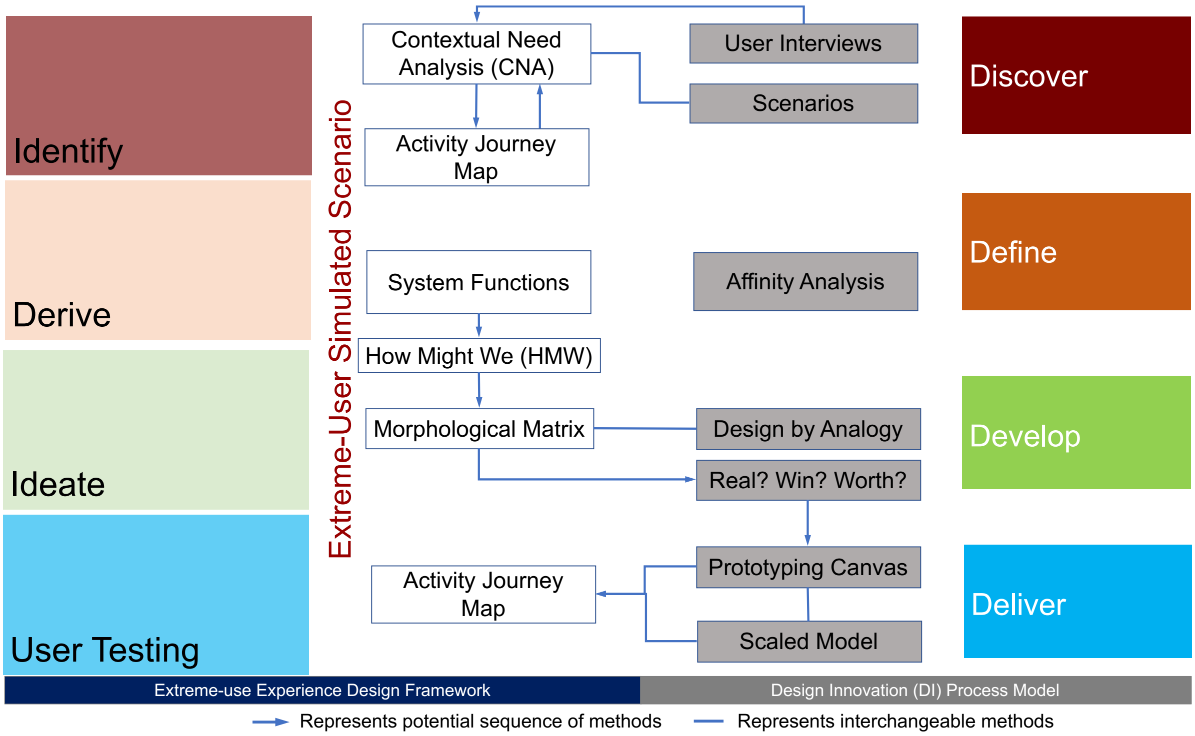


Figure 6-9 Interconnection between the Framework and the DI process model

6.2.2 Method:

The five adapted methods and the Extreme-user Simulated Scenarios provide a guided yet flexible approach to applying extreme-user experiences. With the DI process model emphasising the importance of extremes (Camburn et al., 2017; Lauff et al., 2021), a systematic application method would be highly beneficial in revealing the instances of obtaining high impact by implementing extreme-user experiences.

6.2.3 People:

The Framework is built by systematically embedding extreme-user experiences throughout the framework, enabling designers to develop their ideas with creative new perspectives. People are at the heart of the DI Process, and it seeks to empathise with their needs throughout. The framework embedded with DI would enable the designers to empathise with unique user perspectives that could help uncover the latent design needs among a larger group of users.

6.3 Framework: Conclusions and Future Directions

Every method discussed in this chapter were selected to address specific challenges encountered while adopting extreme-user experiences. The proposed templates are derived from the research studies shared in Chapters 2-5. While various research domains adopt extreme-user experience simulations, there are no systematic approaches to guide their implementation. The framework aims to bridge this gap by presenting design methods that could be used to apply extreme-user experiences during different phases of the design process.

To answer **How do the overall findings of this research contribute to designing with the extreme-user experiences?**

This framework is one of the initial attempts to systematically embed extreme-user experiences in mainstream design. Every method used in this framework challenges designers' acceptance of their design ideas and helps them foresee specific user experiences they might not consider otherwise. With users and their interactions with the PSSs forming the core of the framework, it can be adopted for any domain that involves direct user interactions with PSSs. This thesis demonstrated its application in two different domains and derived the design methods that lead to the impact observed in both domains. We proposed an Extreme-user Simulated Scenario method that reflects our observations from the foundational studies and the differences observed between direct and situational extreme-user experiences from the study shared in Chapter 3. Together they form the framework to adopt extreme-user experiences.

It was an exciting experience to apply the adapted design methods in different domains, and we see opportunities to expand it further into other domains. Especially with identifying and addressing latent user needs at different points of user interactions in systems design. Similarly, we see various areas where future works could bring significant value to the proposed framework. One of them is creating a repository for direct extreme-user experiences and their equivalent situational extreme-user experiences. Identifying latent needs was one of the expected outcomes of extreme-user experiences, but there was no formal way to validate the latency of a need. Hence, we developed a metric to evaluate latency, tested it, and evolved it further based on our study requirements. This metric could be tested more robustly to validate its impact among designers. Validation could include identifying the best ways to represent the four factors (impact, obviousness, efficiency, and implicitness) considered for latency. It would be interesting to apply the complete framework through the design process to see if the transitions between stages are seamless and gain insights on resources that would support the same.

Chapter 7
Insights, Conclusions, and Future Directions

"It's not 'us versus them' or even 'us on behalf of them.' For a design thinker it has to be 'us with them'"

-Tim Brown

7.1 Insights

This thesis empirically tests and answers five research questions to understand and adopt extreme-user experiences as a design tool. We mainly employed simulation tools and scenarios since they provide designers with first-hand knowledge of the extreme-user experiences. The following are some of the insights derived from answering our five research questions.

- Simulated extreme-user experiences enable designers to experience their designs from a perspective that is unlike their own. As a result, inspiring new design concepts that are more sensitive to the various user needs imposed by their PSS.
- Systematic use of extreme-user experiences can greatly improve designers' capacity to discover latent user needs by highlighting the experiences that impact their PSS.
- Situational extreme-user simulations, as opposed to direct extreme-user simulations, can lead to more inclusive design solutions by highlighting the overlap in demands between the extreme users and the general population users.
- Using design methods as a tool to apply extreme-user experiences, one may extract different layers of information that systematically relate user needs to specific user interactions and finally develop design concepts that address user needs at various levels of granularity.

7.2 Conclusions and Future Directions

Immense resources contribute to design processes, methods, principles, and design frameworks. In some ways, it can seem like a jigsaw puzzle, with each piece contributing to the puzzle's overall cohesiveness and comprehension. This thesis started with a desire to unfold the potentials of extreme-user experiences as part of the puzzle. With growing evidence that supports the role of extreme-user experiences in addressing the latent needs among general population users (Conradie et al., 2014; Raviselvam et al., 2016b), we built a tool that promotes their adoption in mainstream design while also addressing the concerns around simulated extreme-user experiences. The framework provided in Chapter 6 is the result of careful observation and insights gained from Chapters 2 to 5. The framework comprises four stages that address the gaps that currently hinder the holistic adoption of extreme-user experiences into the design process. Although the framework can be an independent tool, we propose combining it with the DI process model (Lauff et al., 2021) to create a repository of methods that facilitate multiple aspects of user-centric design.

The thesis also introduces two novel metrics introduced to evaluate the latency of an identified need and the empathic accuracy of the concepts developed using extreme-user experiences. Despite their rudimentary nature, the metrics were vital for assessing the impact of extreme-user experiences. As a result, this thesis makes two contributions: a primary contribution in the form of a framework for designing with extreme-user experiences and a secondary contribution in the form of two metrics that have the potential to be more robust forms of evaluating the impact of extreme-user experiences. The limitations of this thesis open opportunities for future research. For example, we used a limited number of simulation tools and scenarios to test the impact of extreme-user experiences. It is to be noted that the design methods and the framework proposed explores a set of ways to systematically apply extreme-user experiences in design, and this can be expanded further to accommodate various other design methods (Lauff et al., 2021). Expanding the simulation tools, design methods, and resources to adopt extreme-user experiences would add immense value and enhance the role of extreme-user experiences in design. Future extensions of this work could also investigate the unique adjustments necessary to apply this framework to various domains. For example, to accommodate them for medical device design where strong guidelines and regulatory requirements already bombard the designers.

Another domain that can extensively leverage this framework is design education, where inexperienced designers could learn to appreciate diverse user needs and develop more inclusive design concepts. The overall outcomes of this thesis assure that the extreme-user experiences are impactful at providing insights for mainstream design concepts. Future research could also apply this framework to facilitate the exchange of information between the extreme-users and general population users. With this, we believe and sincerely hope that this framework can evolve into a tool that allows actual extreme-users to be creative contributors in design innovation.

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Appendix A: Chapter 2

Solution categories used in clustering design concepts for evaluation of breadth and novelty of concepts

Solution category	Guideline	Example
Technology-general	Any statement that refers to scientific or engineering developments for people with visual impairments without providing any context to where it could be applied.	Advanced technology.
	Design suggestions that mention including needs of people with visual impairments while designing mainstream products will not come under this category	Products that include the needs of people with visual impairments to regular products.
Technology-context	Comments that provide scientific or engineering solutions along with the context where it could be applied.	Incorporate voice feedback to enable using the device.
	Does not include design suggestions that mention including needs of people with visual impairments while designing mainstream products.	Products that include the needs of people with visual impairments to regular products.
Inclusiveness	Inclusion in this case refers specifically to concepts that insist on how a solution could be used by both visually impaired and rest of the users.	Include the needs of people with visual impairments while building a product.
	This need not include concepts that are an improvement to specifically benefit people with visual impairments. .	Provide braille interface - this is an improvement to specifically benefit people with visual impairments so this will not be directly considered as inclusive.
Involve	Concepts that recommend direct involvement of people with visual impairments to derive solutions.	Engage people with visual impairments while creating solutions.

	This does not involve solutions that recommend an inclusive design solution that could be used by both visually impaired and rest of the users.	Consider the needs of people with visual impairments while designing for rest of the population.
cost	Includes comments related to affordability and other expense related issues.	Affordabile assistive tools.
	Does not include support government or non-government organizations.	Policies to support people with visual impairments.
Education	Any response that addresses the challenges faced by people with visual challenges during and related to schooling.	Provide facilities to have proper education.
	Does not include comments that address other interpretation issues due to lack of vision.	Enable mobile phones to read signages.
Medical care	Any response that refers to healthcare and providing treatment to help people with Visual impairments.	Providing good medical facilities.
	Does not include care or attention needed from family members.	Attention from family members.
Tech-less	Any response that provides a non-technological solutions to issues faced by people with Visual impairments.	Braille to enable counting currencies.
	Does not include concepts that solve the issues through technology	Device to convert text to speech- to help read currencies.
Navigation	Includes solutions that specifically help people with Visual impairments to move around without making any changes to the existing infrastructure. These are solutions that apply changes at the user's end to ease moving from one place to another.	Tools to help navigate from one place to another.
	Does not include solutions that modify the infrastructure to make it accessible for people with visual impairments.	Manage uneven roads.
Infrastructure	Any concept that recommend modifying the architectural and structural components to make it more accessible for people with visual impairments.	Audible sign boards.

	These are solutions that apply changes to the existing surroundings and facilities to ease moving from one place to another.	
	Does not include concepts that provide a generic solution to ease navigation.	An app to inform bus timing
safety	Any response that specifically addresses the vulnerability of people with visual challenges to danger.	Being aware of dangers they would encounter while walking on the road
	Does not include responses that recommend infrastructural enhancements without being specific about addressing a potential danger.	Manage uneven roads
Family	Statements that specifically include solutions based on family and family based support received by people with VIs.	Acceptance from family members
	Does not include statements that comment on their challenges related to general public.	Acceptance among general public
Dependence	Statements that encourage trust and reliability on rest of the population.	Accept help from rest of the population
	Does not include the comments that refers to how supportive the general population needs to be.	Create awareness to eradicate social stigma
Compassion	Includes any comment that encourages rest of the population to empathize (understand things from the perspective of people with VIs) or support people with VIs.	Empathize with the people with VIs
	Does not include comments that encourages a general understanding to avoid lack of knowledge among rest of the population.	Workshops to encourage awareness
Awareness	Concepts that address lack of knowledge about the people with Visual impairments among the rest of the population and how they could be educated about that.	Educating people on appropriate ways to help the people with VIs

	Does not include concepts that directly encourage rest of the population to empathize or support people with VIs.	Stop stigmatizing people with VIs
Adaptation	Includes any comment that refers to challenges related to people with visual challenges integrating with rest of the population- how it is and how it should be.	Social integration
	Does not include solutions where the solutions adapt to the needs of people with VIs.	Designs that consider the needs of people with Visual impairments as well
Career	Includes comments that address employment and other income opportunities for people with VIs.	More opportunities to match their skill
	Does not include comments that describe about desires and ambitions in detail at a more personal scale.	Provide opportunities to fulfil their dreams
Aspiration	Includes comments that describe about the non-income related desires and ambitions of people with Visual impairments individuals in detail at a more personal scale.	Provide opportunities to fulfil their dreams
	Does not include career specific comments that are related to income and earning.	Career opportunities
Interaction	Includes comments that express the communication challenges faced by people with Visual impairments while communicating with the rest of the population.	Understanding concepts explained by others
	Does not include challenges faced while interacting with tools and technology.	Understanding recent technology
Transition	Concepts related to the period where the people with Visual impairments experience a phase where they understand or learn to live with VIs.	Support during transition periods in life
	Does not include concepts that refer to challenges faced on a regular day to day basis.	Ease communicating with rest of the population

Organiztion	Comments that refer to support required from the government or NGOs.	Policies catered for people with VIs
	Does not include the support from the general public.	Avoid societal stigma
Abstract	Concepts that are not well defined and hard to interpret.	Clothes
	Does not include concepts that provide a context of application.	Color indicating clothes

Appendix B: Chapter 4

Needs Identified with and without extreme-user experiences

Project	Needs identified without Extreme-user experiences	Needs identified with Extreme-user experiences
Catheter Guidewire Safety	**Phase I** 1. Integrated into Seldinger's procedure- compatible with current equipment 2. Fool-proof mechanism - not reliant on human efforts - not operated through weak visual clues 3. Specific to guidewire used, not easily hacked 4. Cannot overly lengthen procedure duration-> should be doable < 10mins 5. Low change in cost-price **Phase II** 1. Ease of use 2. Biocompatibility 3. Ensure guidewire removal 4. Prevent procedure without removal of guidewire 5. Biocompatible 6. Intuitive/ergonomic	**Phase III** 1. Quick threading 2. Auto-check to ensure guidewire ejection 3. Single hand usage 4. Quick and intuitive threading 5. Less visual with its outputs [not working on visual reminders] 6. Reduce visual demand
Biopsy Needle Stabilization	**Phase I** 1. Stability 2. Sterility 3. CT-Scan Compatible material 4. High degree of freedom 5. Ease of setup 6. Weight 7. Ergonomic 8. Price **Phase II** 1. Robustness 2. Manoeuvrability 3. Accuracy 4. Durability/ Strength	**Phase III** 1. Single hand use 2. Easy to adjust (strength and dexterity) 3. Easy to use (less demand on memory) 4. Small volume- do not hinder movement 5. Transparent to CT-Scan- Reduce Visual obstruction 6. Design needs to be user friendly, single hand usage 7. Size and shape of our product must be catered to single hand usage 8. Thin/palm size-hand size/ comfortable to operate

		9. Single hand dexterity-small mechanisms/parts of the needle that the clinician has to manipulate 10. "Both hand usage- some activities have to have 2 hands to complete, and some activities are required to be done concurrently" 11. "Vision- The entire procedure requires vision to complete" 12. Device needs to be obvious enough 13. Device needs to be small enough to hold easily (Ergonomics) 14. Device is easily operable. Requires less strength & easy to adjust 15. Dexterity- device needs to have suitable grip & size to allow for easier usage/ manipulation 16. Vision- device needs to have parts that are large enough to be easily visualised due to constant interaction 17. Both hand usage- due to nature of holding needle, device should be functional under single-handed use, for both left and right hand(s)
Traction Device for Shoulder Dislocation	**Phase I** 1. Safe shoulder dislocation reduction 2. No sedation treatment 3. Minimal manual assistance (Nurse) 4. Short time consumption (10-15 mins) 5. Fits arm sizes/ sides left/right 6. E-stop (Safety) 7. Ease of setup and use for the Nurse (reduce time consumption) 8. Wipe down disinfectant 9. Non bulky design	**Phase III** 1. Doctor start treatment -> ease of initial set-up (includes action & speed, time) 2. Doctor verification -> A signalling system to notify the doc when the procedure is over to come & check 3. "Visual aspect: Able Sighted- to gain information from pre and post x-rays/ visual understanding of the patient's condition" 4. "Physical Stable- Stable stance and motion is required to manually perform the treatment" 5. Strength to perform reduction 6. Dexterity to hold on to patient arm 7. Vision and dexterity to identify/verify effectiveness

	Phase II NIL	8. Need to have grip on the patient's wrist 9. Need to view if humeral head enters socket 10. Need stand on the floor to apply force on patient's arm 11. Need to hear when humeral head enters socket 12. Need to see x-ray to determine if treatment can be done
Guidewire Introducer	**Phase I** 1. Handheld device 2. Can fit in various dimensions of wires 3. Electronically controlled 4. Splash proof 5. Eo sterilization compliance 6. Ambidextrous usage 7. <10 sec operation 8. Hulas/ wires threading 9. Dummy proof 10. Emergency stop 11. Allow 2 directional movement **Phase II** 1. Easy to insert wire/ catheter/ etc. x fast	**Phase III** 1. "The device needs to have dexterity proof controls so that the clinician does not accidentally operate the wrong functions at the wrong time- This is a single handed dexterity issue" 2. Clear distinction/ indication if direction of movement- Lights/ clear indicator 3. "Coil guidewire & soak in water: 4. Reverse the reeling of wire to be distinguished: 5. Different button (varying colours) -> to clearly identify reeling in and reeling out" 6. Ambidextrous usage at handle & trigger part
Neonatal Health Monitor	**Phase I** 1. Safely wake the baby up without injury 2. Using hypo allergenic materials in contact with neonates' skin 3. Integration to current system. Leverage on existing devices used in the hospital 4. Device/product should be user friendly 5. Reasonably priced, cost effective solution **Phase II** 1. Notify nurse if neonate still doesn't breathe	**Phase III** 1. Reduce the frequency on the need of both hand usage 2. Reduce the need for nurse to attend to baby if there is a false alarm 3. Reduce the frequency of nurse having have to visually inspect if baby is breathing 4. The device/ solution should monitor the vital data from infant and alert caretaker with minimum/zero human intervention 5. The device/solution should control oxygen flow without human intervention

	even with the oxygen stimuli 2. IOT based alert system 3. Alert nurses even when if system shows success in walking baby	6. The device should wake up baby without the help of a nurse 7. Reduce the need for finger dexterity by automating the process 8. Reduce the need for both hand usage by having another system to achieve the same outcome 9. Reduce the frequency or urgency to visually inspect the baby by using a system that automates
Cuffless Blood Pressure Measurement	**Phase I** 1. Precision and accuracy 2. Intrusiveness 3. Repeatability 4. Price 5. Ease of use **Phase II** NIL	**Phase III** 1. Remove the use of cuffs 2. Get an alternative way of measuring BP without getting pressure physically 3. Make aged nurses/doctors easily press the buttons 4. Read off values 5. Audio cue for the readings. Give readings without visuals 6. Eliminate need of stethoscope 7. Must be able to operate with one hand 8. Low dexterity friendly 9. Should not rely on sound or vision only