Co-designing new keyboard and mouse solutions with people living with motor impairments

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ABSTRACT

In this report we share a co-design process for developing more accessible alternatives to traditional keyboard and mouse interfaces, involving individuals with motor impairments. We describe our methodology, including initial discovery phases that inspired three subsequent co-design workshops with three individuals with motor impairments and 26 designers. Based on our experience, we highlight the importance of creating an equitable and effective dialogue between designers and individuals with motor impairments, emphasizing the personal nature of each participant's experiences and the potential of technology as an enabler rather than a generic solution. Guided simulations and hands-on prototyping were employed to trigger meaningful conversations. We underscore the significance of "being with" during the co-design process and the importance of a transparent prototyping and development process for creating genuinely accessible and inclusive interactive systems. By sharing our findings and recommendations, we aim to assist researchers running future co-design workshops that involve prototyping with technology and people of diverse backgrounds.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility**; • **Applied computing** → **Education**.

KEYWORDS

co-design, rapid prototyping, physical disabilities, motor impairments, co-design, human interface devices

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1 INTRODUCTION

Identifying opportunities for new technology to provide more accessible ways for people to interact with computers has been the focus of many accessibility researchers [5][26]. Nevertheless, as researchers, we often struggle in our approach, including designers who unwillingly render users as non-designers, and this is particularly problematic when collaborating with people who identify as having disabilities [4].

Despite the efforts that human-computer interaction (HCI) researchers and product designers have made to collaborate with people with disabilities, for example by leveraging more equitable processes such as co-design, it is still challenging to reach a balance of fluid collaboration [13]. In this report, we share our experiences working with a group of 26 designers without disabilities and three people living with motor impairments across three co-design sessions and describe what we learned. Our co-design workshops were prefaced by surveys ($n = 42$) and in-depth interviews ($n = 9$) to identify what people with physical disabilities, such as motor impairments, look for in accessing computers and smartphones.

During co-design workshops, we guided participants and designers through several group activities to prototype input devices that addressed the needs identified during our prior phases. We included guided simulation of empathetic experiences and hands-on electronics and software prototyping. We found that getting people with motor impairments to guide designers through simulation elicited meaningful conversations. Designers also gave space and time to the people giving them instructions, which in turn brought a deeper reflection on what it meant for technology to be accessible to people with motor impairments.

Building on the work of Bennet and Rosner, our approach was focused on being "with" each other, recognizing that through activities and dialogue, a group of people can learn from each other [4], instead of talking about empathy as a quality that designers should develop so they could be "like" their target users. We contribute to the ASSETS community by highlighting how our co-design activities and hardware prototyping effectively facilitated brainstorming sessions between researchers and designers without disabilities and people with motor impairments.

2 RELATED LITERATURE

Human interface devices (hereafter, HIDs) are devices that facilitate input from human users to a computer and provide output from the computer back to the users. HCI researchers are increasingly gearing their efforts to design accessible HIDs for people with disabilities using various methodologies to uncover user needs. Participatory design, in particular, has emerged as one of the preferred approaches for integrating stakeholders into a closed loop for design [10]. This methodology emphasizes active collaboration with end users, giving them a central role in the design process. In recent years, co-design has emerged as an alternative methodology that offers a transparent framework for individuals to work together, bridging the gap between designers and users [13]. It promotes collaboration and equal participation and enables stakeholders to contribute their unique perspectives throughout the design process[27].

Designers without disabilities have used disability simulations to foster engagement and develop empathy with people with disabilities. One popular simulation technique involves researchers temporarily experiencing the effects of impairment by wearing specialized devices, e.g. wearing a blindfold to simulate a user with vision impairments. However, this approach has faced substantial criticism, including the notable proposal by Bennett and Rosner [4]. They argue that simulations and personas can act as barriers to understanding the real problems and solutions faced by people with disabilities [21, 24, 25]. Often, these simulations leave out the voices of people with motor impairments and unknowingly encourage designers to interpret the lived experiences of people with motor impairments from their lens, e.g., implementing simulation exercises without involving people with motor impairments. Simulations can overlook design insights shared by people with motor impairments and position "disabled bodies as non-designing bodies." [4]. Given this, Bennett and Rosner advocate for a paradigm shift from "be like" to "be with," emphasizing the importance of authentic engagement and direct involvement with the community.

Acknowledging the above criticisms on simulation techniques, we developed a guided simulation co-design activity that attempts to address some of the criticisms. Our activity is inspired by other researchers, who described empathy simulations guided by people with disabilities [16, 22]. Our activity sought to emphasize *eliciting conversation* between researchers and designers without disabilities and people with motor impairments and prioritizing the voices of people with motor impairments to explain their lived experiences in relation to HID. We believe this approach can support "being with" people with motor impairments. To "be with" participants, other researchers have used methods that initiate direct contact with people with motor impairments, ranging from observational studies to visual activity and user stories [3, 23].

Incorporating co-design activities to elicit empathy is not the only factor accessibility researchers need to consider: they must consider prototyping techniques that would facilitate an effective conversation with people with motor impairments. We saw the potential in rapid prototyping to achieve this goal [6, 9]. Rapid prototyping encompasses a broad range of tools and techniques, where designers and people with motor impairments use traditional materials such as paper and cardboard along with electronics and software to iterate and refine their designs rapidly [15]. Novel prototyping technologies have emerged, and they are currently used by occupational therapists and other makers, enabling non-expert users to prototype designs effectively, making the process more accessible and inclusive [2]. Rapid prototyping techniques can be especially beneficial when working with people with motor impairments because they promote self-expression and stimulate creativity [20]. This multi-disciplinary approach naturally supports co-creation of solutions [1].

One common technique to enhance hands-on experiential learning during prototyping is an exercise that involves working with paper to bring conceptual sketches to life. This technique, called paper prototyping, enables designers to explore both the form and functionality of their designs, facilitating iterative improvements [12]. Accessible electronics development platforms such as Arduino have played a significant role in prototyping. For example, Amy Hurst demonstrated the accessibility and versatility of Arduino as a prototyping platform, providing an inclusive environment for designers to bring their ideas to life [14]. Researchers have developed many additional prototyping platforms, such as accessible breadboard electronics tailored specifically for visually impaired learners [7], which supports active engagement and participation.

Our team utilized the Jacdac platform, which has also emerged as a valuable tool to aid the prototyping process and facilitate collaboration among diverse stakeholders [11, 17, 18]. Jacdac is an open-source hardware/software platform that allows everyone to create custom electronic solutions from various hardware devices with standardized PCB-based edge connectors and cables. Our team's approach was based on the exercises commonly used in co-creation workshops focused on the popularization of technology and the DIY (do it yourself) culture [19].

In what follows, we share details of our study procedure to demonstrate how our co-design activities can elicit meaningful dialogue and empathy and how incorporating the Jacdac platform can support brainstorming between researchers and designers without disabilities and people with motor impairments. The first and second authors were the main research team who planned the study and collected and analyzed data. The third and fourth authors contributed to writing this report, sharing their own experiences in collaborating with people with disabilities. We highlight how the co-design process can be broken down into several steps, from discovery phases to actual workshops.

3 METHODS

Our study consisted of three phases. We included Phases 1 and 2 to understand lived experiences of physical disabilities in relation to HIDs and used participants' responses collected during these phases as brainstorming probes for the main co-design workshops.

The third phase included three sessions of two hours with a group of 26 designers without disabilities and 3 people with motor impairments. During these sessions, we worked in small groups to co-design prototypes of accessible alternatives to the use of a mouse and keyboard to interact with a computer.

3.1 Preliminary Data Collection: Phases 1 and 2

We recruited 41 participants who self-reported having physical disabilities. After the recruitment, in Phase 1 we asked the participants about their relationship with computers. Besides demographic information, we asked about their usage of computers and mobile devices, what accessibility features they used, and any habits they had developed. We enquired about their use of accessible and assistive technologies in general, particularly in relation to HIDs.

During Phase 2, we used in-depth semi-structured interviews to collect more data. We identified potential participants through purposive sampling, using an inclusion criteria of people with motor impairments who use assistive technology. We conducted the interviews at the participants' homes to allow a more naturalistic environment, encouraging participants to demonstrate their practices and daily routines as accurately as possible. In addition to asking questions, we showed participants various types of keyboards and other input devices to solicit further thoughts and ideas.

Analysis of the information gathered during Phases 1 and 2 revealed the most common approach was to use an additional external keyboard, mouse pointer, or trackball to mitigate the problems with a laptop's built-in keyboard and touchpad. The overarching challenge was clear: people with motor impairments currently have to make do with inputs designed for the mass market, sometimes to the point where it is physically painful, making it evident we need to develop better solutions and communicate these more widely.

3.2 Phase 3: Main Co-design Workshops

Building on the insights discovered in prior phases, Phase 3 focused on co-design workshops where people with physical disabilities in their upper limbs, along with designers without disabilities, co-designed their own solutions using physical prototypes.

We designed these workshops to facilitate collaboration and creative problem-solving. Each workshop lasted 2 hours and included 26 designers and three participants selected based on their diverse range of motor impairments (hereafter, participants). There were 3 facilitators who led each workshop, working with a group of 28 designers for the first workshop, 22 for the second, and 27 for the last one. Each group included employees from a commercial design studio with a wide range of skills, such as electronics and software engineers, user experience, graphic and industrial designers.

We compensated our three participants for their time, and they were recruited by China's Disabled Persons Federation (Shanghai Pudong local branch):

- **P1:** A self-employed individual living with hemiplegia who uses computers with one hand by alternating between the mouse and keyboard.
- **P2:** An individual with oligodactyly, possessing a total of five fingers, including thumbs across both hands, who experiences slow typing on a standard keyboard. They find it challenging to press key combinations and navigate the space between keys.
- **P3:** A university student with cerebral palsy, who faces difficulties using 3D modelling software due to fine motor skill requirements.

Session 1. Part One - Brainstorming: We briefly introduced the workshop attendees, sharing the insights and findings obtained from the surveys and interviews conducted earlier in the study. This served as a foundation for understanding the main difficulties people with motor impairments encountered when using computers and smartphones. By using notes and drawings, as seen in Fig. 1, we gave time for each attendee to generate several ideas about how technology could be used, specifically pairing up participants that needed assistance creating their notes because of their motor impairments [8]. Each team shared their notes, and the whole group gave constructive feedback.

Figure 1: Visual results from brainstorming in Session 1

Session 1. Part Two - Familiarization with technology: The first hands-on activity was to get people familiar with the technology. We prompted participants and designers to divide into smaller groups, each consisting of one facilitator and one participant. The facilitators were experienced in using Jacdac, a physical computing and prototyping platform enabling digital device interaction [11].

We gave a different Jacdac electronic device connected to a computer to each group, and we directed them through instructions about how to use this to emulate a keyboard or mouse. Three Jacdac input modules were randomly assigned: a push-button switch, a rotary encoder, and a sliding potentiometer. One of the key elements of this activity was that the groups were instructed to have a time constraint of 10 minutes to create a functional prototype to enhance or replace existing keyboard or mouse capabilities.

Session 2. Part One - Familiarization with the needs: While the simulation of disabilities has been pointed out as an inadequate approach to generate empathy, we ran a curated series of experiences to trigger interesting conversations among designers and participants. Each participant designed an activity to let designers have a sensory experience while they explained their pain points when using a computer from a personal perspective. P1, with hemiplegia, guided designers verbally through a series of actions to be performed with his electrically powered wheelchair (Fig. 2). P2 demonstrated the challenges of living with oligodactyly by asking users to put paper tape on their fingers and type specific words and key combinations on a keyboard (Fig. 3). P3, with cerebral palsy, asked designers to take turns sitting on a rolling office chair to control a computer mouse while other designers were rapidly shaking the chair and their hands (Fig. 4). Having people with motor impairments design these activities allowed follow-up conversations among each group about the reasons for the chosen formats.

Session 2. Part Two - Idea generation: Following an affinity mapping framework known as "How Might We" [8], participants and designers employed sticky notes as a tool for ideation. This stage captured opportunities during lightning talks and the Understand phase. This method lets your team take the insights and pain points they hear and reframe them positively. Participants generated ideas and concepts about improving computer and smartphone

Figure 2: P1 instructing how to operate his wheelchair

Figure 3: A designer typing as instructed by P2

interactions and placed them on the sticky notes. These ideas were then grouped into themes to identify common areas of focus and potential solutions, but everyone on the team was encouraged to avoid censoring any ideas.

Session 2. Part Three - Paper prototyping: The groups worked together to create paper prototypes to refine further and validate the ideas. These prototypes served as tangible representations of the proposed solutions, allowing participants to visualize and evaluate their feasibility and effectiveness.

Through this collaborative process, we aimed to leverage the expertise and perspectives of participants and designers to develop innovative and inclusive solutions. The workshops provided an opportunity to explore the possibilities offered by rapid prototyping, physical computing, and software tools in addressing the specific challenges faced by people with physical disabilities in their interactions with computers and smartphones.

Session 3. Part One - Solution development: We reviewed the needs and the paper prototypes created in Session 1 brainstorming. The selected ideas were analyzed and criticized as a group. Then each participant worked with a group of designers to create a series of approximations of that idea, refining them. We showed the final prototypes to each other by the end of the session, collecting feedback.

Using the Jacdac prototyping platform, designers and participants mocked-up solutions that they thought better addressed the needs. The solution of a virtual keyboard controlled with a joystick was very similar to the original paper prototype. But in the other cases, the refinement process uncovered a different approach; for example, the head-mouse function evolved into a ring with a series of buttons that could control pointer direction.

From previous experience running similar workshops, we were aware that interactions within teams composed of highly technical people (e.g., engineers, UX designers, and industrial designers) are not always meaningfully integrated with people with different backgrounds. So in this study we prompted each group to do a role play where the participants with motor impairments were the directors or CEOs of small startups whose co-founders were the other group members. The prompt was not followed closely, but it was mentioned several times by the different team members as a helpful dynamic in their dialogues and interactions. Each group acted as a small company trying to build a product, and the participants made strategic decisions in consultation with the other designers.

Session 3. Part Two - User testing: Once each team had a sample prototype, we shared it with everyone and participants and designers gave feedback about its use. During the sharing session, one team member took notes of the positive comments, aspects of improvement, and technical suggestions of the other teams. The prototypes finally assembled were:

- a mouse ring, which allows typing and mouse control with a single hand;
- a virtual keyboard, where a joystick is used to select a key displayed on a big LED panel, so a single button can make any keystroke; and
- dedicated key shortcuts, where external buttons are mapped to keyboard combinations that people with motor impairments may find hard to press.

4 DISCUSSION

We now make recommendations for accessibility researchers who are planning co-design activities including hardware prototyping, with the goal of establishing a collaborative atmosphere among designers without disabilities and participants with disabilities.

4.1 Recommendations for Co-Design Activities

Excuses work: Throwing designers and participants together from the outset can bring tension to the dynamics and limit how they interact with each other. In other workshops, we had observed how technical or social skills segregated the groups. P3 told us that *"The first time we tried pressing buttons [of a Jacdac prototype] were too difficult. The second exercise we did [using a small display and an automatic sequence of characters], was too long to wait. I prefer this new way, like my wheelchair control. Now I can know where the letter is, and I can select the letter by myself."* By introducing the excuse of doing a guided exercise such as a small technical task, interactions

Figure 4: An activity guided by P3 for designers

naturally led to a 'flat' organization and collaborative atmosphere that lasted throughout our sessions.

Empowering participants: By having the participants share a simulated experience that they designed, they were "forced" to give instructions and be in charge of an initial exercise that put them in the role of being an expert. This view of participants as experts was long-lasting, and when we moved to other design processes that they were less familiar with, designers were consulting them as the experts they actually were. After one of the workshops, P1 articulated what he wanted to build with professional vocabulary *"... and another scenario is playing games, in many types of game operations, it's a combination of mouse and keyboard, these are very important for me."*

Support each other, really: Some of the teams viewed the session as being a flat structure. As such, designers and participants were at ease when they were thinking of solutions and sharing opinions, but were relieved to know that they were still being supported by specialization when it came to the tasks and talents that the team had. P2 told us that *"I think the project is going well, and it's more streamlined and convenient than I imagined; this keyboard design will be more practical and convenient for my way of typing,"* expressing how she was relying on the skills of other designers to address her needs. We found that teams that built the most sophisticated solutions had different members who offered to combine their ideas, contributing to the group solution. Our reading is that it made a difference in ideating solutions when the people with motor impairments trusted the skills of the designers, and simultaneously the designers confidently shared their ideas seeking feedback and listening to suggestions.

Slower pace: While time allocation is a standard recommendation for co-design activities[13], all our workshops needed extra time to complete each activity. In comparison, prior activities we organized with people with disabilities and designers in rapid prototyping sessions required less time. For hands-on collaboration with designers and participants, as we have done in this co-design workshop, we needed between 30 and 70% more time to finish activities such as discussing or actively working with a prototype.

4.2 Recommendations for Hardware Prototyping

Smaller is not better: To enhance the ease of manipulation and ensure accessibility for a wide range of users, researchers have explored prototyping technologies that offer user-friendly interfaces [9, 14]. These technologies aim to minimize the barriers participants face during the prototyping process, allowing for increased engagement and usability. In particular, we used Jacdac wired sensors that were bigger than other industrial sensors. Their bigger size proved to be useful since the connection with cables was easier to understand, and it brought a more accessible entry point than other more complex connections as participants were not familiar with miniaturization, it was an obstacle to think thoroughly about wearables or integrated devices.

Critical timing: In co-design activities, it is essential to create a transparent process, even when there are numerous hidden layers between the input (e.g., physical knob movement or key press) and the output (e.g., mouse pointer position change or generated key combination). By emphasizing transparency, we aimed to alleviate fears associated with understanding the intricate interaction between components involved in the co-design process. In our process, we found that paying attention to the input/output timing helped us to reveal these hidden layers, enabling participants to comprehend the underlying mechanisms and facilitating their active engagement in the design activities.

Sci-Fi meets reality: Right from the first exploratory exercises, there was a persistent "nothing will stop us" attitude that kept building the confidence of the participants, with comments like *"I've only seen this in movies" [P1]* and incredulous expressions like *"Did I just make this?" [P3].* Nevertheless, there were moments when participants needed a reality check because the imagined functions and the actual technical capabilities had a substantial gap. Two examples of these *almost* impossible technical implementations were: trying to use gestures—requiring at least another kind of sensor and computational capabilities; and fabricating complex mechanisms that would have needed a sophisticated mechanical and structural design with advanced prototyping techniques.

Familiar concepts result in familiar solutions: When groups were trying to build "a bigger keyboard" or a "mouse with more buttons", we observed that those not exposed to technology and interactive devices outside of their comfort zone were less exploratory in their solutions. This did not have any negative connotations in itself, but when compared to the kind of solutions ideated and prototypes built by other teams, we believe that providing at least a short exposure to technology to all the team members would have a positive impact on their collaborative process.

5 CONCLUSION

This report showcases our study procedure, demonstrating how co-design activities, integrated with the Jacdac electronics prototyping platform, support collaborative brainstorming and device creation. In particular we report on effective and engaging collaboration between researchers and designers without disabilities and people living with motor impairments, who all worked together to create new keyboard and mouse solutions to facilitate human-computer interaction. We shared eight recommendations with the ASSETS

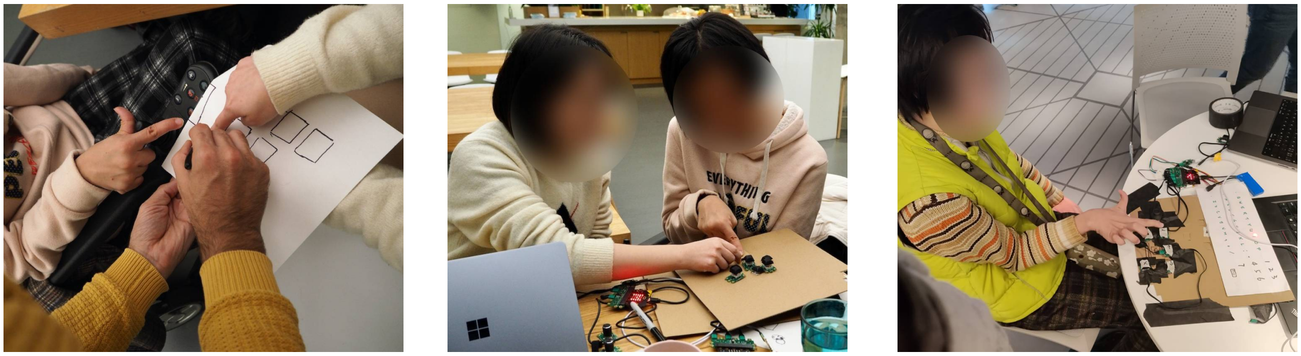

Figure 5: P3 along the different sessions of co-design workshops: paper prototyping (left), using electronics to build a rapid prototype (center), and testing the solution (right).

community which we hope will inform future work to design interactive systems that are truly inclusive and accessible to people with disabilities. Our vision is a world where both hardware and software technologies can be readily adapted, avoiding people with specific needs having to adapt to mass-market solutions.

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