Figure 1: Image of Drawxi board where users can draw freeform diagrams.

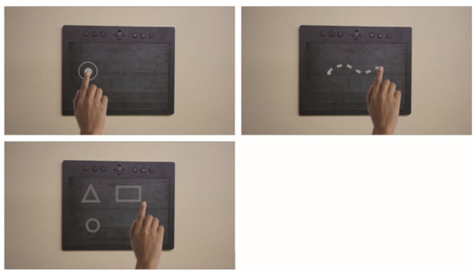

Figure 2: Explains drawing mode triggered by double tap or basic shape buttons.

Figure 3: Visualizes Drawxi being used in a meeting with visually impaired and sighted users.

Drawxi—An Accessible Drawing Tool For Collaboration

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ABSTRACT

Visual impairment can profoundly impact well-being and social advancement. Current solutions for accessing graphical information fail to provide an affordable, user-friendly collaborative platform for visually impaired and sighted people to work together. Therefore, sighted users tend to have low expectations from visually impaired people while working in a team. Hence, visually impaired people feel discouraged to participate in a mixed population collaborative environment.

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Table 1: Pros and cons of previous solutions environment (*Summary of a figure by Jens Bornschein and Gerhard Weber* [2])

Name	*Pros*	*Cons*
TDraw	Voice output	Many components
IC2D	Recursive grid	High cognitive load
Tangram & MIMIZU	Pin matrix and tactile	Bulky and expensive
AHEAD	Force feedback	Needs sighted user

Table 2: Requirement Analysis for non-visual drawing (*Summary of a figure by Jens Bornschein and Gerhard Weber* [2]**)**

General	*Interaction*	*Features*
Independent	Multitouch	Freehand drawing
Multimodal	Keyboard support	Editing options
Object state feedback	Orientation aids	Labeling
Personalized	Smoothing & cleaning	Sharing and collaboration
Compatible	Sequential	Multimedia access

Consequently, their generative capabilities remain devalued. In this paper, we propose an audio-haptic enabled tool (Drawxi) for free-form sketching and sharing simple diagrams (processes, workflows, ideas, perspectives, etc.). It provides a common platform for visually-impaired and sighted people to work together by communicating each other's ideas visually. Thus, enabling the discovery of generative capabilities in a hands-on way. We relied upon participatory research methods (Contextual inquiry, Co-Design) involving visually impaired participants throughout the design process. We evaluated our proposed design through usability testing which revealed that collaboration between visually impaired and sighted people benefits from the use of common tools and platforms. Thereby, enhancing the degree of their participation in a collaborative environment and quality of co-creation activities.

KEYWORDS

Drawing tool; multi-modal; accessibility; inclusive design; gestural; haptic feedback; diagrams; collaboration; touch device; visual impairment

1 INTRODUCTION

In the United States, the number of people with visual impairment or blindness is expected to roughly double from 4.2 million (in 2015) to more than 8 million by 2050 [9]. Thus, the need for accessible education [3] and employment opportunities will increase significantly [4][7]. This demands smooth collaboration between differently-abled individuals with an expectation of fair contribution from each team member. However, there is a lack of accessible tools for collaboration. Accordingly, the generative capabilities of visually impaired individuals are under-utilized, dramatically reducing their visibility in the larger social fabric [8]. This cumulatively results in an overall lower expectation from these individuals. In our research, we found that to overcome lower expectation people need to collaborate more often. Furthermore, there needs to be an ecosystem to foster collaboration between differently-abled individuals. We address this problem by proposing a design intervention that enables positive co-creation between visually impaired and sighted people. We began by assessing the current state of non-visual access to graphical diagrams because it is a primary barrier to solve.

2 LITERATURE REVIEW

Authors Zaira Cattaneo, Tomaso Vecchi, Cesare Cornoldi, et al. [2] state that, forming mental imagery is not a straightforward process. They further state that visually impaired people rely on a multimodal approach for forming mental images to compensate for their visual deficit, predominantly relying on hearing and touch (cutaneous); thus, their mental imagery is a result of combining auditory and tactile information. Sri Hastuti Kurniawan and Alistair Sutcliffe [5] suggest that visually impaired people employ a structural mental model whereas sighted people

Figure 4: Evidence of drawings done by visually impaired participants with finger or pen observed in contextual inquiry.

Figure 5: Participants building prototypes during Co-Design workshop.

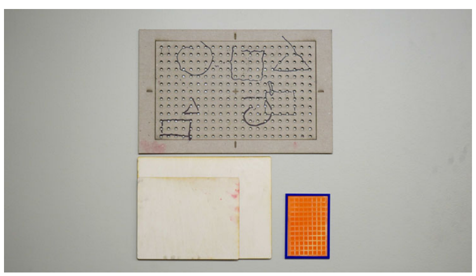

Figure 6: (Above) Concept1-Pin matrix. (Bottom left) Concept 2-Drawing pad.

rely on a survey-like mental model. If confirmed, such studies imply that there exists a correlation between perception and mental imagery. Patrick Headley and Dianne Pawluk [5] state that visually impaired people rely heavily on conveying their understanding via speech, text, or tactile rendering (analog). They further state that these methods have several disadvantages, and, in some cases, the verbal or textual description is inadequate and demands higher cognition [5]. Furthermore, authors Patrick Headley and Dianne Pawluk [5] state that, tactile drawings are difficult to correct. Comparing relevant work, as shown in Table 1, revealed that current solutions either are not readily available in the market or are impractical for regular use[1]. Nonetheless, these projects have uniquely tackled the problem guiding future work. We listed these requirements, as shown in Table 2, to guide our design.

3 PRIMARY RESEARCH

To learn more from our target users we reached out to the Council for Community Accessibility (CCA) in Bloomington, Indiana, and the American Council of the Blind (ACB), Indiana. Members of CCA and ACB voluntarily agreed to work with us for this study. After receiving IRB (#1810001024) approval we contacted interested members and commenced primary research.

3.1 User Interviews

We conducted user interviews with 20 visually impaired participants in the age group of 21 to 45 years out of which 12 participants were female, and 8 were male. Participants belonged to diverse educational backgrounds. Participants were chosen based on severity and type of visual impairment including congenital blindness, acquired blindness, blurry vision, partial blindness, etc. User interviews confirmed that in a mixed population (visual impaired and sighted) collaborative environment participation was hindered because of inaccessible graphical diagrams. They conveyed their ideas verbally which required a sighted collaborator (like a teacher or coworker) to have interest, imagination, and knowledge of subject matter. The effectiveness of communication largely depends on sighted collaborator's interpretation skills. As a workaround, some participants broke down complex ideas into a list and verbally described each point sequentially, using an Excel sheet, Word file, or mobile device. Furthermore, creating tactile material requires advanced preparation, it is difficult to make quick changes and usually, printers or tools are not readily available. Consequently, visually impaired participants seldom shared their feedback or critique for graphical diagrams.

3.2 Contextual Inquiry (CI)

We performed a Contextual Inquiry (2 participants) to study their communication technique in a mixed-population (visually impaired and sighted) collaborative environment. We also intended to study the workarounds they utilized to overcome inaccessibility of graphical representations as well as to observe the exploratory techniques utilized to interpret tactile artifacts. We performed the Contextual Inquiry in a hypothetical setup because we did not get permission to observe the

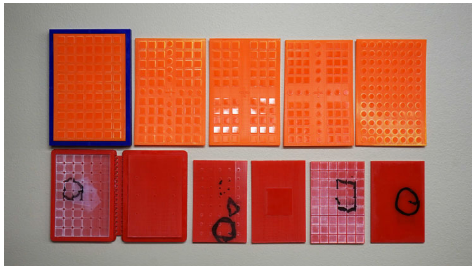

Figure 7: Various forms of gridlines evaluated during usability testing.

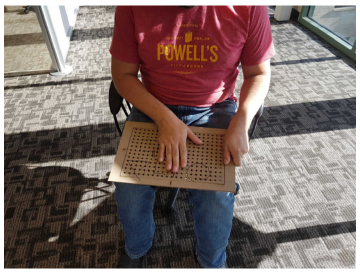

Figure 8: Evaluating Drawxi for various sitting positions.

Figure 9: Final prototype of drawxi with basic shapes, navigation buttons, and edit buttons.

participants at their workplace. Observations revealed that participants had varying strategies to explain complex ideas. One participant used a sequential description based on memory which did not need graphical information, while the other participant utilized lived experiences to explain ideas and used primitive stick figures as illustrations. Closely observing their finger movements revealed that visually impaired people use all their fingers to interpret tactile artifacts. Furthermore, we observed that retracing the starting point of the drawing was challenging as shown in Fig. 4. Moreover, the lines were not smooth, and the individual relied on their non-dominant hand for reference as shown in Fig. 4.

3.3 Co-Design Workshop

The hour-long workshops consisted of three sessions for brainstorming, rapid prototyping, and presentations to combine myriad user perspectives towards a fitting outcome. We performed two Co-Design workshops with 10 visually impaired participants in total. After a brief introduction, "What if" cards helped participants kickstart brainstorming. Later, we formed four separate teams with visually impaired participants and a sighted design student. Each team tried to resolve the problem by proposing a design solution followed by presentations. To enable rapid prototyping, we used materials like clay, popsicle sticks, stickers, stencils, and tactile UI elements (created by laser cutting soft cardboard). The workshop revealed that visually impaired people preferred tactile feedback followed by auditory feedback. They rely on guidance and confirmation until they become familiar with the system. Visually impaired people heavily rely on orientation aids and product semantics (symbolic qualities of form). They start exploring tactile objects by touching the edges and then move inwards. Moreover, communication becomes effective if sighted and visually impaired participants share the same tools as shown in Fig. 5.

4 CONCEPTS

After synthesizing insights from the preceding observations, we began ideating to generate numerous concepts. Through constraints, we narrowed down to two design concepts. Concept 1—the pin matrix concept—consists of two separate boards for input and output as shown in Fig. 6. The input board has a flat surface with a frame signifier and navigation buttons. The output board consisted of the pin matrix for tactile exploration. Concept 2—the drawing pad type concept with circular protrusions—consists of a single drawing board divided into two parts. One side is for exploration and the second part is for drawing. Haptic and sound feedback enable shape exploration with a grid of piezo-electric actuators. It provides navigation buttons on the top as shown in Fig. 6.

5 USABILITY TESTING AND ITERATIONS

We performed usability testing with three participants by creating prototypes via laser cutting soft cardboard material. Although participants felt Concept 1 is better in terms of tactile feedback, they did not feel drawing on the pin matrix is natural. Overall, participants preferred the drawing

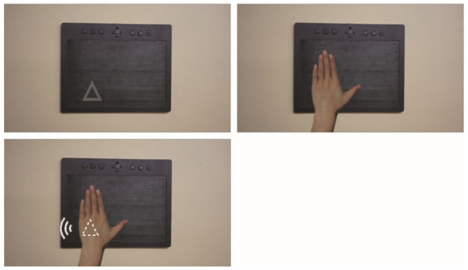

Figure 10: Explains shape exploration using audio-haptic feedback.

Figure 11: Visualizes design of Drawxi canvas for remote collaboration.

Figure 12: Visualizes Drawxi connected with a laptop for remote collaboration by visually impaired users.

pad (Concept 2) because it is compact (200 mm * 160 mm) and participants felt they could easily draw on a flat surface. Participants also stated that the buttons on the top are suitable for both left-handed and right-handed participants. However, participants felt discomfort with the size of circular protrusions. For the next iteration, we tested various types of gridlines as shown in Fig. 7. Participants preferred smooth surface with minimal gridlines. Comparing single finger and stylus for drawing revealed that drawing with a single finger is preferred for a tactile experience.

6 FINAL DESIGN

Drawxi is a tool for multimedia and multi-sensory communication between visually-impaired and sighted users. It consists of a Drawxi board (a touch surface) for creating graphical information and Drawxi Canvas (a web-based collaboration platform) for collaboration.

6.1 User Scenario

Let us consider a visually impaired user wishes to propose an alternative organizational structure in a meeting to improve the organizations transparency. Before the meeting, the user connects Drawxi to a keyboard-enabled device (e.g., desktop, laptop, tablet or any other assistive device) via C-type cable or a USB cable. The user selects a rectangle button (see top-left of Fig. 9) from the Drawxi board for depicting designations. The user performs a double tap interaction on the board with a single finger and starts drawing two lines to specify the location and size of the rectangle (similar interaction is used for drawing a triangle and circle with the buttons). Then the user moves multiple fingers on the board to explore (explore mode) the shapes as shown in Fig. 10. Sound and haptic feedback help the user locate the rectangle as the blank area of the board does not produce any feedback. The user performs a long press interaction and labels the rectangle using a keyboard. Similarly, the user creates another rectangle and labels it. Finally, the user performs a double tap interaction and connects the rectangles using the Draw mode as shown in Fig. 2. To add more elements the user uses the navigation buttons (see top-middle of Fig. 9) and shifts to the next frame on Drawxi Canvas. The undo, redo, and clear frame buttons (see top-right of Fig. 9) allow the user to perform edits. For collaborating with co-workers, the user shares the URL of Drawxi Canvas and a four-digit access code. While the user explains the new organizational structure, a co-worker suggests a minor addition by adding new shapes to a new frame on Drawxi Canvas. The user gets a notification on Drawxi board and the user presses the ok button. The user is taken to the frame where the minor addition is added. The user explores it via explore mode as mentioned above.

Similarly, users can use Drawxi to remotely collaborate with others to complete assignments, clearing doubts, giving directions, helping kids with homework, storytelling for leisure communication, play games like Pictionary, etc. Our design allows users to use their fingers for a profound tactile experience. Haptic feedback at the starting point allows users to create closed shapes and guide their diagrams. Auto-smooth feature assists the user to draw lines clearly.

7 CONCLUSION AND FUTURE WORK

In the forthcoming versions, we plan to extend compatibility with third-party applications, like Microsoft Office, Adobe creative cloud, and other visual graphics platforms. Later, we intend to add wireless connectivity, and voice feedback for labels, shapes, etc. Through Drawxi, we strive to strengthen our social bonds by nullifying the ill-effects of low expectations from visually impaired people. This will allow a healthy exchange of ideas and perspectives in a hands-on way. With greater accessibility, we hope to open new possibilities for partnership in social, economic, and political engagements.

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