Interdependent Variables: Remotely Designing Tactile Graphics for an Accessible Workflow

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ABSTRACT

In this experience report, we offer a case study of blind and sighted colleagues creating an accessible workflow to collaborate on a data visualization-focused project. We outline our process for making the project's shared data representations accessible through incorporating both handmade and machine-embossed tactile graphics. We also share lessons and strategies for considering team needs and addressing contextual constraints like remote collaboration during the COVID-19 pandemic. More broadly, this report contributes to ongoing research into the ways accessibility is interdependent by arguing that access work must be a collective responsibility and properly supported with recognition, resources, and infrastructure.

CCS CONCEPTS

• **Human-centered computing** → Accessibility; Empirical studies in accessibility; Visualization; Empirical studies in visualization.

KEYWORDS

Tactile Graphics, Blind, Low Vision, Collaboration

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1 INTRODUCTION

Data drives decision-making in computer science and society at large, making data representations ubiquitous. They come in many forms, such as text, tables, geographic maps, visualizations, or sounds. While researchers have been studying ways to make data non-visually accessible [12, 13, 17], data representations still mostly rely on visual presentation, remaining inaccessible to people who are blind or low vision (BLV), who then experience barriers to thriving in data-heavy domains like STEM [2, 19, 27]. Further, while accessibility marks growing research, it often comprises work on making end products, rather than processes accessible. Research on non-visual data representations follows in this pattern: little research explores how people incorporate accessible data into workflows, and their associated design and development under-represent BLV people [12].

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To help address this accessibility gap, we share lessons from our team of blind and sighted colleagues, who worked together to create an accessible workflow for a project centered on data representations. While the primary goal of this project was to make digital data visualizations non-visually accessible with screen readers [1], we also made our workflow accessible to make full use of our collaborative potential—the latter of which we detail in this report. Working on this project required a shared set of reference data visualizations, so we created ones that are both tactile and visual. Our process further accounts for our team's needs and contextual constraints, like the remote nature of our collaboration during the COVID-19 pandemic. Building on the philosophy that accessibility is co-created and interdependent (i.e., that it is the responsibility of all team members) [6, 10], we reflect on our collective process for making an accessible workflow that enabled our primary task. We want to motivate others to develop accessible workflows and include BLV collaborators in all decisions, including those informed by data representations.

2 BACKGROUND ON TACTILE MEDIA IN ACCESSIBILITY RESEARCH

Tactile graphics, or representations of graphics accessible through touch, have long been a common and effective method for providing accessible graphics to BLV people [4, 5, 15–17, 26]. As the current "gold standard" for making graphics accessible, they're frequently used as the baseline when evaluating new methods of access [12]. Tactile media are also key to including BLV collaborators in design and computing-related activities [14, 20–24, 28, 29]. Tactile graphics also benefit from BLV involvement. For example, one project that evaluated a system for blind and sighted collaboration on tactile graphics found that iterations and feedback changed their designs, even when they were originally authored by professionals [8].

Advancing touch-based graphics for BLV people is a rich area of research; a recent systematic literature review found at least 292 such publications from the last 10 years [12]. This review also highlighted how only 5 of these papers consider graphics in the workplace and how rarely they involve BLV people in the early design or prototyping stages of developing these graphics-related technologies. Although we do not discuss developing new technologies, we aim to broaden the literature by sharing our experiences of incorporating tactile graphics into our workflow as to include BLV colleagues in developing screen reader accessibility for charts.

3 OUR TEAM AND METHODS

We are researchers—Lilian and Cynthia focused on accessibility and Dominik on data visualization—working together to explore ways to make digital non-visual data representations. We used the tactile graphics described in this report to make our workflow accessible. As the project leader, who is sighted and experienced with crafting, Lilian systematized our workflow early and developed creative solutions for access and remote work. Cynthia brought her expertise in accessibility research, running accessible design workshops, and being a blind braille reader and tactile graphics user. Dominik contributed data visualization expertise and is also sighted.

Our data comprised of expansive documentation of the processes we undertook to create both handmade and embossed tactile graphics. Specifically, material reference sheets, prototyped graphics, instructions for successful and unsuccessful methods for creating them, software files and their respective embossed texture reference sheets and tactile graphics, feedback notes, and co-author reflections on the process formed our data set. Our analysis was a mixture of thematic [11] and feminist reflexivity [3]. We distilled examples for this report, our lessons, and higher-level takeaways through collectively reading and responding to our documentation and each other's reflections. While our initial reading of each other's reflections was systematic, our subjectivity guided subsequent prioritization to share our thorough process with notes on what we found to foster inclusion of all team members in data-driven decision making.

4 DEVELOPING TACTILE GRAPHICS

Our process reflects the contingencies of working remotely due to the COVID-19 pandemic. These constraints meant the tactile graphics we used in our workflow needed to have higher fidelity than those we could have used in person, as we could not spontaneously alter graphics, nor could we see or position each other's fingers to substitute small details with in-situ verbal explanations. In person, we could have bent wires or rearranged magnets on a metal sheet to represent different charts. Remotely, we needed to craft each chart into an understandable, stand-alone artifact. To this end, we invested time into learning how to properly create them. We crafted and shipped handmade tactile graphics to each other, paying attention to quality to avoid needing to redo or reship unusable or incomplete ones. To scale our operations, we later machine-embossed tactile graphics as well. We reflect on these processes in this section, concluding with our perspective on their impact.

4.1 Self-Education About Tactile Graphics

While creating tactile graphics was a supporting task to our main project, we understood that the quality of these graphics would impact the accessibility of our remote workflow and thereby our final outcomes. Hence, self-education in this area was especially valuable as creating high-quality tactile graphics requires developing considerable expertise [8]. As *The Tactile Graphics Guidebook* put it, "It simply cannot be assumed that a graphic will be made meaningful to the blind by merely raising it above the surface point for point" [4].

We took multiple approaches to learn the associated skills. We attended relevant community events hosted by experts, facilitated by Cynthia who paid attention to communications she receives from blindness-related organizations. We attended workshops and professional talks by blind scientists who have developed and regularly use tools to explore data non-visually, learned about DIY tactile art with common home supplies, met with a well-known technology educator to learn basics of embossing tactile graphics, and referenced several publicly-available tactile graphics resources [9, 15, 25]. To help develop an intuition for good tactile graphic design, Lilian also non-visually studied sample graphics we received from embosser manufacturers. Supplementing the best practices we learned, this experience helped reenforce to Lilian how different styles of graphics can support or undermine tactile comprehension, while keeping in mind novice insights cannot replace deep expertise [7, 30]. We ultimately developed a workflow unique to our needs, which we note does not reflect the preferences of all BLV people or all best practices.

4.2 Developing Handmade Tactile Graphics

We began with the practice of using handmade tactile graphics, as we can create them with low-cost, everyday crafting materials. We also learned that handmaking graphics can offer higher fidelity than present-day embossers, especially for some chart types that benefit from a larger variety of textures or from more prominently three-dimensional materials. One such example is a heat map. While a handmade tactile graphic can use prominent 3-dimensional topology to represent a heat map's color scale, an embosser cannot yet provide the same fidelity. The supplementary materials include photos of such a heat map, as well as additional example handmade tactile graphics to supplement those featured in Figure 1.

We first explored what materials to use. Cynthia made a supply list of tactile materials she has used in past accessibility research and personal projects. She weighed the tradeoffs of supplies marketed as accessibility tools versus mainstream supplies, and primarily recommended mainstream supplies for convenience and cost. Lilian purchased them, along with other materials she found while browsing various household, arts, crafts, and first aid supplies. She also purchased equipment for chart creation and shipping. This equipment included a braille slate and stylus informed by Cynthia's expertise that offers ample flexibility to produce braille on a variety of label materials and sizes. To assess the potential of each tactile material and to streamline decision-making, Lilian constructed a reference sheet with samples of the different materials and ways to apply them as pictured in Figure 1 (left). It enabled easy comparison of how different supplies would represent data without the need to repeatedly prototype their use, especially as some materials like puff paint or glue require time to dry. Lilian also consulted Cynthia on preferences and norms, like whether Cynthia prefers grade II braille or how cutting off a graphic's top right corner can facilitate faster orientation.

Our handmade tactile graphics needed to be accurate and robust enough to address our constraints of remote work, so each one required keen attention to detail and between several hours and days to construct. To make best use of this time, Lilian curated their set of charts by considering the concepts important for our main project. Through practice and feedback with Cynthia, Lilian developed a workflow. For each chart, Lilian minimized information according to best practices to ensure they communicated the essential information comprehensibly. Next, she created and arranged text labels of ink and braille; braille requires a lot of space, making text labels a primary constraint for how to lay out the rest of the graphic.

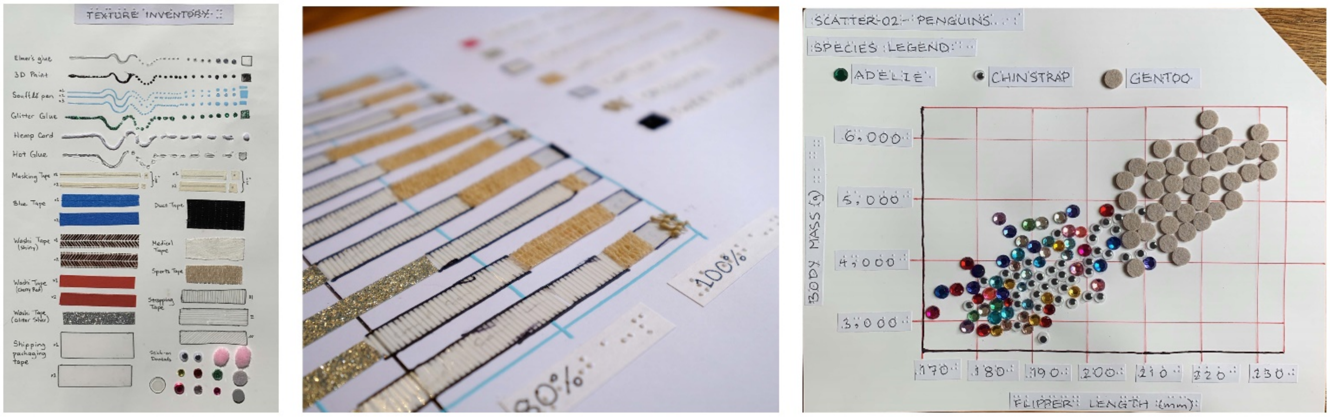

Figure 1: A handmade tactile reference sheet (left) and 2 examples of handmade tactile graphics featuring a variety of materials: a horizontal stacked bar chart and a multi-series scatterplot based on the Palmer Penguins Dataset [18].

She then sketched, measured, and inked the resulting structure of the chart while factoring in any other material constraints like the widths of textured tapes. Flipping the paper over onto a semi-soft surface, she then pressed into the back of these gridlines with a stylus to emboss them into raised lines. Relative to the rest of the chart—rendered tactile with 3D materials like puff paint, textured tapes, and glued-on materials—these raised gridlines were faint. This way, they could fade into the background and bring focus to the data, while also being available for anchoring and guiding exploration. Lilian's reference sheets helped her determine which materials to use for the remaining chart components, highlighting which combination of materials made crisp and tactilely discernable elements.

The workflow incorporated additional practices to better facilitate remote collaboration, such as making the graphics durable, organized, and accessible to remote sighted colleagues. Lilian took several measures to protect these tactile graphics from potentially rough transport in the mail and long-term use: opting for sturdier materials like cardstock, reinforcing braille dots by filling their backsides with glue, and enclosing graphics in sheet protectors. Adhering braille titles to these sheet protectors also helped Cynthia organize these graphics into a binder. So sighted and blind colleagues could remotely reference the same graphics, Lilian made each graphic work visually by choosing contrasting colors, outlining transparent materials, and inking text in addition to braille, as shown in Figure 1. For everyone's benefit, Lilian tracked each tactile graphic in a spreadsheet containing their titles, descriptions, photos, and images of the digital graphics they were based on. This spreadsheet became helpful not only during meetings so all attendees were on the same literal page, but also when concepts came up in unrelated discussions. In this case, a collaborator could search the spreadsheet for the graphic which conveyed the concept and ask attendees to view the respective photo or pull out their tactile version. One lesson we learned was for everyone to communicate with precise language, like chart labels and filenames, and to allow time for Cynthia to find the respective chart as flipping through a binder while reading braille labels took longer than it took sighted colleagues to glance through images. We also learned that during discussions, sighted colleagues needed to ignore the original (non-tactile) version of a graphic and only reference photos of the tactile versions, as Lilian sometimes modified or omitted components when translating between these original and tactile graphics (an established best practice to manage space and improve clarity).

4.3 Developing Embossed Tactile Graphics

To scale our operation, we invested in an embosser. Although the overhead of investigating different embosser and software options and learning to use these tools took multiple weeks, using the embosser ultimately enabled us to quickly iterate on or make variations of a chart. Moreover, we could easily create multiple copies to include more BLV collaborators in our workflow. After jointly working through the learning curve of using these and slow initial production, we could also produce many of the simpler graphics much faster than when making them by hand, some of them taking only an hour instead of half a day.

After conducting research on different embossing products by speaking with product representatives, examining sample graphics, testing trial versions of software, and seeking reviews by BLV users (especially on the non-visual accessibility of embosser and tactile graphics software operation), we decided to use the ViewPlus Columbia 2 embosser and the TactileView software for digitally authoring embossable graphics. Because these decisions are individual, we recommend others also do their own research.

Once again, we developed our workflow to accommodate the constraints of remote work, this time with the challenge of having only one embosser. We developed a tight feedback loop, in which Lilian digitally created the graphics for Cynthia to emboss, followed by Cynthia composing thorough feedback for Lilian to iterate on. As with handmade graphics, Lilian began by creating reference sheets for comparing marks, styles, dot heights, fills, and combinations thereof, pictured in the supplementary materials. Cynthia shipped an embossed set back to her and together, they decided on which of these variations may be appropriate for demarking which chart components. They continued to refine these decisions

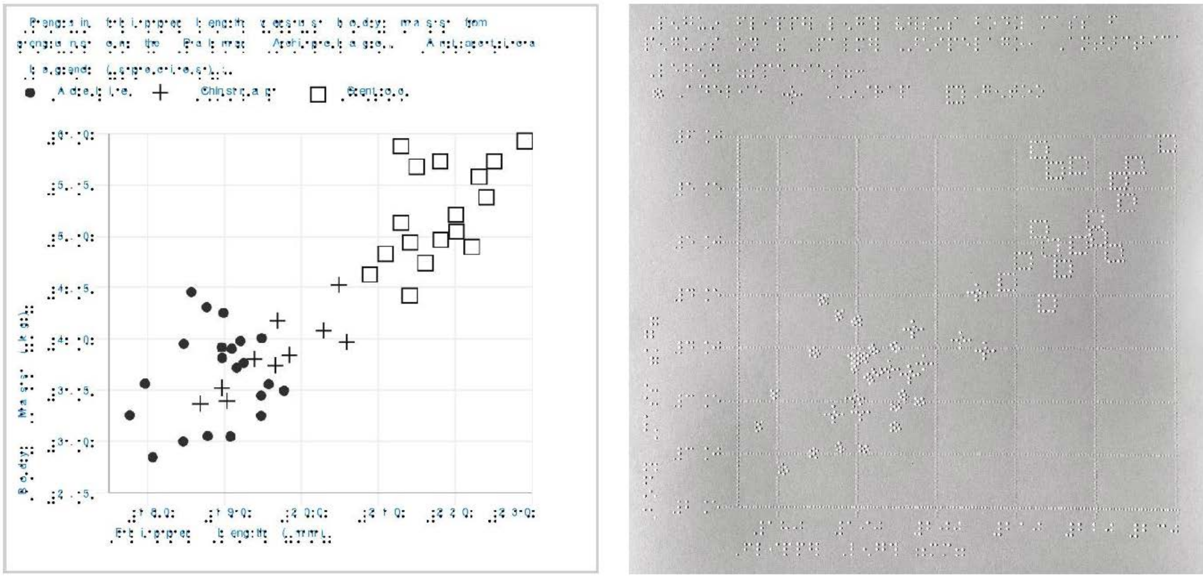

Figure 2: An embossed variant of the multi-series scatterplot featured in Figure 1, with the digital version on the left and the embossed output on the right. The embosser ignores blue pixels and raises different shades of gray at different dot heights.

and learn additional lessons as they iterated on the tactile graphics themselves. For example, we learned that a graphic's digital visualization and embosser output can have different alignments for dots, sometimes skewing braille characters into an unreadable format. These kinds of quirks meant each graphic needed review after its initial emboss, even if it was a variation of a similar chart. Figure 2 shows one of our embossed graphics. More examples are available in the supplementary materials.

4.4 Impact of Handmade and Embossed Tactile Graphics on Our Workflow

The tactile graphics proved invaluable for our work, becoming the basis for discussion during our team's design explorations. All team members, including the authors of this paper, agreed that tactile graphics made a significant difference in participation—everyone had the opportunity to form and share their own insights, follow others' observations, ask for clarifications, and contribute ideas. Using these benefits of tactile graphics, Cynthia (and later other BLV collaborators) initiated, contributed to, and changed several work-related decisions.

The tactile graphics added a communication medium that spawned several 'ah ha' moments, as they offered rich representations of data that other representations like numeric tables or verbal descriptions could not. Descriptions inevitably have gaps. A sighted interpreter may not realize a detail was crucial or that their explanation was complicated and long, as was the case when we explored chart types a BLV collaborator hadn't encountered before. A succinct description also could not communicate all details of charts with complexity, like those in Figure 1 with many data points or series. Tactile graphics offered nuance. For example, after hearing a line chart described as "volatile," examining the graphic revealed to Cynthia just how volatile the line was, erratically fluctuating over a much wider range of the y axis than the description initially implied. Similarly, current digital accessibility tools would be a poor substitute for tactile graphics; relying on them would disable Cynthia from accessing content for our exploration, specifically because we were examining ways to address limitations of these digital tools. By sharing equitable representations of charts, we could collectively dial in to each other's observations, be they as high level as an overall shape or as detailed as an aspect about one specific data point. When evaluating ideas, using tactile graphics helped BLV colleagues examine and explain how different approaches to digitally making data accessible may or may not work.

5 DISCUSSION AND CONCLUSION

From our experiences developing handmade and embossed tactile graphics, we distilled several lessons. To start, we learned how different factors could impact iteration. Working remotely meant that handmade graphics must be constructed with care because we would need to redo them if they were unusable or incomplete. This constraint justified our reference sheets, time investment, and our many conversations during the prototype planning processes. In contrast, we could iterate on embossed tactile graphics more quickly, even though Cynthia kept the only team embosser. Unusable charts could be discarded, and once we became proficient with the intricacies of the requisite tools, our iterations focused on refining details like braille placement in relation to data markers and which textures to use. Our iterations were effective because we took time to plan—thinking through the constraints of remote work helped us to make slower decisions and therefore make high quality, usable graphics the first time. We highly recommend reference sheets and thinking through potential approaches when starting a similar process.

Next, we found it valuable to apply best practices of visual chart design to our tactile graphics. For example, good visualizations emphasize the data by de-emphasizing structural components—a concept we applied to tactile graphics when making their gridlines tactilely subtle. Similarly, color impacts how people interpret visualizations; bolder colors draw people's attention to particular points and evenly saturated colors imply more equal weight between data points. We chose our graphics' textures accordingly to preserve visual saliency, like translating similarly saturated colors to materials or shapes that convey similarly prominent textures.

Finally, this project revealed important considerations for co-created accessibility [6, 10] to thrive. Dominant models of workplace accessibility dissociate accommodations from the rest of the team and into a separate office. Our approach of treating access as a shared responsibility and making this work visible on our team had immense benefits. It would have been unreasonable to expect Cynthia, the BLV colleague relying on the accessible workflow, to simultaneously contribute to our main project, seek all accommodations, and also educate others about accessibility. Everyone's self-education, our taking responsibility for accessibility, and Lilian's coordination helped establish that accessibility was anticipated and not a burdensome add-on—that it is part of the culture, making the team more welcoming and inclusive. Importantly, this work required accounting for necessary resources, especially labor, time, and recognition. We needed to invest a substantial number of hours to developing and executing our accessible workflow, we needed money for the supplies and employee time, and we needed recognition that this was actual work.

Using the case of incorporating tactile graphics into a team's workflow, we provide an example for how to prioritize access not just as key in end product development but as also essential for associated processes. Specifically, we described how we developed both handmade and embossed tactile graphics for BLV collaborators to participate in our workflow through self-education, dedicated time and materials, and taking a collaborative and iterative approach which allowed the workflow to evolve with feedback. Given the positive impact the accessible workflow had on our ability to work together, we encourage continued research on incorporating accessibility into workplace processes and cultures, so the labor does not remain invisible and overburdened onto disabled colleagues [10].

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