Accessible Flowcharts: A Feasibility Study with BVI Participants

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Abstract:

Flowcharts are practical tools for simplifying complex processes and aiding in problem-solving. However, individuals who are blind or visually impaired (BVI) face challenges in accessing and interpreting flowcharts due to their visual nature, creating barriers to academic and professional growth. To address this challenge, we designed and assessed three accessible flowchart representations through a user study with eight BVI participants. Participants engaged with a textual summary description with a question-and-answer interface, an interactive navigable diagram, and a tactile graphic. Each representation offered distinct benefits but presented challenges in forming mental models of flowchart content when used individually. The textual summary provided clear information but could not effectively convey the connections between nodes. The interactive navigable representation featured intuitive navigation, but participants needed a strong understanding of node relationships (*e.g.,* the parent or sibling node) to use it effectively. The tactile graphic helped participants visualize information flows, though some participants found it slower to navigate due to difficulties with reading braille labels and identifying node connections. This study provides valuable insights into the design of accessible flowcharts, demonstrating the feasibility and potential of various representation methods.

Keywords

Accessible flowcharts, Blind and visually impaired (BVI), Multimodal representation, Usability study, STEM education

Introduction

Educators use visual diagrams like flowcharts, concept maps, and decision trees to enhance students' cognitive skills, such as reasoning and problem-solving (Carr; Kimber; Blunt). Flowcharts are particularly popular for clarifying complex processes by visually mapping relationships and steps, aiding in understanding and decision-making. Originally introduced by Von Neumann in the 1950s to represent computer processes (Neumann), flowcharts quickly became essential tools for computer programmers (Whitley). Their effectiveness in depicting processes and structures is well-documented (Scanlan; Conway; Wilson). Studies, including those by Scanlan *et al.* and Conway *et al.,* show that flowcharts improve comprehension in programming and decision-making in fields like pharmaceuticals. Wilson *et al.* also found that student-drawn flowcharts deepen understanding of scientific concepts, proving their utility across various subjects.

Despite their educational value, there is no clear standard for accessible flowchart representations for blind or visually impaired (BVI) students, who often face significant barriers due to the visual nature of flowcharts. While accessible representations exist for similar structures like node-link diagrams, such as AudioGraf (Kennel) with auditory cues and speech descriptions, and interactive systems like TeDUB (Petrie) and GSK (Balik). Zhao et al.

developed a tablet-based system that uses musical tones and speech for accessible diagram exploration. Still, effectively conveying flowchart-specific attributes—such as link directionality, sequential flow, and decision-making paths—remains unclear and underexplored.

To address this, we designed three accessible flowchart representations and tested them with BVI users to assess the usability of each representation and how the representations can support flowchart comprehension. Using affinity diagramming to group participant feedback, we identified the benefits and drawbacks of each accessible flowchart representation and how these different formats impact a user's mental image and understanding of flowcharts.

Accessible Representations

We designed three distinct representations, each offering a unique approach to presenting flowchart information: a textual summary with a question-and-answer (Q&A) interface, an interactive navigable diagram, and a tactile graphic. Along with the original image of a flowchart example, these representations are illustrated in Figure 1, highlighting their unique designs and accessibility features. Below, we describe the design and functionality of each representation in detail. Each of these interfaces operates on a data structure that contains a complete representation of the flowchart sorted in a JSON format.

Textual Summary with Question-and-Answering

The textual summary provides all critical information from the flowchart in a structured text format. It starts with a high-level overview, including the starting and ending points, followed by a list of nodes and edges. Each node is described by its label and shape, while edges specify the label, source, and destination.

We also integrated a text entry area for users to query the flowchart structure. This was implemented as a Wizard-of-Oz interaction for the purposes of our study. Q&A systems have been increasingly used to make visual information, such as visualizations, more accessible to BVI users (Kim), and we wanted to learn what sorts of questions they would ask about flowcharts and test the viability of using a large language model to answer those questions.

Interactive Navigable Representation

The interactive navigable representation, built with D3.js, allows users to explore flowcharts through keyboard navigation. Users can navigate through flowchart elements using keyboard controls, providing real-time descriptions of each node and edge. As users move through the flowchart, they receive detailed feedback about nodes (*e.g.,* label, type, connected edges) and edges (*e.g.,* source, destination, style). This interaction mirrors the natural flow of the diagram, allowing users to either follow the process linearly or dive into specific branches for deeper exploration. The interactive navigable representation was initially developed with MacOS VoiceOver, but future iterations will aim to expand compatibility with other screen readers.

Tactile Representation

Prior research has shown that tactile encoding can be an effective strategy for understanding information-dense visualizations such as maps and diagrams (Zhang; Bardot; Gotzelmann). For the tactile flowchart representation, we used swell paper, which creates raised lines and bumps when black ink is heated in a thermoforming machine, allowing users to feel the flowchart through touch.

Given the impracticality of printing long labels in braille and that many blind individuals are not fluent in braille, we replaced the labels with braille numerals and resized nodes accordingly. Additionally, we provided users with a digital legend on their phone or computer, mapping each numeral to the full (often verbose) label. This setup allowed users to navigate the tactile flowchart while referring to the legend for the original labels.

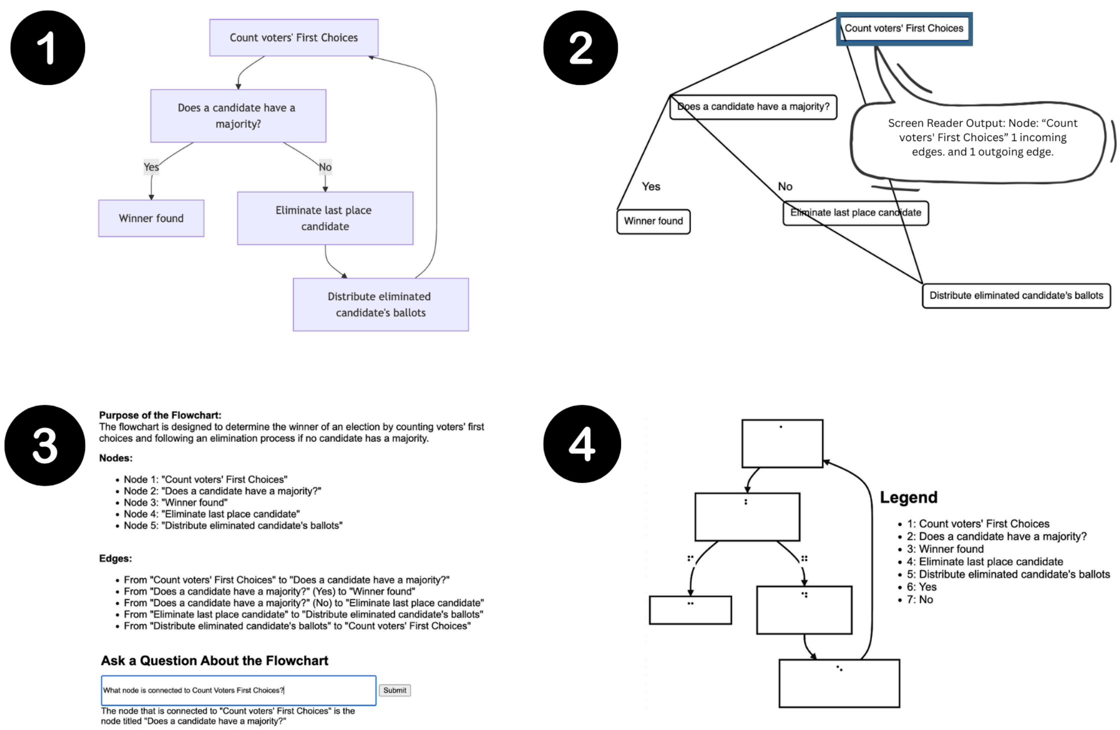

Figure 1. Four representations of a flowchart: (1) a standard flowchart image, (2) an interactive navigable representation featuring screen reader output when a node is in focus, (3) a textual summary with interactive Q&A support, and (4) a tactile-ready format with braille labels and a legend for accessibility.

Methods

We conducted a user study with eight BVI participants (five women, three men) to evaluate the usability of our accessible flowchart representations. The study aimed to gather feedback on each representation's strengths and weaknesses and assess how participants used them to answer flowchart-related questions, such as identifying next steps, tracing flow between nodes, and determining decision outcomes.

Participants, recruited through a partnership with NSITE.org (Nsite), a disability-focused professional organization, attended 90-minute in-person sessions at the organization's headquarters. All sessions were recorded with consent, and participants received a $60 Amazon gift card as compensation. Ages ranged from 36 to 67 (mean = 51 years, SD = 12), and several reported regularly encountering flowcharts in their jobs.

Upon arrival, the research team greeted participants and provided an overview of the study's purpose and procedures. Researchers confirmed that participants had completed the consent form and demographic survey. Each session began with an introduction to flowchart concepts, covering terms like nodes, edges, and node relationships (*e.g.,* parent-child, siblings). The study had two phases: a usability evaluation and a comprehension assessment. Five participants completed both phases, while three only participated in the usability evaluation.

During the usability evaluation, participants explored the different representations, starting with the Q&A format. In this setup, participants asked questions aloud or through a text box, and researchers employed a Wizard of Oz technique, where participants believed they were interacting with an automated system, though a human was controlling it behind the scenes

(Dahlback). While participants were experienced with various screen readers, none regularly used VoiceOver on their personal computers. To accommodate this, we also used the Wizard of Oz technique to input commands for the interactive navigable representation. Participants gave verbal commands (e.g., right arrow, left arrow), and the researcher navigated the flowchart while VoiceOver announced the results. In the tactile representation, participants first familiarized themselves with the feel of nodes and edges before exploring the complete tactile flowchart with a digital legend. Since four of our participants were unfamiliar with reading braille, researchers provided verbal label information on request. After exploring each representation, participants answered usability questions and provided feedback on their experience. Next, participants were instructed to use the representation(s) of their choice to answer three flowchart comprehension questions (see Table 1 for comprehension questions).

Recordings and transcripts were analyzed using an affinity diagramming process, initially known as the KJ method. This approach involves organizing and clustering data into themes or categories based on similarities in content (Scupin). Throughout this process, we focused on the usability of each representation, their effectiveness in assisting participants in answering flowchart-related questions, and identifying areas for enhancement based on participant feedback. We adopted a binary scoring system for the comprehension assessment: correct responses were assigned a score of 1, and incorrect responses received a score of 0. The overall comprehension score was calculated by dividing the total number of correct responses across all questions by the total number of possible correct answers, yielding a percentage that reflects participants' overall accuracy across the entire set of comprehension questions. The accuracy of each question is detailed in Table 1.

Table 1. Comprehension Questions and Assessment Results

Comprehension Questions	Number of Correct Responses (N=5)
If the decision at [Node X] is [Option A], what is the next step?	5 (100%)
How many edges leave from [Node Y] and what node(s) do they lead to?	5 (100%)
What condition or decision leads the flowchart from [Node Z] to [Outcome #1]?	4 (80%)

Results

Based on their performance on the comprehension questions, participants achieved an overall comprehension score of 93.3% (SD = 13.3). They also provided valuable insights into the usability and effectiveness of the textual summary description, Q&A feature, interactive navigable, and tactile representations, highlighting strengths and areas for improvement. Notably, participants frequently combined the tactile representation with the textual summary or the interactive navigable representation with the textual summary to answer comprehension questions effectively.

Textual Summary Description

Participants with residual vision found the textual summary easier to navigate, as they could adjust the text size to suit their needs. P5 mentioned, "I can enlarge it, and it's all precise," highlighting the benefit of modifying the text for better readability. However, screen reader users faced challenges forming a mental model from the text alone, as they relied solely on the sequential reading of content. P8 shared, "I wasn't really getting the layout. I wasn't able to understand the structure." While participants appreciated the clarity of the textual description, they noted that it would become less effective as the complexity of the flowchart increased. As P3 explained, "If you have three or four [edges], it starts getting complicated," pointing to the limitations of a purely textual format for representing more intricate flowcharts.

Question-and-Answer Feature

Five of the eight participants used the Q&A feature with this representation. Their queries focused on requesting summaries, navigating paths, and confirming understanding. For example, participants asked, "Can you summarize the findings of this flowchart?" or "Under node six, 'Not OK,' does this mean the flowchart stops here?" Those who avoided using this feature found it challenging to come up with practical questions. P2 shared, "I wouldn't know what to ask when it came to the [flow]chart," and P7 commented on the challenge of figuring out the right questions to ask. Additionally, all participants used the Q&A feature only during the exploration phase and did not answer the comprehension questions.

Interactive Navigable Representation

Participants familiar with keyboard shortcuts and screen readers found the interactive representation intuitive. P7 noted, "I felt I was able to quickly and efficiently map it out with shortcuts." Similarly, P8 shared, "From using arrow keys with screen readers and spreadsheets… It's much easier for me. I can quickly go back and forth [between nodes]." Although the navigation was efficient, some participants struggled to understand the relationships between nodes and edges. As P3 explained, "Trying to understand which nodes are attached to the edges and the different labels was somewhat difficult." Overall, participants appreciated the practicality of the interactive navigable representation, especially given how often they use computers.

Tactile Representation

Participants appreciated the tactile flowchart for its ability to support their mental visualization of the flowchart. P8 noted, "It helped me understand what people are seeing." However, challenges arose with reading braille labels and identifying the types of connections between nodes. P5 explained, "You kind of have to figure it out based on the edges—what's outbound, what's inbound." Additionally, some participants found the tactile representation slower to navigate than expected. P7 remarked, "It definitely took some getting used to, especially where the edges connect to the nodes and understanding the shape of the node."

Our findings reveal that each of the three accessible flowchart representations offers distinct benefits and limitations. We also highlight the opportunity to combine these representations to create more comprehensive access for BVI users.

Discussion and Implications for Design

Refining representation design is crucial to meet diverse user needs. Our study highlights how different representations impact the usability and comprehension of flowcharts for users. The following sections examine the benefits and challenges of the textual summary with Q&A, the interactive navigable representation, and the tactile representation.

Textual Summary with Q&A. The textual summary provided a static, holistic overview of the flowchart, allowing users to examine the flowchart’s content at once, though without the spatial relationships that visual or tactile representations offer. It was adequate for participants with residual vision, who could enlarge and easily navigate the structured format. However, screen reader users faced challenges with visualizing the flowchart's layout. Some participants were familiar with navigating data in tables and preferred nodes and edges listed in a tabular format instead of verbal descriptions.

While the Q&A feature allowed targeted questions, some participants had difficulty formulating effective queries. Improving the interface to assist in question formulation or suggesting queries could enhance the experience. The Q&A feature enabled users to engage with the flowchart non-linearly by focusing on specific details, though this required familiarity with effective questioning.

Interactive Navigable Representation. The interactive navigable representation allowed participants to explore the flowchart by following its structure and tracing decision outcomes. Participants familiar with screen readers and keyboard shortcuts found the navigation intuitive, as real-time feedback made moving through the flowchart engaging. However, the primary challenge was understanding the node-edge relationships underpinning the flowchart, particularly parent-child and sibling connections. Participants unfamiliar with these relationships struggled, highlighting the need for training or more intuitive navigation cues to better support users in grasping the structure before fully utilizing keyboard shortcuts

Adding more advanced commands to the interactive representation—such as notifications for when loops or cyclic paths occur or when the user reaches the end of the flowchart—could improve guidance and navigation. Despite these challenges, participants found this representation the most practical and applicable for everyday use. As a digital interface compatible with screen readers, it provided a flexible, technology-driven solution that could be easily integrated into existing workflows, making it particularly well-suited for users accustomed to digital environments. This combination of real-time interaction, verbal descriptions, and potential for integration into educational or accessibility platforms made it a valuable tool for BVI users navigating flowcharts.

Tactile Representation. The tactile representation on the swell paper allowed participants to physically engage with the flowchart, aiding their mental visualizations and understanding of node relationships by tracing arrows. However, its static format has flexibility and navigation speed limitations. A dynamic, touch-based interaction on a tablet could enhance the experience, allowing users to tap or swipe for audio feedback, zoom out for an overview, or double-tap for node connection descriptions. This interactive system would enable faster navigation and offer features like highlighting critical paths, summarizing sections, or switching between detailed and broad views—capabilities unavailable in a static tactile graphic. In addition, larger or more complex flowcharts also pose challenges for swell paper as they become more complicated to display in an accessible format. Optimizing the layout to maintain accessibility and prevent users from losing track of the flow remains an important consideration for these diagrams.

The Value of Combined Approaches

Our study shows that each representation offers unique benefits for accessing the flowchart. Combining these approaches results in a more complete and adaptable access method, accommodating user preferences and needs. For example, participants used the textual summary or Q&A to grasp the overall content, while the interactive or tactile versions helped them explore the layout and confirm node connections. The tactile representation, in particular, provided a physical point of reference that solidified or refined their mental image. Transitioning between representations enabled users to build a more apparent mental model and adapt the experience to their needs, technology familiarity, or learning preferences. Multimodal approaches should offer easy switching between representations and include educational elements to enhance understanding flowchart structures.

Conclusion

This study underscores the value of providing multiple accessible flowchart representations for BVI users, each with its strengths and limitations. The textual summary, interactive navigable, and tactile representations offer unique ways to engage with flowcharts, and combining them results in more comprehensive and flexible access. Educators and developers can better support BVI users in accessing flowchart diagrams by integrating these approaches. Future efforts should focus on refining these representations, especially for complex diagrams. Overall, a multimodal approach that allows users to choose how they interact with flowcharts will create more inclusive and effective learning environments.

Acknowledgements

We want to express our sincere gratitude to all participants from the NSITE organization for their valuable insights. This work was supported by a Google PhD Fellowship, as well as a grant from the natNational Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR grant number 0REGE0026-0100) funding the Center for Research and Education on Accessible Technology and Experiences (CREATE). NIDILRR is a Center within the Administration for Community Living (ACL), Department of Health and Human Services

(HHS). The contents of this work do not necessarily represent the policy of NIDILRR, ACL, HHS, and you should not assume endorsement by the Federal Government.

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