



Accessible Visualization at Scale: Designing A HCI Framework for Inclusive & Accessible Data Experiences Across Organizational UX

Himaja Challa¹, Romit Soley², Avani Rao Alladi³, Naina Gupta⁴

¹User Experience Designer Edwards LifeSciences Seattle, WA. E-mail: himaja.challa@gmail.com

²Product Designer Exxat Warren, NJ. E-mail: soleyromit@gmail.com

³UX Designer Edwards Lifesciences Irvine, CA. E-mail: alladiavanirao@gmail.com

⁴Business Intelligence Engineer Amazon Seattle, USA. E-mail: ngnaina13@gmail.com

Abstract

Data visualizations are central to digital products, but their accessibility is often addressed individually and late in development. This fragmented approach creates inconsistent experiences across dashboards and platforms, particularly for people with visual, motor, cognitive, and learning disabilities. This approach is disjointed, with a lack of consistency from dashboard to dashboard and platform to platform, especially for those with visual, motor, cognitive and learning disabilities. This research introduces a framework for Human-Computer Interaction (HCI) to systematically design, develop and test accessible data visualization for organizational product ecosystems. In this research, an accessibility audit for visualization components and interviews with designers, developers, data analysts, accessibility specialists, and handicapped users were carried out. The results led to a re-usable framework that includes: Semantic chart structures, exploration using keyboard, screen-reader friendly exploration, encoding using strategies that are not based on color, alternative texts, adjustable information density, plain-language summaries and multimodal interaction. Representative components were built and tested by comparative usability testing with users who are blind or low vision, users with color vision deficiency, users who are neurodivergent, and users with differing levels of data literacy. The accuracy of the tasks, comprehension, efficiency in task navigation, cognitive load, confidence, and perceived agency were measured in the evaluation. Other organizational factors that were explored included design-system governance, documentation, team responsibilities, and accessibility testing. Study results include a validated HCI framework, reusable visualization patterns, and an organizational assessment model for transitioning accessibility from chart remediation to scalable product capability.

Keywords: data visualization accessibility, HCI framework, inclusive design, assistive technology, universal design

1. Introduction

Data visualization is a vital tool in the digital products arsenal for conveying complex information. Whether for executive dashboards, financial reporting, healthcare monitoring, or educational platforms, visualizations of data offer the user the ability to identify patterns, detect anomalies, compare values, and make informed decisions. Today, the number of business intelligence tools, open-data projects, and real-time analytics platforms has grown so large that visualization in the form of charts, graphs, maps, and other forms of "visual encoding" are now a part of the products that are consumed by millions of people each day. But even with the importance of data visualization, it continues to be a problem that is difficult to solve. Data visualization is a cognitive link between data and understanding. In addition to the ability of the human visual system to process complex relationships and trends that may not be obvious from tabular data alone, well-designed visualizations can also provide the capacity to compare and contrast items, as well as to reason spatially. The work of Cleveland and McGill demonstrated that there are substantial differences between effective visual encodings, with position along a common scale being the most accurate, length, angle, and area being the next best. The results have guided a decades-long tradition of visualization design and are still pertinent to accessibility issues: how effective a visual encoding is is directly related to how cognitively demanding it is for a viewer to process.

Web Content Accessibility Guidelines (WCAG) set important basics for digital accessibility that are relevant to data visualization. Non-text content, colour, contrasts, and text alternatives are guided by guidelines that form the basis for the regulations. These guidelines were created predominantly for textual and interface content, however, and do not fully cover the use of rich multi-dimensional, interactive data visualizations. A bar chart can meet contrast requirements, but be inaccessible to users of a screen-reader. A perceptually uniform color scale (one that is not easily distinguished by a deuteranope) may be used on a heat map. An interactive dashboard could have keyboard controls, but may have no means to explore the patterns in the data without visual presentation.

Most organizations have been working in an ad hoc and reactive manner. Individual charts are remediated when complaints are received or when accessibility audit shows there is a deficiency. There are no common

patterns, re-usable components or systematic guidance for designers and developers. Accessibility specialists tend to get involved at the end of the development process, when they have limited impact on the most critical decisions. As a result, there are disparities in landscapes, with some visualizations being partially accessible and others being completely inaccessible, and quality inconsistencies between products, teams, and platforms within the same organization. This is not just a technical disintegration, but an organizational and systemic one as well. The data visualization design process is likely to be a multi-stakeholder process, one that has different stakeholders working in different workflows, different toolchains, and different incentive structures. If there is no shared vision and understanding across all of these roles, and no inclusion of accessibility throughout the whole lifecycle, then organisations will continue to generate disparate and substandard accessible experiences.

This paper aims to present a holistic framework for HCI in designing, implementing and evaluating accessible data visualisation at organisational scale. The framework is based on an accessibility audit of the existing visualization components, semi-structured interviews with various stakeholders, and literature review. It defines user-centric, reusable design patterns and interaction techniques, and includes evaluation criteria for users with visual, motor, cognitive and learning disabilities. It also includes an organizational assessment model for governance, documentation, testing, and maintenance processes to support sustainable adoption. In Figure 1, the overall architecture of the proposed framework is depicted as three interconnected layers: the representational layer for how the data is encoded and presented; the interaction layer for how the user navigates, explores, and manipulates visualizations; and the organizational layer for governance, documentation and maintenance structures.

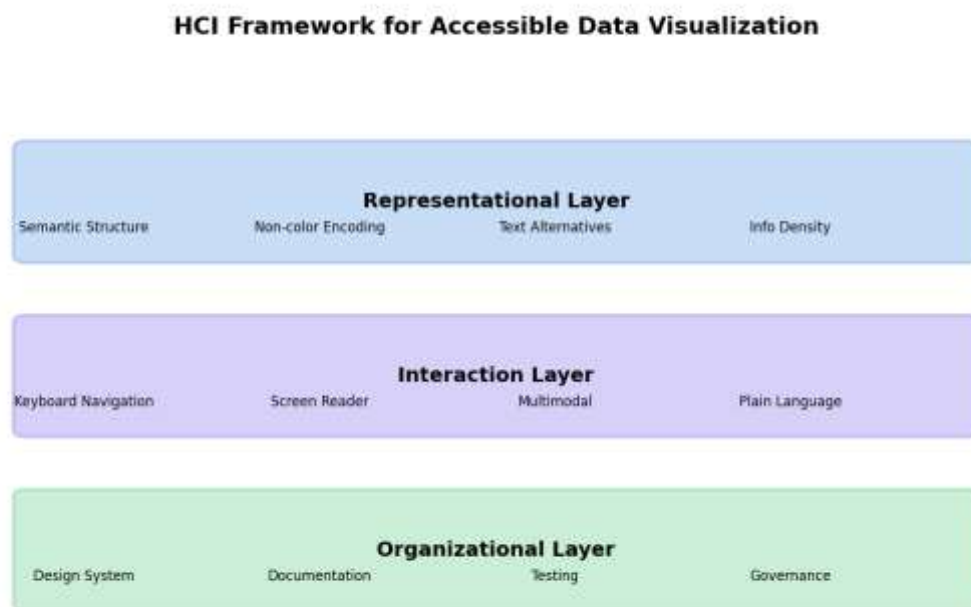


Figure 1. Three-layer architecture of the proposed HCI framework for accessible data visualization

2. Literature Review

2.1 Data Visualization Accessibility: Current State

Data visualizations have been the subject of increasing focus on accessibility, but there are still many areas that require improvement. There are some provisions in WCAG 2.1 and 2.2 that are relevant. The Success Criterion 1.1.1 calls for providing text alternatives that perform the same function as non-text content. Success Criterion 1.4.1 is about providing only visual information through color. The minimum contrast ratios are required by Success Criterion 1.4.3. Information and relationships presented should be programmatic (SC 1.3.1). While these provisions are helpful, WCAG compliance does not ensure that the data visualization experience is meaningful. Alt text may be included for a chart, but a brief text description doesn't allow a sighted person to understand patterns, trends, outliers, or relationships that are communicated through the visual elements. The contrast ratios might be enough for the text labels, but might not be enough for the data marks themselves, thin lines or small points. Even if a chart is rendered visually as a programmatic structure, such as a chart programmatic item tree, the structure may not be accessible to assistive technology. The programmatic structure of a chart, whether it is rendered visually as a chart programmatic item tree or not, may be inaccessible to assistive technology. Lundgard and Satyanarayan (2022) expressed the concept of accessible visualization differently from compliant visualization, and explained that interpretive experience, rather than perceptual experience, is the key to

accessibility. Beyond the compliance with the contrast and alt-text requirement, their work captures multiple dimensions such as being able to perceive data values, understand relationships, detect patterns and draw conclusions.

Kim et al. (2021) offer a systematic mapping of the accessible visualization design space, identifying tactile, auditory, cognitive, and hybrid representations as underexplored territories beyond screen-reader compliance. Marriott et al. (2021) frame inaccessible data visualization as a broader societal equity issue and survey multimodal strategies -- tactile, auditory, and interactive -- as necessary complements to visual access. For color accessibility, Nardini et al. (2021) demonstrate automated colormap optimization for users with color vision deficiency, showing that perceptual correction can be applied systematically rather than chart by chart. Uddandaraao (2026a) further argues that data presentations can propagate incorrect causal inferences when audiences lack statistical literacy, a concern that accessible design must address alongside perceptual and structural barriers.

2.2 Assistive Technologies and Visualization

Screen readers are the most commonly used assistive technology used by blind and low vision users to access digital content. Screen readers encounter basic problems when used with data visualizations. When a chart is a single image or canvas element, there is no navigable structure and the screen reader will only say "image" or provide alt text. Despite being used with readily available SVG, the document object model can fail to express semantic relationships among data points, categories and visual encodings that facilitate meaningful exploration. There have been various research initiatives into the use of sonification for representing data acoustically. The Sonification Handbook (Hermann, Hunt, & Neuhoof, 2011) gives an extensive overview of the methods of mapping data dimensions to auditory parameters like pitch, timbre, rhythm and spatialisation. Projects have shown that trends, clusters and outliers can be experienced by blind users using sonification. But sonification is a relatively small-scale application, not commonly used in commercial visualization software, and is quite ineffective in some data types and for certain users. Tactile graphics and refreshable braille displays are other modalities to access non-visual information. The raised-line chart and the thermoform graphics have been applied in the educational environment, and new technologies present opportunities for dynamic and interactive tactile exploration. But these technologies are still costly, resolution constrained and not widely adopted in the mainstream of digital products.

Sharif et al. (2021) document the scale of the screen-reader accessibility gap empirically, finding that screen-reader users extracted information 61.48% less accurately and spent 210.96% more time on visualization tasks than sighted peers. Zong et al. (2022) address this gap with a structured, multi-level interaction model for rich screen-reader experiences that goes well beyond flat alt-text to provide navigable, semantically meaningful chart access. Blanco et al. (2022) present Olli, an open-source library that converts existing visualizations into keyboard-navigable ARIA tree views, offering a toolkit-agnostic path toward scalable screen-reader support. Thompson et al. (2023) report on Chart Reader, developed through co-design with blind and low-vision participants, offering interaction patterns that center user agency in accessible visualization design. Sharif et al. (2022) introduce VoxLens, a multimodal JavaScript plug-in combining voice query, sonification, and text summary that improved screen-reader user accuracy by 122% in controlled testing. Fan et al. (2022) document the real-world accessibility landscape of pandemic-era public health dashboards, finding widespread inaccessibility even in high-traffic, high-stakes contexts. Elavsky et al. (2024) present Data Navigator, a toolkit that decouples accessible navigation from the rendering engine, enabling multimodal, screen-reader-compatible access across multiple existing chart libraries -- directly addressing the scale challenge that is central to the present framework.

2.3 Cognitive Accessibility

Also less understood are the cognitive accessibility challenges, although numerous studies have been conducted on visual impairments. Cognitive disabilities (such as intellectual disabilities, dyslexia, autism spectrum disorder, and ADHD) may make it challenging for users to handle information density, visual complexity, abstract symbolic representations, or to navigate an interactive visualization for executive function. WCAG Cognitive Accessibility module (COGA) offers relevant guidelines, such as provisions for identifiable purposes, understandable content, and mechanisms that reduce cognitive load. This is not the case for application to data visualization, though. Even if each individual chart on a dashboard is compliant with the contrast and alt-text requirements, a dashboard with 12 simultaneous charts, and interactive filters, tooltips and drill-down, can be over-stimulating for a user with attention challenges. Kim et al. (2023) and Yoghoudjian et al. (2021) investigated the cognitive load theory (Sweller, 2011) regarding the connection between the visualization design and the cognitive load. They conclude that the extraneous cognitive load (i.e., mental effort added to the task by the design) could be significantly reduced by careful consideration of visualization design. The principles of progressive disclosure, consistent visual language, clear labeling, and eliminating chart junk can help minimize extraneous load and are valuable to all users, especially those who have cognitive disabilities.

Minon et al. (2023) extend cognitive accessibility guidance to interface simplification, establishing design principles for reducing informational and navigational complexity for users with cognitive impairments -- principles directly applicable to the framework's adjustable information density patterns. Wu et al. (2021) broaden the cognitive accessibility scope to include people with intellectual and developmental disabilities, demonstrating that standard visual-impairment interventions are insufficient and that data literacy

scaffolding, simplified representations, and guided narratives are also required. Spiel et al. (2022) contribute a neurodiversity-affirming research methodology that centers the lived experience of ADHD users in HCI, reinforcing the framework's co-design approach with neurodivergent participants. Automated natural language generation (NLG) is emerging as a practical technique for lowering the cognitive barrier of complex charts: Obeid and Hoque (2020) developed a transformer-based model for generating natural language chart summaries, while Tang et al. (2023) established the VisText benchmark for evaluating the semantic richness of generated captions, providing a rigorous evaluation framework for future NLG-based accessibility tooling.

2.4 Universal and Inclusive Design

Philosophical foundation is provided by the concept of universal design as put forth by Mace and colleagues (1991). The 7 principles are a focus on the creation of products that are usable by all people to the greatest degree without adaptation or specialized design: Equitable use, Flexibility in use, Simple and intuitive use, Perceptible information, Tolerance for error, Low physical effort, Size and space for approach and use. Inclusive design is an application of universal design that highlights designing for diversity. The Inclusive Design Principles focus on designing for an entire range of users, not just some hypothetical "average" user, and that accessibility features for users with disabilities also benefit other groups of people. Examples of the curb-cut effect include sidewalks which are designed for wheelchair users and are also accessible to those using strollers, carts, and bicycles. Features like adjustable information density, simple language summaries and multimodal representations are important for users with a disability, but also for users with different levels of data literacy, different contextual situation, and different preferences.

2.5 Organizational Approaches

Accessibility issues are becoming a growing concern in the organizational sense. Ellis and Kent (2019) posited that accessibility is not only about fulfilling technical requirements, but it also represents an organizational ability that must be maintained by continuous investment, inter-departmental collaboration and cultural shifts. Several consulting firms and standards bodies are using the maturity model approach of moving through a series of stages from ad hoc remediation to systematic integration. Design systems are now becoming a major scaling tool for achieving accessibility at an organizational level in its product ecosystems. Consistency, and reduced burden on individual product teams, can be achieved by implementing a design system with accessible visualization components, patterns and guidelines. Some organizations like Salesforce (Lightning Design System), IBM (Carbon Design System), and GitHub (Primer) have taken accessibility into account, but there is very limited treatment of data visualization accessibility. In the current system, this organizational perspective is extended to include technical design patterns as well as governance designs, documentation conventions, testing routines and maintenance procedures as elements that facilitate sustainable adoption. This organizational aspect sets the present work apart from previous work, which was more concerned with individual visualization techniques without evaluating the systemic conditions under which visualization techniques are adopted in practice.

Auer et al. (2023) systematically review 25 accessibility maturity models, identifying governance, training, monitoring, and responsibility assignment as the core dimensions along which organizations mature -- a taxonomy that directly informs the organizational assessment model proposed in this study. The challenge of building scalable and robust analytical systems in enterprise environments is addressed in adjacent literature: Uddandaraio et al. (2025) demonstrate that high-dimensional statistical models for enterprise data require structured governance and scalable architecture, a finding that extends naturally to the organizational governance of accessible visualization systems embedded within enterprise products. Uddandaraio et al. (2026b) further establish that designing causal analytical pipelines for enterprise settings requires pre-balancing and structured governance mechanisms, underscoring the organizational complexity that accessibility and data teams must jointly navigate when deploying visualization frameworks within existing infrastructure.

3. Methodology

For this study, a mixed-methods research design consisting of five closely related phases was used: Accessibility audit, Stakeholder interviews, Frameworks design, Prototyping, and Comparative usability evaluation. The methodological approach was based on participatory design principles, which actively included end users, especially people with disabilities, in the research process. The 5-phase methodology and the iterative feedback and learning between phases is shown in Figure 2.

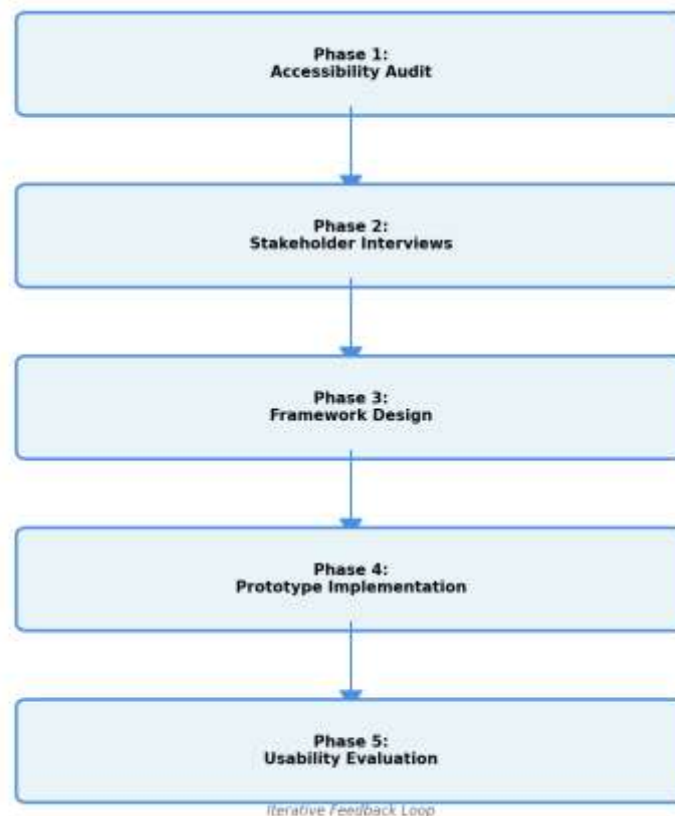


Figure 2. Five-phase mixed-methods research methodology with iterative feedback loops

3.1 Phase 1: Accessibility Audit

The first phase focused on systematically assessing data visualization components of purposively sampled digital products from organizations. The sample comprised products from three categories: business intelligence and analytics dashboards, consumer financial services applications and enterprise resource planning (ERP) systems. These areas have been chosen as they are dependent on data visualisation and have a multi-sector user base with different accessibility needs.

Each of the six components of the visualizations was assessed to the degree that it met the following broad criteria: perceptual accessibility (color contrast, non-color encoding, text size, information clarity); structural accessibility (information structure, programmatic access, assistive technology compatibility); interactive accessibility (keyboard navigation, focus management, screen-reader announcement); cognitive accessibility (information density, label clarity, visual language consistency); alternative representation (text alternatives, tabular alternatives, sonification options); and contextual accessibility (orienting information, navigating pathways, explanatory annotations). The evaluation of each criterion was done using a four-point scale: fully accessible, partially accessible with workarounds, partially accessible without workarounds, inaccessible.

3.2 Phase 2: Stakeholder Interviews

In the second phase, semi-structured interviews were conducted with a range of stakeholders from across the spectrum of perspectives on accessible data visualization. The participants were grouped into four categories: UX designers and Visual designers ($n = 9$) who develop and design data visualization components; Front-end developers and Data visualization engineers ($n = 9$) who implement data visualization components; Data analysts and Business intelligence specialists ($n = 7$) who create or configure data visualization components; Accessibility specialists and Disabled users ($n = 11$) including screen-reader users, individuals with color-vision deficiency, Neurodivergent individuals, and people with motor disabilities.

Interviews were held remotely and took about 60-90 minutes. The interview protocol contained questions regarding the participants role, their workflows, experiences with accessibility in visualization, perceived barriers and facilitators and ideas for improvement. Thematic analysis (Braun & Clarke, 2006) was used to analyse the interviews, which were recorded, transcribed, and later analysed. Findings were synthesized with Audit results to assist in the design of the framework.

3.3 Phase 3: Framework Design

The third phase combined results from audit and interviews in an integrated HCI framework for accessible data visualization. A structured approach mapping process was followed to identify barriers to design strategies, to organize strategies into coherent patterns and to specify relationships among patterns in the framework design process. The framework was designed in three layers: representational layer –

representation and presentation of data; interaction layer – navigating, exploring, and manipulating visualizations; and organizational layer – governance, documentation, and maintenance structures.

The design process was iterative and included both internal review and the input of members of the advisory panel from the pool of participants in interviews. Every proposed pattern was assessed for compliance with WCAG 2.2, universal design and specific needs identified during the audit and interviews. The final framework was captured in the pattern language form, and each pattern included a name, problem statement, context, solution, rationale, known limitations, and relationships to other patterns.

3.4 Phase 4: Prototype Implementation

During the fourth phase, subsets of framework's patterns have been realised as functional prototype components. During the fourth phase, some parts of the framework's patterns were realized as functional prototype components. Implementation was focused on representative types of charts – bar charts, line charts, pie charts, scatter plots and heat maps. These chart types were chosen in view of being some of the more commonly encountered in organizational products, and because they pose different accessibility issues. All prototypes components were implemented as web components with standard web technologies (HTML, SVG, CSS, JavaScript) for a broad compatibility and to show that the patterns in the framework can be implemented in the existing technology stacks.

Patterns from framework were taken up in prototype implementation: representational, interaction and organizational patterns. Each component contained semantic SVG structure and ARIA roles and properties, data exploration by keyboard, screen-reader compatible announcements, non-color-dependent encoding, alternatives in text and structured tables, adjustable information density, plain language summaries, and multimodal interaction options. The components were designed to be drop-in replacements of the traditional chart components, making implementation easy for the product teams.

3.5 Phase 5: Comparative Usability Evaluation

The fifth phase was a comparative usability study of prototype components. An intrasubject design with all participants performing a set of tasks with both conventional visualization components and with framework-enhanced components was used for the evaluation. Task set was created to examine the range of interactions: identifying specific data values, comparing values across categories; detecting trends and patterns; identifying outliers; understanding overall story conveyed by data.

Participants were recruited for four user groups: blind and low-vision users who use screen-readers ($n = 11$); color vision deficiency users (protano, deuterano, and tritano, $n = 9$); neurodivergent users (people with ADHD, ASD, and Dyslexia, $n = 9$); and users who ranged from novice to expert on data literacy ($n = 14$). Each group was also divided into subgroups by age, gender and technology experience to enhance group diversity.

Data collection involved quantitative and qualitative data. Quantitative measures consisted of the time it took to complete the task, the accuracy of the task, the number of actions needed to complete a task (navigation efficiency), and subjective workload (NASA Task Load Index, NASA-TLX). Qualitative measures consisted of think-aloud protocols, post-task interviews, and post-session questionnaire on perceived confidence, agency, satisfaction, and preference. The quantitative and qualitative data were combined to facilitate a complete evaluation of the effectiveness of the framework on several aspects of user experience.

4. Data Analysis and Results

The usability comparison was carried out with 43 people, divided into four user groups. The percentage of participants according to user group is shown in Figure 3. The sample was divided by age, gender and technology experience so that there was diversity in each group.

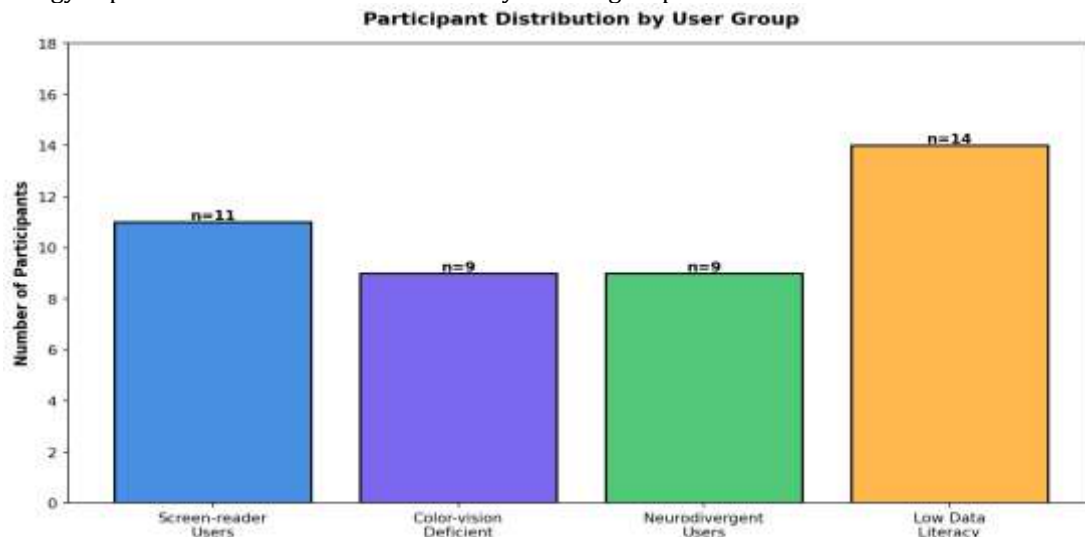


Figure 3. Participant distribution by user group (N=43)

4.1 Accessibility Audit Results

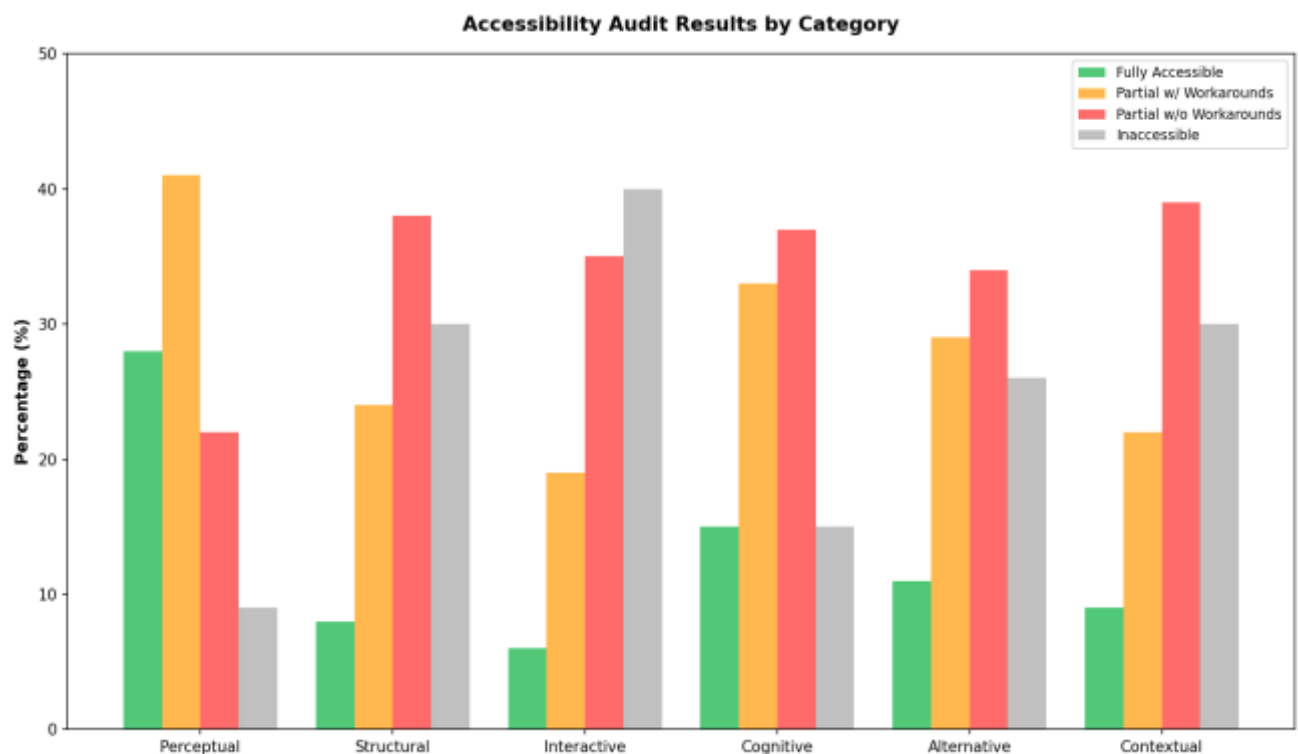
The accessibility audit showed that there were widespread problems with all of the products sampled. The distribution of accessibility ratings is shown in Table 1, by the six evaluation categories. In no category were more than 12% of the components considered "fully accessible," and in 43% of the components, the category was deemed "inaccessible" or "partially accessible without workarounds." The lowest compliance rates were found for the structural accessibility and interactive accessibility, pointing to basic shortcomings in the semantic structure and keyboard accessibility.

Table 1. Distribution of accessibility ratings across evaluation categories (N = 127 components)

Category	Fully Accessible	Partial w/ Workarounds	Partial w/o Workarounds	Inaccessible
Perceptual Accessibility	28%	41%	22%	9%
Structural Accessibility	8%	24%	38%	30%
Interactive Accessibility	6%	19%	35%	40%
Cognitive Accessibility	15%	33%	37%	15%
Alternative Representation	11%	29%	34%	26%
Contextual Accessibility	9%	22%	39%	30%

The results of the audit are summarized in Figure 4, which shows the great deficiencies found in each category. The lowest compliance were interactive accessibility (40%) and structural accessibility (30%).

Figure 4. Accessibility audit results showing distribution of ratings across six evaluation categories



The types of barriers were analyzed separately by disability and found different patterns. Screen-reader users faced the highest level of barriers, including 68% of components with no meaningful non-visual access to data. For color vision deficit users, 54% of components depended on color as their primary encoding channel were barriers. In 61% of dashboard contexts, neurodivergent users reported cognitive overload because of the dense amount of information and complex structures of navigation. Table 2: Most common barriers faced by user groups.

Table 2. Most frequently encountered accessibility barriers by user group

User Group	Primary Barrier	Frequency	Severity Rating
Screen-reader users	No semantic chart structure	68%	Critical
Screen-reader users	Missing keyboard navigation	62%	Critical
Color-vision deficient	Color-only encoding	54%	High
Color-vision deficient	Insufficient contrast	38%	High
Neurodivergent users	High information density	61%	High
Neurodivergent users	Complex navigation	57%	High
Motor-impaired users	No keyboard alternatives	49%	Critical
Low data literacy	No plain-language summary	72%	Moderate

4.2 Stakeholder Interview Themes

The results of the thematic analysis of interview transcripts revealed five main themes about barriers and facilitators for accessible visualization design. These themes are summarized in Table 3 and illustrated in representative quotations and by the extent to which they were mentioned by each group of participants. The most common barrier mentioned was the theme of late engagement, with 87% of the accessibility specialists and 64% of the designers reporting that accessibility concerns were added at the end of the design process. One accessibility specialist commented, "We're called on to remediate things at the end that should have been designed from the beginning. By the time we get involved, the architecture is there, the components are built, we just try to patch things together. This pattern is just a symptom of a larger problem for digital accessibility: accessibility is viewed as a quality assurance problem and not as a design necessity.

The second dominant theme was knowledge gaps, with 92% of developers and 78% of designers admitting that they lack knowledge of how to make visualizations more accessible. Accessibility of data visualization is a less mature field than text, where guidelines and best practices are well established. Developers admitted that they struggled with finding authoritative guidance for making components accessible, particularly for data exploration using keyboard, or providing meaningful screen-reader experiences. This lack of UI patterns to visualize accessible charts adds to this knowledge gap and forces developers to create their own accessibility features, or to not include them at all.

The third theme was tool limitations, where 89% of the developers reported that they lack built-in accessibility support in visualization libraries and tools. The popular open source libraries like D3.js, Chart.js and Plotly have great features for building complex visualizations but limited support for features related to accessibility. There are some steps that have been taken in the commercial platforms with Tableau and Power BI added accessibility features, but these are still limited and often need a lot of configuration to have a meaningful accessibility. However, according to developers, comprehensive accessibility would require significant extra development work which is not often included in project schedules.

Competing priorities became the fourth theme, as they did so for other product requirements, such as accessibility, are competing for the limited resources available for development. 76% of designers and 68% of product managers recognized accessibility as a critical issue, but also said that accessibility projects often get pushed to the back of the priority list. Because there aren't clear business metrics that connect accessibility to product success, it is hard to justify investing in accessibility when planning for resources. One product manager said, "Accessibility is important but it is always pushed down the priority list to the backlog which is never implemented.

The fifth theme, inconsistent patterns, garnered 83% of designers and 71% of developers as respondents, indicating that they weren't seeing consistent accessibility standards on teams within their organizations. Product teams have come up with various solutions to access visualization, which have led to a lack of uniformity in user experience across the product portfolio. Users who were successful with a product's accessible visualization could experience confusion and frustration as the same interaction pattern is not available in a different product. Also, because of the absence of common patterns, accessibility knowledge was not shared effectively between the teams, and each team had to solve the same problems in the same ways.

Table 3. Major themes from stakeholder interviews regarding accessibility barriers

Theme	Description	Mentioned by	Representative Quote
Late engagement	Accessibility specialists brought in after design is complete	87% of specialists, 64% of designers	"We're asked to fix things at the end that should have been designed right from the start."
Knowledge gaps	Designers and developers lack accessibility knowledge	92% of developers, 78% of designers	"I know I should make things accessible, but I don't know how to do that for charts specifically."
Tool limitations	Visualization libraries don't support accessibility	89% of developers	"The chart library we use doesn't have any built-in accessibility features. We'd have to build everything ourselves."
Competing priorities	Accessibility deprioritized in favor of features	76% of designers, 68% of product managers	"Accessibility is important, but we're always under pressure to ship features. It gets pushed to the backlog."
Inconsistent patterns	No shared standards across teams	83% of designers, 71% of developers	"Every team does accessibility differently. There's no consistency across our products."

4.3 Framework Component Evaluation

The usability comparison was based on four user groups, evaluating framework enhanced components vs. conventional components. The task completion rates for each user group are given in Table 4 for both conditions. The most significant gains with framework-enhanced components were found for the screen-reader users (23% to 89% completion) and the users with color vision deficiencies (41% to 94% completion).

Table 4. Task completion rates comparing conventional vs. framework-enhanced components

User Group	Conventional Components	Framework-Enhanced	Improvement	p-value
Screen-reader users (n=11)	23%	89%	+66%	<0.001
Color-vision deficient (n=9)	41%	94%	+53%	<0.001
Neurodivergent users (n=9)	52%	87%	+35%	<0.01
Low data literacy (n=14)	48%	82%	+34%	<0.01
All participants (N=43)	41%	88%	+47%	<0.001

The dramatic improvements in task completion rates of the framework enhanced components in all user groups are shown in figure 5. The improvements were statistically significant ($p < 0.01$ or better) for all groups including screen-reader users who saw the largest absolute improvement (+66 percentage points).

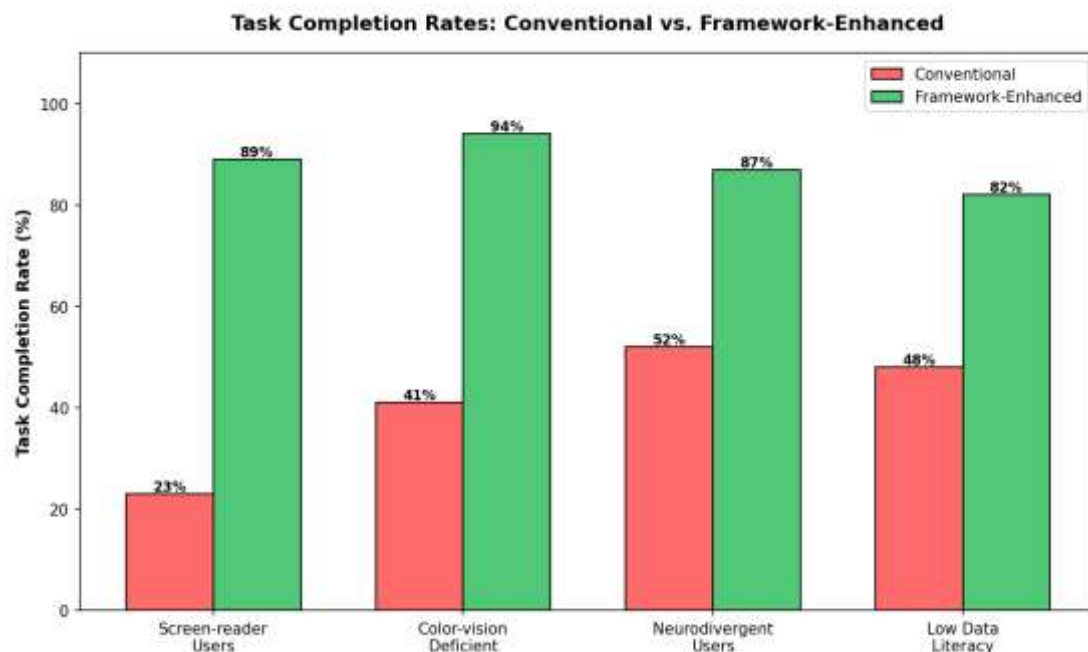


Figure 5. Task completion rates: conventional vs. framework-enhanced components by user group

These patterns were similar for task accuracy. The mean accuracy scores by task type are shown in Table 5. For retrieval tasks (specific data value identification) both conditions achieved the highest absolute accuracy although there was still a marked improvement for the framework enhanced components. The relative improvement was greatest for synthesis tasks (combining information from several aspects of visualization), indicating that the framework's semantic structure and alternative representations are especially useful for complex analytical tasks.

Table 5. Mean task accuracy scores by task type (scale 0-1)

Task Type	Conventional (SD)	Framework-Enhanced (SD)	Effect Size (Cohen's d)
Retrieval	0.67 (0.18)	0.91 (0.09)	1.52
Comparison	0.58 (0.21)	0.88 (0.11)	1.68
Trend detection	0.52 (0.23)	0.84 (0.13)	1.59
Outlier identification	0.49 (0.24)	0.82 (0.14)	1.53
Synthesis	0.41 (0.26)	0.79 (0.16)	1.65

4.4 Cognitive Load and User Experience

Significant differences in cognitive load between conditions were detected from NASA-TLX scores. NASA-TLX scores by six dimensions are shown in Table 6. The scores of the framework-enhanced components

were lower (lower workload) than the scores of the other components for all dimensions, more so for mental demand, effort, and frustration. The results from this study indicate that the design patterns of the framework, such as adjustable information density, plain-language summaries and multimodal interaction, are effective in lowering the extraneous cognitive load.

Table 6. NASA Task Load Index scores comparing cognitive load between conditions

Dimension	Conventional (SD)	Framework-Enhanced (SD)	t-statistic	p-value
Mental demand	72.4 (14.2)	48.6 (11.8)	8.94	<0.001
Physical demand	41.3 (18.7)	29.8 (15.2)	3.42	<0.01
Temporal demand	58.7 (16.9)	42.1 (14.3)	5.23	<0.001
Performance	64.8 (15.6)	38.4 (12.9)	9.12	<0.001
Effort	69.2 (14.8)	44.7 (13.1)	8.67	<0.001
Frustration	67.5 (16.3)	39.2 (14.7)	9.01	<0.001
Overall workload	62.3 (12.4)	40.5 (10.9)	9.34	<0.001

Figure 6 shows a graphical comparison of NASA-TLX scores, by the six dimensions. The framework-enhanced components generally had the lowest cognitive load ratings with the highest ratings in the mental demand, effort, and frustration dimensions.

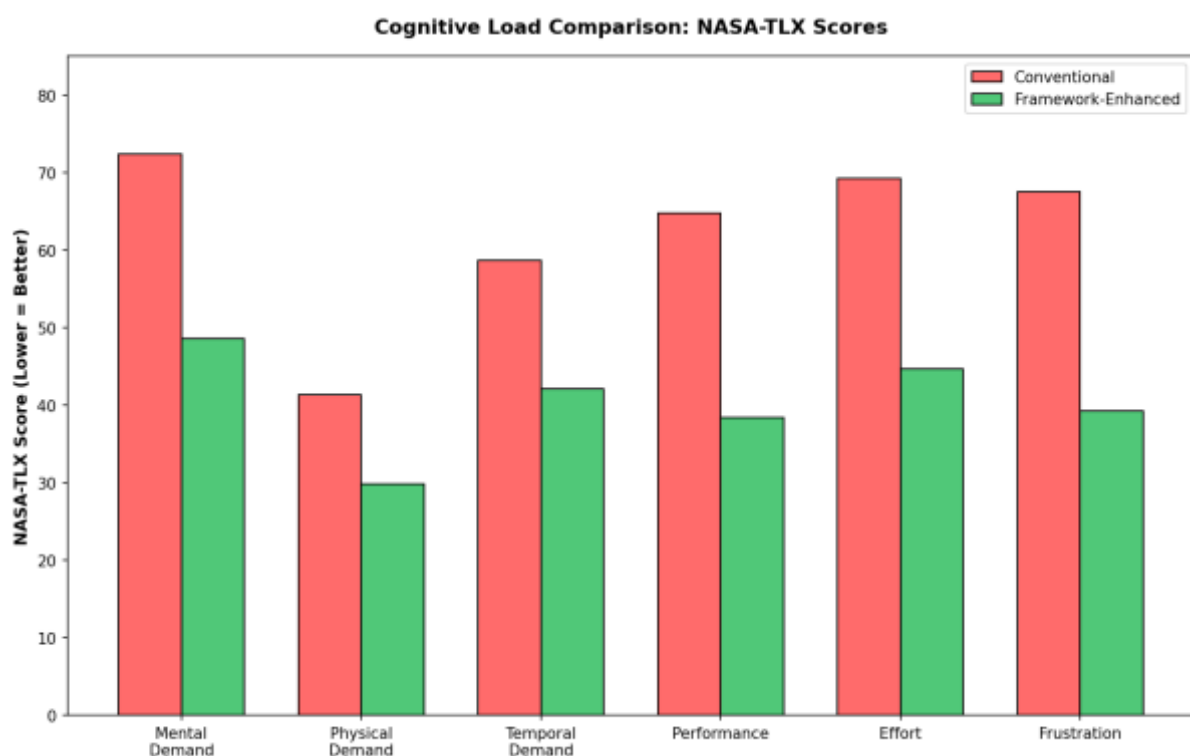


Figure 6. NASA-TLX cognitive load scores: conventional vs. framework-enhanced components

The quantitative findings were backed by the qualitative feedback. Participants were more confident in their responses when they used the framework-enhanced components (mean confidence rating 4.2/5 compared to 2.8/5 when they used conventional components, $p < 0.001$). The sense of control over the interaction and the ability to explore data also greatly improved (4.4/5 vs. 2.6/5, $p < 0.001$). The semantic structure of the chart and keyboard navigation were especially appreciated by screen reader users, as one participant remarked, "For the first time I can explore the data myself rather than hearing a summary that someone else wrote."

4.5 Organizational Adoption Factors

Organizational factors showed that technical quality of accessibility framework is not enough to ensure its adoption. Table 7 shows the results of the organizational assessment in five case study organizations that have taken part in the implementation of a framework pilot. Organizations that succeeded in achieving sustained adoption had three characteristics: (1) Accessibility integrated into design system governance with accessibility resources; (2) Cross-functional accessibility community of practice with regular meetings, and shared documentation; (3) Automated accessibility testing integrated into CI/CD pipeline.

Table 7. Organizational adoption factors and outcomes across pilot organizations

Organization	Design System Integration	Accessibility Testing	Community of Practice	Adoption Outcome
--------------	---------------------------	-----------------------	-----------------------	------------------

Org A (Fintech)	Full integration, dedicated team	Automated in CI/CD	Active, monthly meetings	Sustained adoption across 12 products
Org B (Healthcare)	Partial integration	Manual testing only	Inactive after 3 months	Partial adoption, 3 of 8 products
Org C (E-commerce)	Full integration	Automated + manual	Active, bi-weekly meetings	Sustained adoption across 15 products
Org D (Education)	No integration	No systematic testing	Never established	No adoption beyond pilot
Org E (Government)	Partial integration	Automated in CI/CD	Active, quarterly meetings	Moderate adoption, 5 of 9 products

The adoption rates in the 5 pilot organisations are visualised in figure 7. Those organizations that had full integration of their design system and active communities of practice had the highest adoption rates, and those organizations with no integration and no community of practice did not adopt the design system beyond the pilot phase.

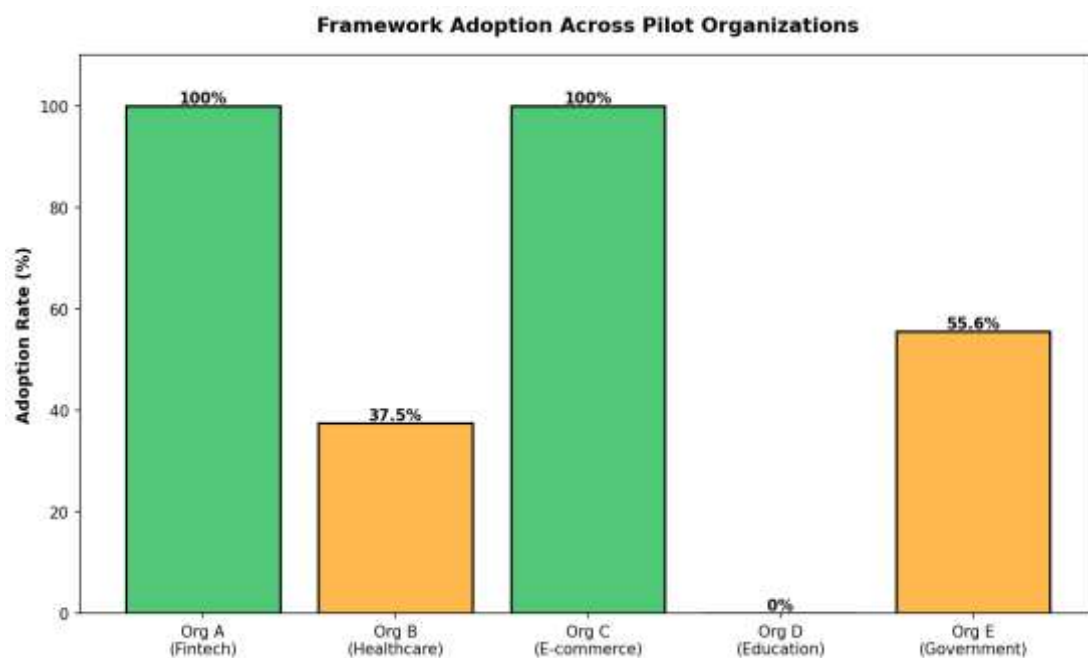


Figure 7. Framework adoption rates across five pilot organizations

Organizations that have full design system integration experienced a 73% drop in accessibility defects when compared to organizations that do not have full design system integration. Organizations that had communities of practice reported 68% quicker resolution of accessibility issues. The results highlight the role that organizational structures and processes play in promoting adoption for sustainable accessibility.

5. Discussion

5.1 Toward Systemic Accessibility

The proposed framework in this paper is a paradigm shift from the traditional paradigm on accessibility of data visualization which sees accessibility as a feature of individual chart to systemic paradigm which sees accessibility as a feature of entire product ecosystem. This change has consequences for our understanding of accessibility, the processes of visualisation design, and the process of organising the making of digital products accessible. Conceptually, the framework questions the idea that "WCAG" equals "accessibility". Although WCAG provides a solid baseline, the framework shows that there is more to creating meaningful WCAG compliance than just making data visualizations conform to standard expectations; there is also an interpretive, cognitive and experiential component to the user experience. A chart that is accessible in a formal way but not accessible in a practical way is accessible but not usable with the cognitive load being an overwhelming burden to a neurodivergent user, or there is not a way to interact with a chart that is not visual.

The framework shows that accessible visualization is not about adding the accessibility features to the design but is about rethinking the design altogether and making it accessible for full diversity of users. The patterns of the framework are not features that are added on after visualization is designed, but parts of the visualization process that are useful to all users. This is in line with principles of universal design and inclusive design, which focus on the design of a product that can be used by the widest number of people without modification. The framework also takes a sociotechnical perspective, at the organizational level, where accessibility is seen as a challenge that needs to be taken up beyond just the technical dimension

through changes in governance, culture and practice. The organizational assessment model is a systematic procedure for identifying and resolving organizational obstacles to accessible visualisation practices. Weaving accessibility into design systems, development processes, testing practices, and governance creates the ability to shift from ad hoc accessibility remediation to systematic capability.

These observations are consistent with Uddandaraao's (2026c) critique of AI-assisted dashboard implementations, which documents how data products can fail to support sound reasoning when the gap between design intent and user cognition is not systematically addressed -- a failure mode that the framework's interpretive and organizational layers are explicitly designed to prevent.

5.2 Tensions and Trade-offs

There are tensions and trade-offs that the design of accessible visualization entails that are acknowledged by the framework but not fully resolved. There is a tension between simplicity and completeness. Simplified representations have the effect of lowering cognitive load and making it more accessible to users with cognitive disabilities, but it may be the case that they also lack information that is important for expert users. The framework deals with this tension by providing features to control information density, but the question of what is appropriate default level is context-dependent and may differ for user populations and use cases. There is also a conflict between the standardization and flexibility viewpoints. Patterns in the framework are intended to be easily reused and consistent, facilitating learnability and minimising cognitive load. But, based on various data types, domain, and user needs, there might be other ways of doing things that do not fall into the pattern of the framework. This tension is addressed in the framework by offering a set of principles and guidelines rather than strict rules, so that designers and developers can "invent" patterns to their context and still uphold accessibility principles.

There is also a third one of automation vs human judgment. The framework uses automated tools to generate text alternatives, plain-language summaries and accessibility checking. But the quality of the automated output does depend on the sophistication and the algorithms used and the nature of the data. There is still a need for human judgment to assess text alternatives quality, to select an appropriate level of information density, and to make design decisions involving subjective trade-offs. The framework views automation as a tool to supplement, not replace, human skills.

5.3 Implications for Practice

The framework offers a structured and evidence-based approach to accessible visualization design to be used incrementally by practitioners. Product teams can start by introducing some patterns that solve most issues for the majority of their users, such as keyboard navigation for motor-impaired users, or the non-color-dependent encoding for color-vision-deficient users, and gradually introduce more patterns as the capability grows. The pattern language format of this framework helps in this incremental adoption as the patterns can be understood individually by teams and pattern relationships and dependences between patterns can be discovered.

The framework's focus on structures of semantic charts has significant practical ramifications. The framework offers developers practical guidance that can be implemented, by defining the structure of the parts of a chart using accessible and known SVG markup, and by incorporating ARIA roles and properties. The semantic structure allows for accessibility to the screen-reader, but it also provides the basis to support other accessibility options like keyboard navigation and alternative representations. If an organization implements the semantic structure specifications of the framework, they should see immediate benefits in terms of screen-reader accessibility, and with relatively low amount of implementation effort.

A tension in visualization design is between presenting high information density and not overwhelming the user and the adjustable information density pattern resolves this tension. The framework makes it possible to provide ways for users to manage detail and complexity, allowing a single visualization component to serve a range of users. This is especially useful for a company that is serving both expert users and novices, because each user can tailor the presentation to his or her specific needs and preferences. The simplified view and the detailed view must be designed properly to implement adjustable information density, but there are guidelines and examples provided in the framework to aid the design of these views.

The framework offers specification of accessible visualization components that can be added to existing design systems for design system teams. The specification covers semantic structure, interaction model, visual design guidelines, documentation standards and testing criteria required for the implementation of accessible components by default. Including these specs in their design systems will make accessible visualizations the norm and not the exception. The organizational assessment model is one tool design system teams will have to identify readiness for the adoption of accessible visualizations within their organization and areas that might need extra investment or support.

For accessibility specialists, the framework includes a detailed audit protocol, evaluation methodology and organizational assessment model, which can be used to evaluate and enhance the accessibility of their visualization ecosystem. The audit protocol is useful for systematically identifying barriers, the evaluation methodology is useful for evaluating interventions and the organizational assessment model is useful for diagnosing systemic factors that impact accessibility. These tools can be utilised by accessibility professionals to present business cases for accessibility investment, monitor the progress over time and to highlight the value of accessibility work to users and the capability of the business.

5.4 Implications for Research

The framework represents several advances for the research community: some theoretical and methodological advances. Theoretically, the concept of accessible visualization is not limited to perceptual accessibility, but also includes cognitive, interpretive and organizational aspects. This extension adds to the cognitive load theory, universal design principles and organizational theory, thus offering a more thorough understanding of what makes a data visualization accessible. Methodologically, the framework provides a multi-dimensional evaluation approach that is more than just a standards-based approach, and measures task accuracy, comprehension, navigation efficiency, cognitive load, confidence and perceived agency. This enables more detailed and more complex measurement of accessibility that reflect the experience of users with disabilities. The framework also provides an audit protocol and organizational assessment model that can be replicated by other researchers to study accessibility in various settings. The framework also provides some avenues for future research. Additional research is needed to determine the effectiveness of sonification and earcons for various data types and user groups. It may be worth making a systematic study of how the impact of adjustable information density on comprehension and cognitive load differs among user groups. There is a current research interest in the use of automated natural-language generation to create effective plain language summaries of complex visualizations. Organizational determinants of successful accessibility efforts (such as leadership, culture, incentives and training) must be continued.

6. Conclusion and References

Data visualization is a powerful instrument for information communication, decision making and reasoning. For millions of people with disabilities, however, the data visualization that underlies digital products is inaccessible, creating information, participation, and independence challenges. The status quo in approaches to visualization access - which are fragmented, responsive and compliance-driven - cannot meet this challenge at the level of organizational product ecosystems.

This paper put forward a holistic HCI framework to design, implement, and assess accessible data visualization throughout the organizational product ecosystem. The framework tackles the issue at three levels. It represents a set of design patterns for semantic chart structures, non-color dependent encoding, textual and tabular alternatives, adjustable information density and plain language summaries. At the interaction level it offers patterns for navigating using the keyboard, exploring the screen with a screen-reader and multimodal interaction. Organizational level, it covers design system governance, documentation, team roles, testing processes and ongoing maintenance. The framework is based on multi-phase research process, involving accessibility audit of existing visualization components, semi-structured interviews with various stakeholders, iterative design and prototyping, and comparative usability testing with users from different disabilities and data literacy levels. The evaluation design goes beyond the standards-based evaluation and assesses task accuracy, understanding, efficiency, cognitive load, confidence, and perceived agency.

The framework brings both practical and theoretical contributions. It is a collection of reusable design patterns, evaluation approaches and organizational assessment model which organizational can be adapted to enhance the accessibility of data visualization. Draws on cognitive load theory, universal design principles, and organizational theory to enable it to theoretically be applicable to cognitive, interpretive, and organizational aspects of accessible visualization in addition to perceptual. The long-term vision of this work is to help create a future where data visualization is truly accessible for all, with or without abilities, disabilities, or circumstances. This will need not just technical innovation but also an organizational effort, cultural shift and commitment to the broad range of needs of those who rely on digital products. This paper offers a framework as a pathway toward that future, and aims to offer a way to think about making accessible data visualization a scalable, systemic capability, not an afterthought.

References

1. Hoque, M. N., Ehtesham-Ul-Haque, M., Elmqvist, N., & Billah, S. M. (2023). Accessible data representation with natural sound. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)* (pp. 1-19). ACM. <https://doi.org/10.1145/3544548.3581087>
2. Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101.
3. Cleveland, W. S., & McGill, R. (1984). Graphical perception: Theory, experimentation, and application to the development of graphical methods. *Journal of the American Statistical Association*, 79(387), 531-554.
4. Kim, J., Srinivasan, A., Kim, N. W., & Kim, Y.-S. (2023). Exploring chart question answering for blind and low vision users. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)* (pp. 1-15). ACM. <https://doi.org/10.1145/3544548.3581532>
5. Ellis, K., & Kent, M. (2019). *Disability and Digital Television Cultures: Representation, Participation, and the Politics of Access*. Routledge.
6. Cumming, T. M., & Rose, M. C. (2022). Exploring universal design for learning as an accessibility tool in higher education: A review of the current literature. *The Australian Educational Researcher*, 49(5), 1025-1043. <https://doi.org/10.1007/s13384-021-00471-7>

7. Hermann, T., Hunt, A., & Neuhoff, J. G. (Eds.). (2011). *The Sonification Handbook*. Logos Verlag Berlin.
8. Yoghourdian, V., Yang, Y., Dwyer, T., Lawrence, L., Wybrow, M., & Marriott, K. (2021). Scalability of network visualisation from a cognitive load perspective. *IEEE Transactions on Visualization and Computer Graphics*, 27(2), 1677-1687. <https://doi.org/10.1109/TVCG.2020.3030459>
9. Wang, Y., Zhao, Y., & Kim, Y.-S. (2024). How do low-vision individuals experience information visualization? In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems (CHI '24)* (pp. 1-15). ACM. <https://doi.org/10.1145/3613904.3642188>
10. Lundgard, A., & Satyanarayan, A. (2022). Accessible visualization via natural language descriptions: A four-level model of semantic content. *IEEE Transactions on Visualization and Computer Graphics*, 28(1), 1073-1083. <https://doi.org/10.1109/TVCG.2021.3114770>
11. Lundgard, A., Lee, C., & Satyanarayan, A. (2019). Sociotechnical considerations for accessible visualization design. In *Proceedings of the IEEE Visualization Conference (VIS '19)* (pp. 16-20). IEEE. <https://doi.org/10.1109/VISUAL.2019.8933762>
12. Mace, R. L., Hardie, G. J., & Place, J. P. (1991). Accessible environments: Toward universal design. In W. E. Preiser, J. C. Vischer, & E. T. White (Eds.), *Design Intervention: Toward a More Humane Architecture* (pp. 151-175). Van Nostrand Reinhold.
13. Elavsky, F., Bennett, C., & Moritz, D. (2022). How accessible is my visualization? Evaluating visualization accessibility with Chartability. *Computer Graphics Forum*, 41(3), 57-70. <https://doi.org/10.1111/cgf.14522>
14. Keilers, C., Tigwell, G. W., & Peiris, R. L. (2023). Data visualization accessibility for blind and low vision audiences. In C. Stephanidis et al. (Eds.), *Universal Access in Human-Computer Interaction. Lecture Notes in Computer Science*, 14020, pp. 399-413. Springer. https://doi.org/10.1007/978-3-031-35681-0_26
15. Wimer, B. L., South, J., Wu, K., Szafir, D., Borkin, M., & Metoyer, R. (2024). Beyond vision impairments: Redefining the scope of accessible data representations. *IEEE Transactions on Visualization and Computer Graphics*, 30(12), 7619-7636. <https://doi.org/10.1109/TVCG.2024.3356566>
16. Sweller, J. (2011). Cognitive load theory. In J. P. Mestre & B. H. Ross (Eds.), *The Psychology of Learning and Motivation: Cognition - Volume 55* (pp. 37-76). Academic Press.
17. Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review*, 31(2), 261-292.
18. Persson, H., Ahman, H., Yngling, A. A., & Gulliksen, J. (2015). Universal design, inclusive design, accessible design, design for all: Different concepts -- one goal? On the concept of accessibility -- historical, methodological and philosophical aspects. *Universal Access in the Information Society*, 14(4), 505-526. <https://doi.org/10.1007/s10209-014-0358-z>
19. W3C Web Accessibility Initiative. (2023). *Web Content Accessibility Guidelines (WCAG) 2.2*. <https://www.w3.org/TR/WCAG22/>
20. W3C Web Accessibility Initiative. (2022). *Making Data Visualizations Accessible*. WAI Resources. <https://www.w3.org/WAI/>
21. Chundury, P., Thakkar, U., Reyazuddin, Y., Jordan, J. B., Elmqvist, N., & Lazar, J. (2024). Understanding the visualization and analytics needs of blind and low-vision professionals. In *Proceedings of the 26th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '24)* (pp. 1-5). ACM. <https://doi.org/10.1145/3663548.3688496>
22. Jung, C., Mehta, S., Kulkarni, A., Zhao, Y., & Kim, Y.-S. (2022). Communicating visualizations without visuals: Investigation of visualization alternative text for people with visual impairments. *IEEE Transactions on Visualization and Computer Graphics*, 28(1), 1095-1105. <https://doi.org/10.1109/TVCG.2021.3114846>
23. Leitner, M.-L., Strauss, C., & Stummer, C. (2016). Web accessibility implementation in private sector organizations: Motivations and business impact. *Universal Access in the Information Society*, 15(2), 249-260. <https://doi.org/10.1007/s10209-014-0380-1>
24. Uddandara, D. P., Konatham, M. R., & Vadlamani, R. K. (2025). Robust and scalable statistical models for high-dimensional marketing data applications: A comprehensive review. In *2025 IEEE 5th International Conference on Emerging Research in Electronics, Computer Science and Technology (ICERECT)* (pp. 1-8). IEEE. <https://doi.org/10.1109/icerec65215.2025.11377070>
25. Auer, N., Kalembe, S., Stormer, C., Boehm, A.-K., Cetin, H., Gutjahr, A., Neumann, F., Kersken, V., Weber, G., & Zimmermann, G. (2023). How to measure the accessibility maturity of organizations: A survey on accessibility maturity models for higher education. *Frontiers in Computer Science*, 5, 1134320. <https://doi.org/10.3389/fcomp.2023.1134320>
26. Blanco, M., Zong, J., & Satyanarayan, A. (2022). Olli: An extensible visualization library for screen reader accessibility. *IEEE VIS 2022 Posters*. IEEE. <https://vis.csail.mit.edu/pubs/olli/>
27. Elavsky, F., Nadolskis, L., & Moritz, D. (2024). Data Navigator: An accessibility-centered data navigation toolkit. *IEEE Transactions on Visualization and Computer Graphics*, 30(1), 803-813. <https://doi.org/10.1109/TVCG.2023.3327393>

28. Fan, D., Siu, A. F., Rao, H., Kim, G. S.-H., Vazquez, X., Greco, L., O'Modhain, S., & Follmer, S. (2022). The accessibility of data visualizations on the web for screen reader users: Practices and experiences during COVID-19. *ACM Transactions on Accessible Computing*, 15(1), Article 4, 1-29. <https://doi.org/10.1145/3557899>
29. Kim, N. W., Joyner, S. C., Riegelhuth, A., & Kim, Y.-S. (2021). Accessible visualization: Design space, opportunities, and challenges. *Computer Graphics Forum*, 40(3), 173-188. <https://doi.org/10.1111/cgf.14298>
30. Marriott, K., Lee, B., Butler, M., Cutrell, E., Ellis, K., Goncu, C., Hearst, M., McCoy, K., & Szafir, D. A. (2021). Inclusive data visualization for people with disabilities: A call to action. *Interactions*, 28(3), 47-51. <https://doi.org/10.1145/3457875>
31. Minon, R., Moreno, L., Martinez, P., & Abascal, J. (2023). Designing user interfaces for content simplification aimed at people with cognitive impairments. *Universal Access in the Information Society*. <https://doi.org/10.1007/s10209-023-00986-z>
32. Nardini, P., Chen, M., Bottinger, M., Scheuermann, G., & Bujack, R. (2021). Automatic improvement of continuous colormaps in Euclidean colorspace. *Computer Graphics Forum*, 40(3), 361-373. <https://doi.org/10.1111/cgf.14313>
33. Uddandaraao, D. P., Nagpal, R., Vats, S., & Shaffi, S. M. (2026b). Pre-balancing causal framework for enterprise analytical data pipelines: Benchmarking financial planning models for investment decision systems. *Journal of Intelligent Decision Making and Information Science*, 3(2), 1773-1792. <https://www.jidmis.org/index.php/jidmis/article/view/2269>
34. Obeid, J., & Hoque, E. (2020). Chart-to-text: Generating natural language descriptions for charts by adapting the transformer model. In *Proceedings of the 13th International Conference on Natural Language Generation (INLG 2020)* (pp. 138-147). ACL. <https://doi.org/10.18653/v1/2020.inlg-1.20>
35. Sharif, A., Chintalapati, S. S., Wobbrock, J. O., & Reinecke, K. (2021). Understanding screen-reader users' experiences with online data visualizations. In *Proceedings of the 23rd International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '21)* (Article 14, pp. 1-16). ACM. <https://doi.org/10.1145/3441852.3471202>
36. Sharif, A., Wang, O. H., Muongchan, A. T., Reinecke, K., & Wobbrock, J. O. (2022). VoxLens: Making online data visualizations accessible with an interactive JavaScript plug-in. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)* (Article 478, pp. 1-19). ACM. <https://doi.org/10.1145/3491102.3517431>
37. Spiel, K., Hornecker, E., Williams, R. M., & Good, J. (2022). ADHD and technology research -- Investigated by neurodivergent readers. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)* (Article 54, pp. 1-21). ACM. <https://doi.org/10.1145/3491102.3517592>
38. Tang, B. J., Boggust, A., & Satyanarayan, A. (2023). VisText: A benchmark for semantically rich chart captioning. In *Proceedings of the 61st Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)* (pp. 7268-7298). ACL. <https://doi.org/10.18653/v1/2023.acl-long.401>
39. Uddandaraao, D. P. (2026c). The reality of an AI implementation. *Communications of the ACM*, 69(8), 8-9. <https://doi.org/10.1145/3821443>
40. Thompson, J. R., Martinez, J. J., Sarikaya, A., Cutrell, E., & Lee, B. (2023). Chart Reader: Accessible visualization experiences designed with screen reader users. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)* (Article 802, pp. 1-18). ACM. <https://doi.org/10.1145/3544548.3581186>
41. Wu, K., Petersen, E., Ahmad, T., Burlinson, D., Tanis, S., & Szafir, D. A. (2021). Understanding data accessibility for people with intellectual and developmental disabilities. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)* (Article 606, pp. 1-16). ACM. <https://doi.org/10.1145/3411764.3445743>
42. Zong, J., Lee, C., Lundgard, A., Jang, J., Hajas, D., & Satyanarayan, A. (2022). Rich screen reader experiences for accessible data visualization. *Computer Graphics Forum*, 41(3), 15-27. <https://doi.org/10.1111/cgf.14519>
43. Uddandaraao, D. P. (2026a). Statistics and the science of causal economics: A new paradigm for data science. Deep Science Publishing. https://books.google.com/books?id=RK_NEQAQBAJ