Journal of Visualization and Interaction

Navigating and Narrating Interactive Flowcharts

Jona Pomerance, Andrew Boyd, Marian Dörk

A peer-reviewed publication in the Journal of Visualization and Interaction (JoVI).

This article is an extended version of a publication from the Information+ Conference 2023.

DOI: 10.54337/jovi.v1i1.8418 (the public peer reviews can also be found at this link)

- Submitted: 2024-12-30
- Accepted: 2026-02-25
- Published: 2026-04-10 (version 1)

Publisher

Aalborg University Open Publishing
Kroghstræde 1-3
9220 Aalborg Øst
DENMARK
ISSN: 2794-5502

Navigating and Narrating Interactive Flowcharts

Jona Pomerance, Andrew Boyd, and Marian Dörk

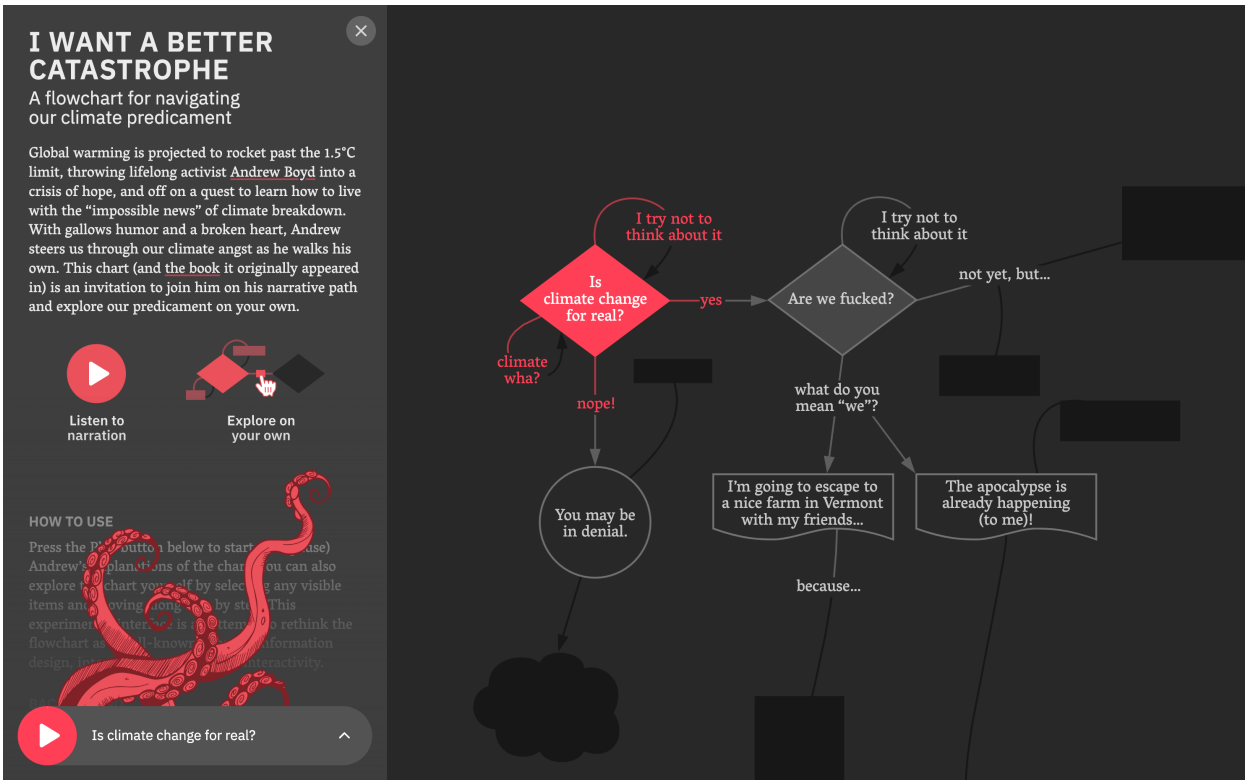

Fig. 1: Screenshot of the *I Want a Better Catastrophe* flowchart website. To introduce the project and present the two modes of narration and navigation, the panel on the left temporarily slides in upon opening the page. The flowchart can be explored in the main part of the interface by clicking any of the available nodes or by triggering the narration with the play button.

Abstract—

Introduction. While the nonlinear and interconnected nature of flowcharts makes them well-suited for representing and communicating complex narratives, flowcharts can appear impersonal, unapproachable, and disorienting, especially with a large number of elements. We propose an interaction technique for flowcharts that combines the narrative depth of linear storytelling with the autonomy of open-ended exploration.

Related Work. This research builds on existing research on interactivity in data visualizations, sonic approaches to representing data, and flowcharts as a usually static genre of node-link diagrams conveying the structure and dynamics of nonlinear systems.

Design. We introduce a flowchart interface that integrates audio narration, progressive disclosure, and animated transitions with interactive capabilities for navigating the content of the narration and flowchart. Readers of the interactive flowchart can choose between narrated or exploratory perspectives, switching between linear and nonlinear readings of the chart.

Demonstration. We illustrate the technique's design principles using the case study "I Want a Better Catastrophe", a flowchart taking viewers on a journey through the diverging paths of our climate predicament.

Evaluation. We study the potential of the technique by analyzing the reception of the case study through a feedback survey and anonymous activity logs, and by reflecting on the authoring of further interactive flowchart projects using an open-source template in the context of a university design course.

Conclusion. The results of the evaluation demonstrate the potential of an interactive flowchart that combines linear storytelling and open-ended exploration. Additionally, several directions for further development as well as new design opportunities emerge from the project. We believe the outlined technique underscores a more general potential for the harmonization and integration of narrative and exploratory approaches into data visualizations.

Materials. Links are available to the "I Want a Better Catastrophe" case study as well as the open-source interactive flowchart template. All materials, including those used for the purposes of the evaluation, are provided within this repository.

Index Terms—Flowchart, Interactivity, Interactive visualization, Narration, Audio narration, Exploration, Climate crisis.

1 Introduction

Flowcharts, typically comprising boxes and arrows, are a genre of node-link diagrams that convey the structure and dynamics of a nonlinear system, enabling readers to piece together an understanding of the system's components and behavior by moving through a flowchart's elements. For example, flowcharts can help explain the structure of computer algorithms and applications [22, 32]. Compared to a linear description, complex narratives can make particularly good use of a flowchart's nonlinear properties and the connectivity among various elements. While a flowchart can in principle scale up to many nodes and links, the growing number of elements also comes at a cognitive cost to the reader, to whom an increasingly vast and interconnected flowchart can at first glance appear disorienting and overwhelming [26]. In addition, flowcharts tend to exhibit an impersonal and unapproachable demeanor that may not be suitable for many contemporary issues that require an empathetic and personal connection. The promise to accommodate complexity and the challenge to effectively communicate it motivate our inquiry into flowchart navigation and narration. We aim to make individual pathways through a flowchart more easily navigable, while at the same time giving readers the option to follow a linear narration providing context and relatability.

In this paper, we propose an interaction technique for flowcharts that combines the narrative depth of linear storytelling with the autonomy of open-ended exploration. Building on prior work on flowcharts and data visualizations, we devise an interface concept for flowcharts that is intended to integrate narration and interactivity in a way that makes a complex topic approachable and encourages readers to alternate between narrated and exploratory modes of perusal. To achieve this, the interactive flowchart combines audio narration, progressive disclosure, and animated transitions with interactive navigation. The flowchart interface is designed to enable the transition between narrated and exploratory perspectives and thus allow for linear and nonlinear readings of the chart. Beyond the scope of flowcharts, we imagine that this dual-mode approach holds broader applicability to other visualization types. Our results suggest that pairing narration with exploration could offer relatable entry points to complex topics across domains and chart types.

After summarizing related work, we introduce our methodological approach and ambitions for this research. We then present the design decisions taken during a case study applying this methodology to a flowchart about the climate crisis. We evaluate the potential of interactive flowcharts by analyzing online feedback and anonymous activity logs from the case study as well as by reflecting upon the authoring of further interactive flowchart projects in the context of a university design course. We close by discussing the limitations of this research, opportunities for future work, and the generalizability of our approach.

2 Related Work

This research builds on prior work on flowcharts, interactivity and exploration in data visualization, and sonic approaches to representing data.

2.1 Flowcharts

Flowcharts originate from the need of visually representing complex processes such as the operation of weaponry [18], the influences among art movements [21], and the structure of algorithmic systems [9, 22, 32]. The main purpose of flowcharts has been to communicate the interdependencies of processes within a system, often with the aim to aid understanding and support maintenance tasks. While they were first employed in the mid-1920s, flowcharts rose to prominence in the 1960s in the context of software development [14]. The proposal for a "distributed hypertext system", which became the World Wide Web, prominently featured a flowchart illustrating the feasibility of complex evolving systems [4]. Over the years, flowcharts have become a diagrammatic genre for depicting time-ordered events, interconnected processes, and hierarchical structures. Flowcharts can also be used to facilitate the comprehension of texts [17]. They have been used in various domains from military strategy [8] and advocacy [33] to art and architecture [1]. Network visualizations resembling flowcharts have also been devised to generate visual explanations of redress paths in a judicial system [31]. Flowcharts can be viewed as a unique form of information visualization in their own right. Segel & Heer [35] recognize flowcharts as one of seven basic genres of narrative visualization, underlining their use and relevance in a visualization and storytelling context. They note, however, that "interactivity is not yet common in flowcharts", an assessment which still holds true today: while flowcharts represent the dynamics of complex processes, they tend to remain a largely static form of representation.

2.2 Interactivity and Exploration

For the visualization community, interaction can be broadly understood as a kind of dialogue or interplay between an interface and a person intently pursuing a task [10, 40]. While interactivity can be considered an integral component of visualizations, the visual representation aspects tend to be considered separately from interactive capabilities [7]. In the context of data stories, interactive exploration has been widely examined as a means of activating audiences in the experience of narratives [3, 16, 19, 20, 35]. In these cases, exploratory experiences are often combined with static, linear, and usually textual types of content, typically resulting in hybrid models like the "martini glass structure", interactive slideshows, and drill-down stories [35], while entirely nonlinear narratives can also be facilitated through interactive exploration, though are less common [19]. Despite the prevalence of data stories that contain both explorative and narrative elements, Boy et al. found that adding narrative components at the beginning of data stories did not significantly increase subsequent exploration [5]. Several taxonomies have been proposed to evaluate the degree of interactive exploration afforded within a data story, such as a spectrum of author-driven vs. reader-driven approaches [35], levels of user agency [29], and indicators of "paternalistic" design decisions impacting interactivity [2]. The uniqueness and pacing of exploration have been identified as key metrics for characterizing the open-endedness of exploration in visualizations [15]. Open-ended exploration, in the context of our work, refers to the viewer's autonomy in choosing a path through a flowchart, as opposed to the prescriptive nature of narrative-driven experiences guiding the viewer along a predefined trajectory. We situate our research of open-ended and authored experiences within this broader framework of balancing viewer autonomy and guidance.

Regarding the design of the employed visualizations, "flow-factors" such as navigation elements and progress controls [25] as well as "fluidity" through strategies like smooth transitions and visual feedback [13] have been highlighted as crucial components for facilitating interactive reading experiences. Walny et al.'s [38] application of the concept of "active reading" to paper-based and digital node-link visualizations sketches out a taxonomy of flowchart-applicable reading interactions, but calls for further research into active reading within digital environments as well as the possibility of supporting personalized active reading. One simple strategy for personalization is the use of progressive disclosure, i.e., the gradual, step-by-step unveiling of subsequent options as opposed to the immediate availability of a large and complex set of options [27], which has been explored in the context of educational concept maps [26]. Considering that flowcharts tend to be used to represent complex subjects, progressive disclosure could help readers avoid being overwhelmed by comprehensive flowcharts.

The communicative potential of subjectivity and personality in data visualization is increasingly recognized. Pousman et al. have observed a prevalence of visualization projects designed for personal reflection and self-awareness, rather than exclusively analytical insights [28]. These works collectively emphasize the importance of relatability, fostering deeper connections between audiences and visualization creators.

- *Jona Pomerance and Marian Dörk are with Fachhochschule Potsdam. E-mail: {jona.pomerance, marian.doerk}@fh-potsdam.de.*
- *Andrew Boyd is an independent author and climate activist. E-mail: andrewontheroad@gmail.com.*

Similarly, Thudt et al. highlight how personal visual narratives can incorporate subjectivity to reflect individual perspectives and experiences [37]. This approach underscores the value of subjectivity to convey personal meaning and foster emotional engagement with a complex topic, something that is central to our research as well.

2.3 Sonification and Audio Narration

While visual modalities have been extensively studied, the role of the audio channel as an additional modality for expressing personality and delivering relatable narratives remains under-explored. In our work, we wish to examine how audio narration can imbue data visualizations with personality, enhancing both accessibility and emotional resonance. There is already a growing research interest in multimodal approaches towards data visualization to enhance information communication, with two such techniques being data sonification and audio narration. Sonification, defined as "the use of non-speech audio to convey information" [23], can be employed to complement or replace visual representations of data in order to foster the communication and interpretation of said data. Rind et al. investigate the integration of sonification and visualization, noting that "multimodal approaches, that are based on complementary and supportive interplays between data represented on the visual, auditory, or any other domain, are rare" [30]. In order to reach diverse audiences, Lenzi & Ciuccarelli [24] highlight the role of intentionality in the design of data sonification projects related to social issues. Whitelaw et al. [39] demonstrate the interplay between auditory and visual layers in their project "The Sound of Water," where they integrate data visualization with audio recordings of environmental sounds and sonifications of hydrological data to convey the response of a wetland ecosystem to environmental changes. This approach not only shows the creative potential of multimodal visualization, but also underscores the importance of multidisciplinary collaboration.

While sonification offers unique ways to represent data, recent research also emphasizes the value of audio narration in improving data visualization accessibility. Siu et al. [36] conducted workshops with screen-reader users to develop design principles for generating audio data narratives. Their findings indicate that audio narratives can significantly improve user comprehension of data. In addition, audio narration has been included in data visualization to evoke personal connections and emotional resonance, especially when dealing with sensitive or qualitative data. Elli et al. emphasize how incorporating human voice recordings in their project "Tied in Knots" brought attention to the deeply personal and often distressing experiences of sexual harassment victims in academia [12]. By integrating audio, the project not only amplified the emotional impact of the data but also fostered solidarity and empathy. Such approaches underscore the potential of audio narration to enhance the accessibility and relatability of visualizations, thereby complementing and enhancing the communicative power of the visual representations for diverse audiences.

3 Flowchart as Interface

Our research builds upon this foundation by exploring the viability of an interactive and narrated flowchart. Considering the rare use of interactivity within flowcharts, we wish to investigate how interactive capabilities and storytelling can enrich the experience of reading and understanding the nonlinear content of a complex flowchart. For this endeavor, we consider the flowchart itself to be the central vehicle for both navigation and narration: the flowchart acts as an interface providing the interactive controls that progressively disclose its content, and itself accommodates the story elements that the audio layer weaves together into a linear narrative.

Whereas static and interactive elements tend to be separated within data stories and narrative visualizations, and often lean either towards a more author-driven or more reader-driven approach, we aim to support a form of multimodality that is based on the complementary interplay between visual items and spoken words to enable both exploratory and narrative experiences of a common body of content. By providing access to the chart's information in two distinct, yet equivalent and interconnected ways, readers are encouraged to freely switch between these modalities and alternate between different degrees of agency.

3.1 Design Goals

Building on prior work on flowcharts, interactive visualizations, and audio narration, we formulate design goals that outline a framework for enhancing flowcharts with interactive and narrative features. Each goal addresses a specific challenge for the design of interactive flowcharts:

- **DG1:** *Support both narrative and exploratory experiences.* Our first objective is to integrate both linear and nonlinear modes of interaction within a single, cohesive flowchart interface. To this end, the interactive flowchart needs to be carefully designed to fully support a dual-mode experience, where readers can opt for a structured, narrative-driven exploration or delve into the content autonomously, driven by their curiosity and interest in specific elements of the flowchart, while both experiences should yield similar insights. The underlying intention is to foster a deeper engagement with the material and cater to diverse preferences and learning styles.
- **DG2:** *Encourage shifts between linear narration and open-ended exploration.* This goal is predicated on the belief that readers should not have to choose between a guided narrative and the freedom to explore but should be able to transition between these modalities as they engage with the same content. Visual cues should subtly guide readers towards alternating between narrated and self-directed pathways. This dynamic interaction model is intended to enhance the discovery process and give readers control over the way they experience the flowchart.
- **DG3:** *Lower the threshold to engaging with the flowchart.* Recognizing the potential for complexity to become a barrier to comprehension, the flowchart interface should utilize navigational controls and animated transitions to realize the principle of progressive disclosure, resulting in the step-wise unveiling of elements based on the progression of the reader's interaction with the chart and the spoken voice of the audio narration. By gradually revealing information and ensuring that transitions between different parts of the flowchart are smooth and logical, the interface should minimize cognitive load and make complex flowcharts more accessible and engaging.
- **DG4:** *Convey personal character through audio narration.* To imbue the flowchart with a sense of vitality and personality, audio narration should be deeply integrated with the flowchart's structure. The auditory modality should not only enrich the textual content with nuance and emphasis but also introduce the author's personal perspective, making the information more relatable and engaging. Audio narration offers a multisensory experience that can enhance comprehension and emotional connection to the material. By leveraging the unique strengths of auditory storytelling, the flowchart should offer a richer, more immersive experience that complements the visual and textual elements.

Taken together, these four design goals underscore the ambition to devise a kind of flowchart that conveys complex matters in a compelling and comprehensible manner. By addressing the inherent limitations of traditional flowcharts, i.e., the solely visual and static form, and integrating navigation and narration deeply into the flowchart as an interface, we hope to revise the user experience of flowcharts and foster a more profound engagement with complex information.

3.2 Case Study

Developing and evaluating such a concept of an interactive and narrated flowchart necessitated a case study that would allow and invite such an approach to a complex subject matter. The static flowchart *"I Want a Better Catastrophe"*, included as a fold-out in the book of the same name [6] and shown in Figure 2, served as this case study, as it not only exhibited the complexity so typical for flowcharts, but also offered an innovative approach to making the planetary crisis relatable.

The chart represents a personal journey of coming to terms with our collective climate predicament. Thoughts, questions, dilemmas, and decision points are interwoven with definitions of key terms and

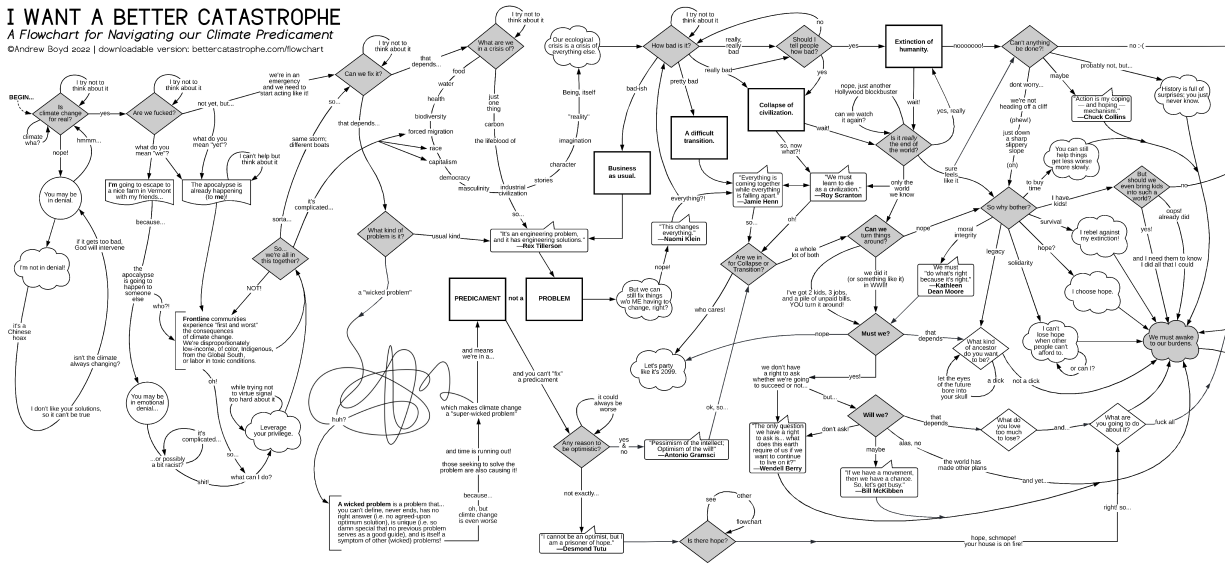

Fig. 2: The left half of the static version of the flowchart included in the book *"I Want a Better Catastrophe"* by Andrew Boyd [6].

quotes from leading voices within climate activism. The flowchart consists of 330 nodes and offers no singular pathway or sequence; instead, themes and sections within the chart are interconnected, while some segments appear as loops or dead ends. As such, any reading of the flowchart depends on a sequence of many decisions and therefore results in unique pathways through its content.

3.3 Methodology

We collaborated closely with the flowchart's creator, the second author of this paper, who also recorded the audio narration after initial design explorations, and continuously provided feedback on features and the project's visual style [11, 34]. In addition to the exchanges during the collaborative research and design process, we drew upon regular exchanges with visualization scholars and designers from our research group, whose suggestions we incorporated into our refinement of the prototype. The most significant changes that were introduced based on their feedback are noted in section 4.

The design and research process resulted in a prototype released as a standalone website,[1] which we promoted through the social media channels associated with our research group and the book. As part of a book presentation with the author at our university, we demonstrated a large banner version of the static flowchart together with a wall-projected version of the interactive flowchart. For the evaluation of the prototype, we employed an online feedback survey which viewers were asked to complete on the project's website, and also collected anonymous logs from website visitors, containing data on their modes of perusal, paths through the chart, and interactions with the interface. In contrast to prior feedback from our research group, this data was primarily used to gain insight into visitors' experiences with the interactive flowchart. The only change prompted by survey feedback was adding a session-resumption feature (see subsection 4.6).

To assess the technique's potential of being applied to other flowcharts and topics, we subsequently developed a customizable template alongside written documentation and a tutorial. Utilizing the template as the main tool, we then conducted a one-week block course at the design department of our university, in which mostly first-year design students created 13 interactive flowchart projects using the template.

[1]The "I Want a Better Catastrophe" prototype can be accessed at https://flowchart.bettercatastrophe.com/, with its source code being available here: https://github.com/jonamil/better-catastrophe

4 Designing an Interactive Flowchart

Below we describe the design decisions that emerged from the case study and ultimately shaped the features of the resulting prototype of an interactive flowchart. Central concerns were the coupling of audio narration and interactive navigation, the treatment of different types of elements contained in a flowchart, and their shifting appearance during the progression of narration and exploration.

4.1 Modes of Perusal

Upon loading the page, visitors are greeted with an introductory panel suggesting two viewing options: listening to the narration or exploring the chart on their own (DG1) (see Figure 1, left).

Selecting the play button starts playback of the audio *narration*, in which one possible path through the chart is narrated, expounding on its textual content and providing additional context, emphasis, and wit (DG4). Whenever the narration moves on to a subsequent node, the view of the flowchart updates accordingly, keeping the element currently being discussed centered within the viewport of the web browser. A control interface is available in the bottom left-hand corner (DG3), which contains a pause button as well as a progress indicator when narration is active, giving an overview of the length of the narration as a whole and the current position within it (see Figure 3 ⓐ).

Audio playback can be paused at any time to enter into self-guided *exploration*. Clicking any available node activates this node and again centers it within the viewport, allowing visitors to move along the nodes' edges and explore the flowchart on their own. In its paused state, the control interface widens to indicate the section within which the narration has been paused (Figure 3 ⓑ). Upon moving away from this pause location by selecting other nodes in the flowchart, an additional "jump" button appears to the right of the current section (Figure 3 ⓒ).

Visitors now have two options of switching back to the audio narration, i.e., *alternating* between exploration and narration. Clicking the play button resumes the narration where it has been paused, therefore returning the node discussed previously to the center of the viewport. Clicking the "jump" button, on the other hand, keeps the currently active node centered and instead changes the playback position, skipping to the next section in which the active node is described. The "jump" button takes on the highlight color of the active node to encourage the shift between the two modes (DG2), for instance, by moving through parts of the flowchart independently and later resuming the narration at specific points of interest.

Additionally, the control interface can be expanded to reveal a list of all sections covered within the narration. In order to prevent the list of

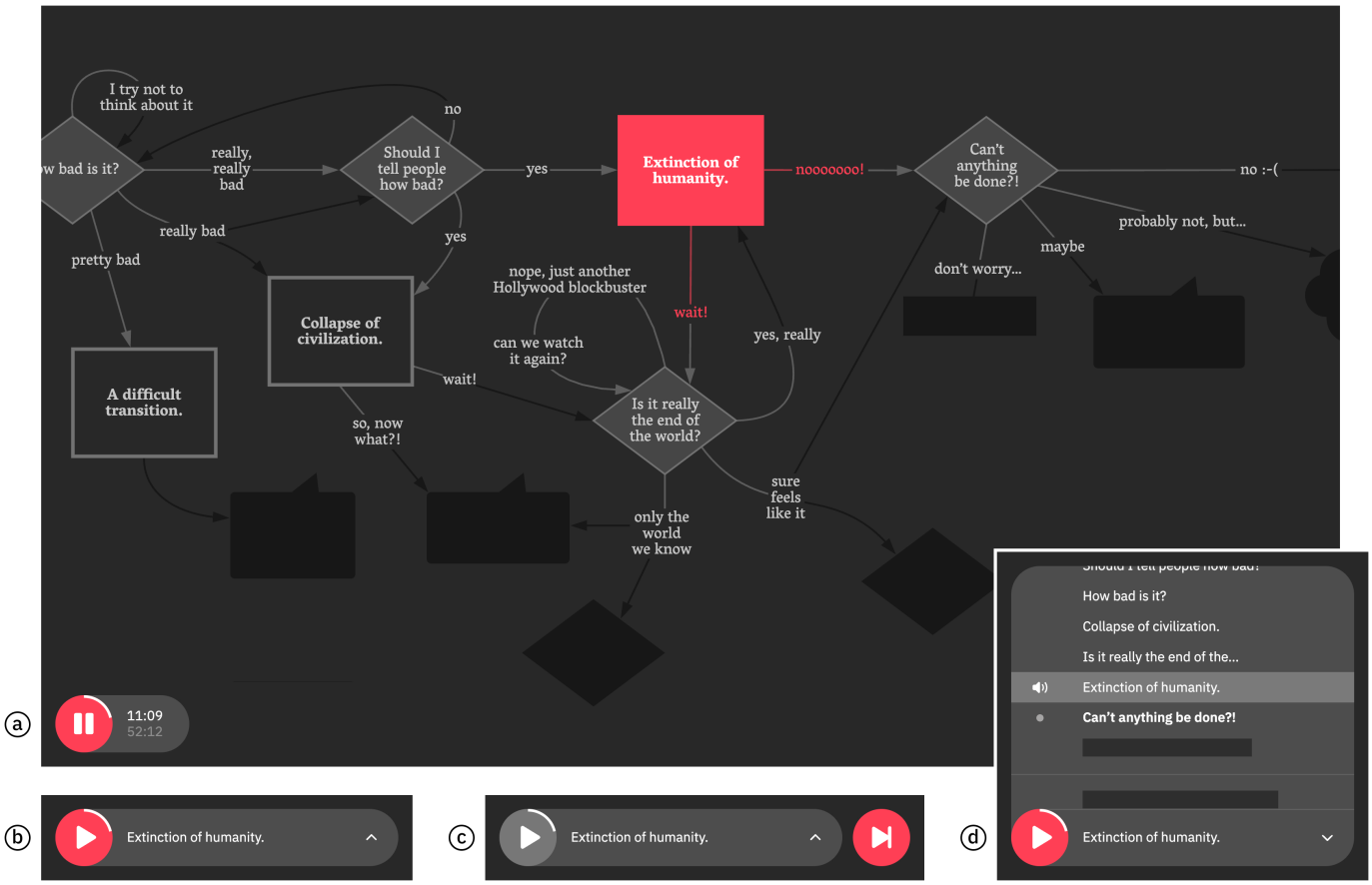

Fig. 3: Placed at the lower left corner of the browser window, the control interface provides feedback on the current state of the audio narration and interactive control over the progression of the narration: ⓐ audio narration playing, ⓑ playback paused, ⓒ "jump" action to current node available, and ⓓ an expanded list of the main flowchart elements in the order of appearance in the narration with the current item marked with a speaker symbol, unplayed items in bold type and prefixed with a dot, and not yet revealed items blanked out.

sections from becoming excessively long, only a subset of nodes within the flowchart (those surrounded by a background shape as opposed to labels placed along an edge) are included in the list. To increase readability, dividers are additionally inserted before each diamond-shaped node, which function as chapters markers within the chart. These entries indicate which sections have already been listened to and can also be selected to advance the playback position (see Figure 3 ⓓ).

4.2 Progressive Disclosure

Not all nodes within the flowchart are immediately visible and accessible. Instead, each node can appear in four distinct states, referred to as *revealed*, *current*, *next*, and *teased* (see Figure 4), enabling the flowchart to be progressively disclosed as visitors navigate it (DG3). Nodes that have previously been narrated or visited are in the *revealed* state and can be clicked. The currently active node, either selected through such a click or the advancement of the audio narration, is in the *current* state and triggers the *next* state for all immediately subsequent nodes its edges connect to, which then also become clickable.

Finally, all nodes reachable through these *next* nodes appear in the *teased* state, which is not yet clickable and only reveals a silhouette, keeping text labels concealed. This acts as a kind of "foreshadowing", giving visitors an impression of which options their next decision will uncover while still constraining their focus to the nodes immediately up ahead (see Figure 3 ⓐ) .

4.3 Animated Transitions

Whenever a new node becomes active, either through user input or the advancement of the audio narration, it moves to the center of the viewport in a smooth, animated transition, providing immediate visual feedback and ensuring visitors do not lose track of their position within the flowchart (DG3). To avoid jarring movements, the length of the animation increases with the distance traveled across the flowchart during the transition.

Owing to the lively style of narration, certain sections change the currently selected node in quick succession, causing extended periods of rapid movements with each switch to a new node triggering a pan animation. After feedback from our research group revealed some of these sections being perceived as jarring and hard to follow, a movement threshold based on the current viewport dimensions was added to reduce this rapid movement and thus improve readability. Only if the distance from the center of the screen to the subsequent active node exceeds this threshold, a transition is triggered.

4.4 Focused Point of View

While the ability to zoom in and out is commonly found in the context of navigating content on a two-dimensional canvas, special consideration must be given to the fact that the progressive disclosure outlined above renders the flowchart largely invisible at first, with its unfolding relying on the gradual traversal of nodes. In order to ensure that viewers do not feel dislocated from their position within the flowchart and to encourage the step-by-step exploration of its content, the prototype does not provide zoom capabilities. However, feedback responses from our research group as well as the online survey included the wish for zoom functionality to be available, especially as a means of making it easier to return to a specific area of the chart after having reached the latter's narrative conclusion. Implementing zoom without sacrificing the focus on step-by-step navigation remains a challenge for future iterations of the prototype and technique.

Fig. 4: Nodes in the interactive flowchart can appear in four states: ⓐ *revealed*, ⓑ *current*, ⓒ *next*, and ⓓ *teased*.

The initial release of the prototype paused the audio narration as soon as visitors began panning elsewhere. However, feedback exchanges within our research group revealed a recurring request for being able to scan neighboring sections of the flowchart while still keeping the audio narration playing. Therefore, the prototype's behavior was adjusted to allow such panning without interrupting playback, returning the node being discussed to the center of the viewport after a period of inactivity or through a button within the control interface.

4.5 Adjustment of Playback Position

Due to the interconnected and at times circular nature of the "I Want a Better Catastrophe" flowchart, the audio narration covers a number of nodes multiple times, raising the question to which of these occurrences the narration is moved when a "jump" action is triggered. A number of conditions are employed to determine the most appropriate playback position in this case. If a "jump" is performed while playback is paused, the narration jumps to the first occurrence of the selected node that has not yet been listened to, and to the final one if all have already been listened to. If, in contrast, a "jump" is triggered by clicking a node while playback is running, the next node occurrence following the current playback position is used regardless of whether it has previously been listened to, or the final one in the narration if no more occurrences exist after the current playback position. This approach balances the possibility of shifting between exploration and narration with the aim of conveying visual and auditory content cohesively and comprehensibly (DG2, DG3).

4.6 Session Resumption

Considering the case study flowchart contains 330 nodes and the narration spans over 52 minutes of audio, visitors might not be able to experience its entirety as part of a single session. In the initial version of the prototype, progress was reset upon each reload of the page, prompting feedback survey responses requesting to be able to interrupt a session and return to the same location within the chart at a later point in time. A feature storing the state of the flowchart in the browser's local storage, which does not require the setting of a cookie or any authentication, was subsequently added to the prototype. Upon reloading the page within the same browser, the flowchart as well as the audio narration return to their previous state, while an option to reset the progress and start over is provided in the sidebar.

5 Evaluation

In the following section, we evaluate the interactive flowchart from two perspectives. The first revolves around the reception of the "I Want a Better Catastrophe" prototype, while the second centers on the application of the outlined interactivity technique to other flowcharts within the scope of a university design course.

5.1 Reception

To evaluate the reception of the interactive flowchart prototype, we draw upon two sources. The first is an online feedback survey which viewers were asked to complete on the project's website (see Table 1), to which we received 177 responses. The second is a set of anonymous activity logs that were collected from website visitors, who were informed of this data collection in the project's introductory sidebar. The logs contain the types and timestamps of interactions made within the flowchart interface, along with a random identifier set upon each individual loading of the page. No additional data, such as information about the visitor's location, device, or browser, was captured or stored, and no cookies were used. In total, 29,112 such logs were collected, of which we will use 23,346 for further analysis, ignoring sessions without any interaction with the flowchart.

5.1.1 Modes of Viewing

Considering the design goals of enabling both narrative and exploratory experiences (DG1) and encouraging visitors to switch between them (DG2), how and how much these two modes of reading are used as well as whether visitors alternate between them present key evaluation criteria. Survey respondents were asked to explain their preference for one of or both modes (see Table 1, Q3). Respondents favoring the narration attributed this to the informative and engaging mode of delivery:

> *The narration had a lot more information than just looking at the flowchart. It did a good job of creating this narrative story that I really enjoy.* [P105]

> *I started listening and loved Andrew's narration. The emotion, humor and urgency were clear.* [P110]

Those who favored open-ended exploration explained this preference through the desire to experience the flowchart at their personal pace and the wish for self-guided interpretation without the distraction by a speaker:

> *I prefer to work at my own speed with my own internal resources.* [P94]

Q1	How did you learn about the flowchart?
Q2	What is your preferred mode of experiencing the flowchart?
	a. Listen to the narration
	b. Explore on your own
	c. Use both modes alternately
Q3	Can you briefly explain the choice you made above?
Q4	What would you change about the flowchart interface? Any suggestions?
Q5	What did you learn from this experience?
Q6	Do you have any additional comments?

Table 1: The online feedback survey was kept deliberately succinct and contained questions about visitors' preferences, suggestions, and takeaways.

> *I like to explore on my own, form my own thoughts and take my time with it.* [P106]

> *I want to reflect and explore my own insights as they arise, not be captured by someone else's.* [P30]

These two types of answers suggest both modes of reading are used, and that visitors have different motives and reasons for preferring one over the other. However, some answers also suggest that visitors appreciated being able to use both modes and switch between them:

> *Having listened, I like to go back and look at the inter-relationships and where and how connections might occur differently and also map my own experience and journey.* [P72]

> *Tried it for myself first and then listened to the narration to make sure I didn't miss anything.* [P32]

These responses indicate that some visitors take advantage of both modes, switching from primarily listening to later primarily exploring and vice versa. The distribution of answers given to the question about the preferred mode of experiencing the flowchart (Q2) reveals a slight overall preference for narration (40%), followed by using both modes alternately (34%), and exploring on one's own (26%) (see Figure 5).

Within the anonymous activity logs, we can compare visitors' total time spent listening to the audio narration to the total time spent exploring the flowchart on their own. To account for time spans in which visitors are idle (i.e., not actively interacting with the page), the calculated intervals between interactions are capped at 60 seconds while audio playback is paused. To relate these values to the self-reported preferences from the feedback survey, we designate a visitor's session to have a preference when one mode is used more than twice as long as the other one. Conversely, if neither of the two time spans is longer than twice the other, the session is considered to have been "balanced".[2]

Applying this calculation to all 23,346 analyzed logs suggests that most visitors spent the majority of their time in one particular mode of reading, with a preference for exploration (54%) being slightly more widespread than a preference for narration (39%) (see Figure 5). Compared to the preferences submitted within the survey, the "balanced" use of both modes is noticeably rarer (7%). This might be related to the visitors' subjective experiences of either mode, but is also attributable to the fact that the logs present a different, much larger sample that likely does not reflect the same behavior as that of the subset of participants inclined to submit a feedback response. Additionally, in response to Q3, about 7% of survey respondents reported not or not initially to have noticed the existence of either the audio narration or, less commonly, the option to explore on one's own, so some visitors might have spent all of their time in a single mode due to not having discovered the full extent of features offered by the interface.

5.1.2 Temporal and Spatial Insights

The average session time across all logs analyzed is 7:57 minutes. Between the three viewing preferences outlined above, session times differ considerably: viewers with a preference for narration spend a much longer average time of 15:15 minutes on the page, while the average session of viewers making "balanced" use of both modes lasts 4:06 minutes and that of viewers who prefer to explore on their own is 3:08 minutes long. Plotting the total session times for each of the three preferences (Figure 6) reveals that listening to the audio narration tends to hold visitors' attention longer than a self-guided exploration of the flowchart, with a notable spike of visitors reaching a session time above 52 minutes, which equals the length of the full audio narration.

[2]As submissions of the feedback survey include an anonymous log identifier set upon each unique page visit, we can determine that nearly two thirds (66%) of respondents' self-reported reading preferences match the categories derived from the logs of their visits using the outlined definition. The remaining third differs mostly due to the applied ratio of 2:1.

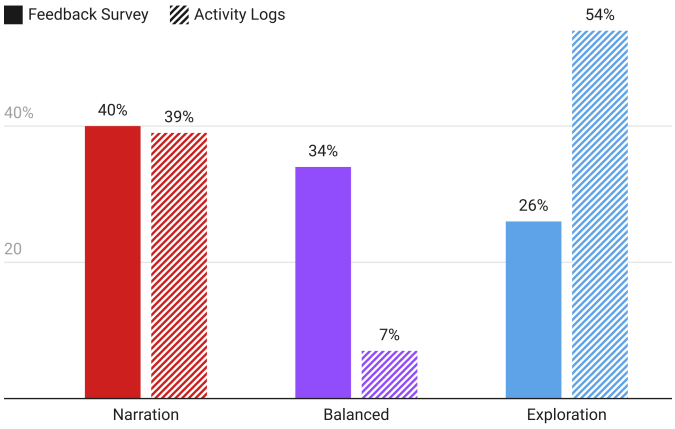

Fig. 5: Preferences for narration, a balanced use of both modes, and exploration, as recorded through the feedback survey and anonymous log data.

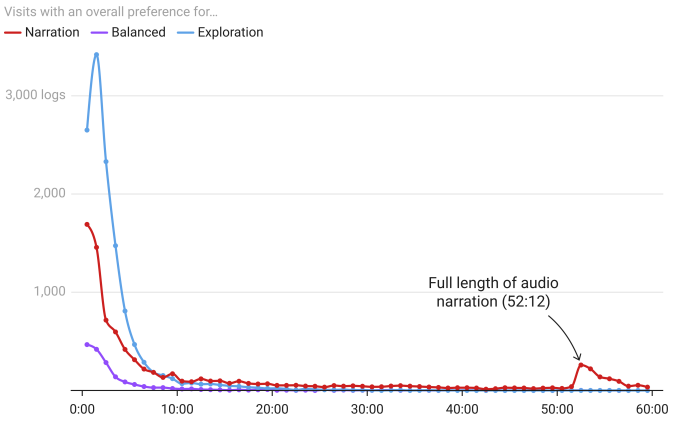

Fig. 6: Total session time (i.e., the time after which visitors left the page), binned as 1-minute intervals and separated by visitors' preferences for narration, a balanced use of both modes, and exploration. The spike of logs with a session time above 52 minutes can be attributed to visitors having listened to the audio narration in its entirety.

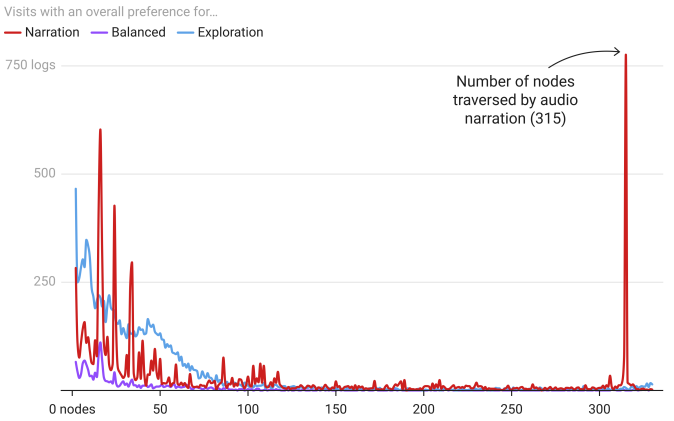

Fig. 7: Number of total visited nodes, separated by visitors' preferences for narration, a balanced use of both modes, and exploration. The spike of logs that have traversed 315 nodes corresponds to the spike in Figure 6, as listening to the full audio narration results in 315 visited nodes.

The median session time of 2:24 minutes is much shorter than the average time, which is caused by the existence of a considerable number of very short visits that exhibit only few interactions with the chart, visible as the initial set of data points within Figure 6. While it is difficult to attribute these short sessions to a specific reason, one contributing factor may be the fact that individual visitors are not tracked across visits. Multiple sessions by interrupted or returning visitors thus register as separate session times.

Of all 330 nodes in the flowchart, the average number of nodes visited is 61, while the median is 30. Comparing the three types of viewing preferences results in average values of 89, 37, and 44 nodes for viewers preferring the narrated, balanced, and exploratory modes respectively. This indicates that the longer time visitors who primarily listen to the audio narration spend on the page also translates into them traversing more of the chart, with the spike of viewers visiting 315 nodes (Figure 7), equal to the number of nodes included in the audio narration, corresponding to the spike in sessions lasting at least 52 minutes (Figure 6).

20% of all analyzed sessions reach the flowchart's final node, meaning one in five visitors makes their way to the narrative conclusion of the flowchart, traversing a median number of 102 nodes in the process. About 4.6% of visitors reach a narration time of at least 52:12 minutes, which equals the full length of the audio track.

5.1.3 Personal Impacts

In addition to these observations, the responses to the feedback question about what visitors learned from this experience (Q5) paint a detailed picture of the flowchart's impression and impact on visitors. Having largely been circulated in contexts related and/or relevant to climate research and advocacy, many visitors were likely familiar with the factual contents and arguments contained within the flowchart. However, several respondents highlight the overview provided by the flowchart and its style of presentation as a potential to make the underlying topic more accessible:

> *I'm very deep into my learning of the subject, but I would say I discovered an excellent method of simple presentation of the issue.* [P93]

> *I knew most of the facts, and the people quoted [. . .]. But importantly I earned a beautiful way of communicating – which has the potential to reach people for whom worthy documentaries or 10 pages of closely typed A4 in another climate report are just not accessible.* [P34]

Some respondents explicitly praise the use of a flowchart as a creative means of representing the nonlinear, "messy" nature of the complexities making up the climate crisis:

> *Really seeing a new way to tell a non-narrative story. I thought we'd be here decades ago with hypertext, but I haven't seen anything else use technology to so creatively and simply change the linear style of storytelling that text usually forces on us.* [P38]

> *I loved the use of a messy flowchart to depict the predicament. It's a gritty and realistic representation of how interconnected and complex the situation we are in is. It helped me to see how the big-picture systemic change and small-scale both matter and are both necessary.* [P79]

Another theme touched upon by various respondents is an emotional response and the feeling of being heard and recognized:

> *It was affirmative of my own life experience and changeable emotions (impotent rage) around and about the climate emergency.* [P72]

> *I was amazed that many of my own thoughts and ideas about the climate crisis, what it means and where we're at and where we're going, were reflected back at me. Also reflected back were the seemingly inexplicable attitudes of some of those around me. It helped to explain.* [P125]

A number of respondents additionally describe a change in perspective or an inspiration to act on the challenges raised by the climate crisis:

> *It gave me some nudges to re-think my attitude (I found myself in various spaces in the flow chart and am not sure if they contradict each other).* [P143]

> *I am already thinking about this a lot, but the experience helped organize my thinking and lets me know that if I want to contribute, it needs to be in deepening engagement, art making, comedy in the context of some areas of this chart.* [P131]

Aside from mostly positive responses, a few respondents report feelings of disappointment about the lack of novel information:

> *Nothing really. It's a cool site, but after I went through various branches it didn't tell me anything I didn't already know or make any actually useful suggestions I could act on.* [P65]

Overall, the prior familiarity of many visitors with factual content about the climate crisis must be noted as a factor that likely influenced their experience of navigating the flowchart. However, several of the personal responses cited above suggest that the chart nevertheless seems to have enhanced visitors' understanding and inspired a more personal connection and proactive attitude towards the complexities of the issue.

5.2 Authoring

To assess the potential of this approach for creating other interactive flowcharts, we developed a customizable template based on the code and implementation of the "I Want a Better Catastrophe" prototype.[3] The template is intended to be as accessible and extensible as possible by not imposing technical constraints on the flowchart creation and design process. The template is functionally identical to the prototype used in the case study, with the exception of the control interface, which, for simplicity's sake, does not contain the table of contents (see Figure 3 ⓓ).

Creating an interactive and narrated flowchart with the template involves a few steps. First, the content, structure, and layout of the flowchart can be prepared using any vector graphics software that supports SVG export. Within the graphics software, layers or frames containing nodes and edges are renamed according to a simple schema—"n-001" for the first node and "e-001-002" for the edge connecting it to the second node—so they can be recognized by the template's interaction logic. After finalizing the design, the SVG file is exported and placed in the folder of the template, which renders it as an interactive, progressively-disclosing flowchart. To incorporate audio narration, both an audio track and a text file linking timestamps with nodes need to be included in the template folder. Finally, the visual appearance of the flowchart can be enhanced by including alternate visual variants of nodes and edges matching their different interaction states and by adjusting the theme colors used by the sidebar and the control interface.[4]

To test the potential of the template for reuse, and to explore how it enables the creation of custom interactive flowcharts, we conducted a one-week block course with first-year design students. The students were tasked with devising an interactive flowchart revolving around a

[3] The template is provided under the MIT license and available here: https://github.com/uclab-potsdam/interactive-flowchart

[4] A step-by-step tutorial is available on Figma (https://www.figma.com/design/oEk2RN9Ebt9KQkU8KIrR3a/Flowchart-Tutorial) or as a PDF document (https://raw.githubusercontent.com/uclab-potsdam/interactive-flowchart/main/docs/Tutorial-Interactive-Flowchart.pdf).

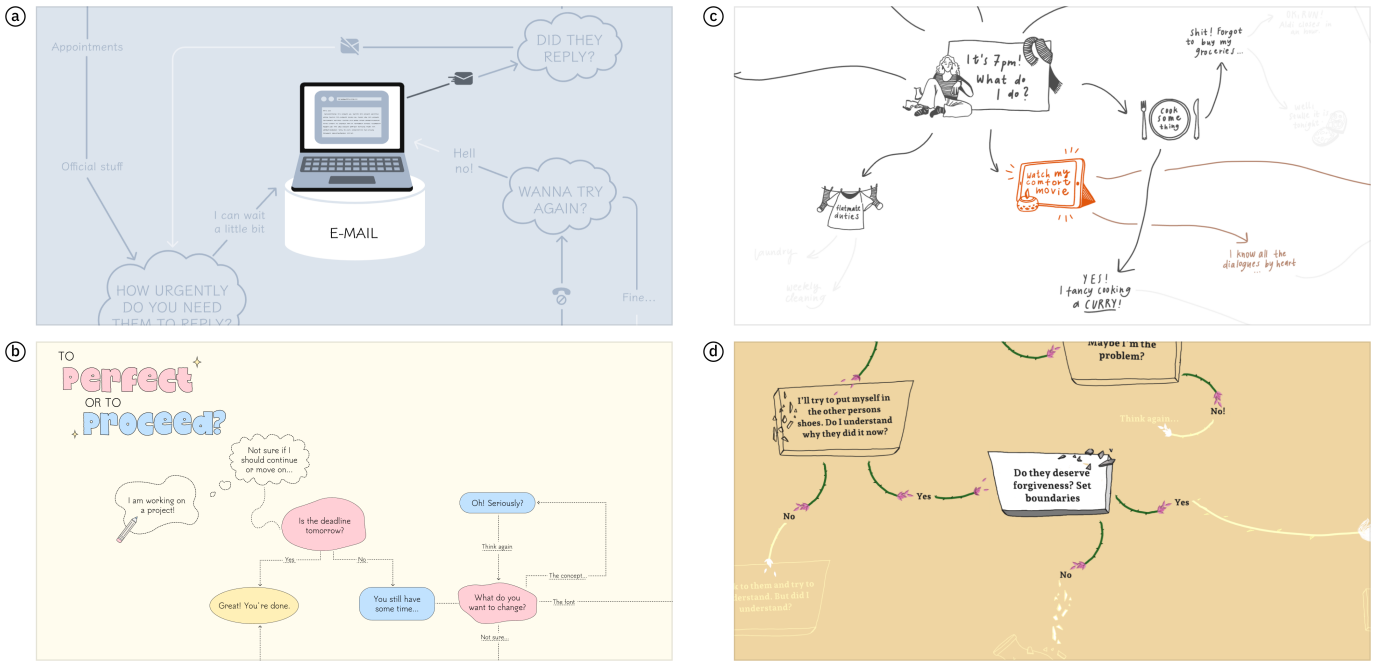

Fig. 8: Flowchart projects about personal dilemmas created by students as part of the one-week design block course: ⓐ "So You Have Something to Say?" by Maria Dinitz, ⓑ "To Perfect or to Proceed?" by Yana Cholakova, ⓒ "It's 7 PM: What Do I Do?" by Merle Kauf, ⓓ "I'm Mad! Should I Forgive Them?" by Valentina Lafchieva.

personal dilemma of their choice, recording an audio track narrating a path through their chart, and assembling these elements using the template. The course participants created 13 flowchart projects, each showcasing unique visual and narrative styles (see Figure 8).[5]

The flowcharts created during the course featured between 25 and 82 nodes, with a median of 58 nodes per project. Audio narrations ranged from 1:17 to 5:10 minutes in length, with a median runtime of 2:15 minutes. These projects demonstrated the ability to support both narrative and exploratory experiences (DG1) while allowing shifts between these modes of interaction (DG2), facilitated by the template's interface.

Students had creative freedom in designing their flowcharts, and many extended beyond the original prototype by incorporating more expressive shapes, illustrations, and images. The template's built-in progressive disclosure mechanism proved especially effective for these cases, gradually guiding viewers through the unfolding visual complexity (DG3). However, some students encountered challenges in crafting engaging audio narrations (DG4), with many noting the difficulty of delivering their narrations in a captivating manner and the unfamiliarity with recording their own voice. In contrast to the visual and interactive design of flowcharts, the preparation of audio narration was not explicitly covered in presentations by the instructors.

6 Discussion

While the possibility of interactivity within flowcharts has been pointed out [35], it is still a largely static diagram usually associated with a printed medium. The results of the evaluation demonstrate the potential of interactive, narrated flowcharts that combine linear storytelling and open-ended exploration.

The survey responses and activity logs offer encouraging insights into users' interactions, experiences, and preferences, yet the asynchronous and anonymous nature of these sources also limits the study of engagement with the interactive flowchart. Our understanding could be further deepened through in-person usability studies and interviews as well as by comparing certain features using customized prototypes with restricted capabilities evaluated in a more controlled environment.

[5]The student projects can be viewed here: https://uclab.fh-potsdam.de/interactive-flowchart/projects/

Another limiting factor is the specificity of the case study's topic and the "charismatic" style of its narration, whose impact was also apparent within the creation process of other flowchart projects. Evidently, the impact of a narration heavily relies on the narrator's capacity to convey a story in a compelling manner. It can be questioned whether case studies with a less "charismatic" narrator as well as less personally relevant and emotionally moving content would lead to similar levels of engagement.

From an authoring perspective, the diversity of visual styles and narrative structures employed within the student projects demonstrates the advantages of reducing constraints on the flowchart creation process. However, this creative freedom comes with the tradeoff of requiring significant manual effort in designing the flowchart's structure and visual elements before integrating narration and interactivity. Automating parts of the flowchart creation using structured data could lower the barrier to entry and broaden the applicability of the technique. This, however, would likely come at the expense of some of the structural and visual expressiveness of bespoke design highlighted by this study.

During the course of the project, several directions for further development emerged. While facilitating exploration and integrating progressive disclosure enables a personalized experience of reading a flowchart, the structure and content of all charts studied within this research nonetheless remain static. Exploring ways of dynamically annotating or adjusting a flowchart's layout and elements based on audience input could open up potentials for further personalization and nonlinear storytelling. Implementing a feature to share one's position and progress within the chart, for instance through a personalized link, could encourage visitors to share their personal experiences of the flowchart with others and enable the latter to more directly relate.

New design opportunities arose as well. The visual modality, on one hand, could be further enhanced by adding images or other visual elements to the flowchart, a potential that some of the showcased student projects have already begun exploring. The use of captions to extend the context added by the audio narration to the visual domain could also be explored as an opportunity for increased accessibility.

The audio modality, on the other hand, could potentially be enriched by adding multiple narrative perspectives by different narrators. This approach, however, opens up further questions such as whether this potential might again be limited if multiple voices narrated the same

content or how the switching between narration and exploration would work if multiple parallel narrations were available and how intersecting and diverging narrative paths would manifest themselves in the interface.

7 Conclusion

In this paper, we investigated the potential of integrating linear storytelling with open-ended exploration in interactive flowcharts, demonstrated through a case study embedded in climate advocacy. We designed a prototype that combined audio narration, progressive disclosure, and interactive navigation to balance structured guidance with user autonomy. We evaluated this approach through online feedback and interaction logs, highlighting its effectiveness in engaging audiences with complex topics. To extend the technique's applicability, we developed a reusable template, which was tested in a university course where students created personalized interactive flowcharts. The diversity of results emphasize the promise of this method in making complex and emotionally charged topics more approachable and relatable.

While the "I Want a Better Catastrophe" flowchart allowed us to develop the concept and prototype with a concrete case study, we believe the technique underscores a more general potential for the harmonization and integration of narrative and exploratory approaches into data visualizations. When visualization projects focus on narrative, there may be the risk of presenting a complex matter within a linear story that could be overly prescriptive or simplistic. When emphasis is placed on exploration, visitors can feel overwhelmed by the complexity of an open-ended structure and freely configurable interface. Exploring further how both perspectives can be appropriately balanced presents a promising opportunity for future research.

The combination of narration and exploration in our interactive flowchart has proven effective in facilitating engagement with a challenging subject matter. While this dual-mode approach has been productive for flowcharts, we are confident it holds broader applicability for other visualization types. Interaction techniques, such as audio narration and multimodal navigation, show potential for communicating complex topics. These methods imbue visualizations with a sense of relatability and emotional resonance, offering audiences an engaging and accessible experience. Future work could investigate how this interplay between exploration and narration can be adapted to other visualization types, potentially transforming the way multifaceted issues are conveyed across domains.

Information+ Presentation

This article was presented at the Information+ 2023 conference titled *"Navigating and Narrating an Interactive Flowchart of the Climate Crisis."*

Research Material Statements

The source code of the case study project and flowchart template as well as supplemental material used for purposes of evaluation is available within this OSF repository: https://osf.io/5usfm. The complete submissions to the feedback survey (see subsection 5.1) are not shared publicly, as participants were not asked to consent to their responses being shared with others, and the data entered by some survey respondents contains personal information such as names, affiliations, and email addresses.

Authorship

Jona Pomerance: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft. **Andrew Boyd**: Conceptualization, Resources, Writing – Review & Editing. **Marian Dörk**: Conceptualization, Methodology, Resources, Writing – Original Draft, Supervision.

License

Conflicts of Interest

The authors declare that there are no competing interests.

References

[1] M. Allen. Flowcharting: From abstractionism to algorithmics in art and architecture. *gta edition*, 3, 2023. doi: 10.54872/gta/4616 2

[2] E. Appelgren. An illusion of interactivity: The paternalistic side of data journalism. *Journalism practice*, 12(3):308–325, 2018. doi: 10.1080/17512786.2017.1299032 2

[3] B. Bach, M. Stefaner, J. Boy, S. Drucker, L. Bartram, J. Wood, P. Ciuccarelli, Y. Engelhardt, U. Koeppen, and B. Tversky. Narrative design patterns for data-driven storytelling. In *Data-driven storytelling*, pp. 107–133. AK Peters/CRC Press, 2018. doi: 10.1201/9781315281575-5 2

[4] T. J. Berners-Lee. Information management: A proposal. Technical report, CERN, 1989. https://cds.cern.ch/record/369245/files/dd-89-001.pdf. 2

[5] J. Boy, F. Detienne, and J.-D. Fekete. Storytelling in information visualizations: Does it engage users to explore data? In *CHI '15: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 1449–1458. ACM, 2015. doi: 10.1145/2702123.2702452 2

[6] A. Boyd. *I Want a Better Catastrophe: Navigating the Climate Crisis with Grief, Hope, and Gallows Humor*. New Society Publishers, 2023. https://newsociety.com/books/i/i-want-a-better-catastrophe. 3, 4

[7] V. Brüggemann, M.-J. Bludau, and M. Dörk. The fold: Rethinking interactivity in data visualization. *DHQ*, 14(3), 2020. https://www.digitalhumanities.org/dhq/vol/14/3/000487/000487.html. 2

[8] E. Bumiller. We have met the enemy and he is powerpoint. *New York Times*, 26:1–1, 2010. https://www.nytimes.com/2010/04/27/world/27powerpoint.html. 2

[9] N. Chapin. *Flowcharts*. ERIC, 1971. https://archive.org/details/flowcharts0000chap. 2

[10] E. Dimara and C. Perin. What is interaction for data visualization? *IEEE transactions on visualization and computer graphics*, 26(1):119–129, 2019. doi: 10.1109/TVCG.2019.2934283 2

[11] M. Dörk, B. Müller, J.-E. Stange, J. Herseni, and K. Dittrich. Co-designing visualizations for information seeking and knowledge management. *Open Information Science*, 4:217–235, 2020. doi: 10.1515/opis-2020-0102 4

[12] T. Elli, U. Hinrichs, A. Bradley, Z. Hills, C. Collins, and K. Kelsky. Tied in knots: A case study on anthropographic data visualization about sexual harassment in the academy. In *2020 IEEE VIS Arts Program (VISAP)*, pp. 29–44. IEEE, 2020. doi: 10.1109/VISAP51628.2020.00010 3

[13] N. Elmqvist, A. V. Moere, H.-C. Jetter, D. Cernea, H. Reiterer, and T. Jankun-Kelly. Fluid interaction for information visualization. *Information Visualization*, 10(4):327–340, 2011. doi: 10.1177/1473871611413180 2

[14] N. Ensmenger. The multiple meanings of a flowchart. *Information & Culture*, 51(3):321–351, 2016. doi: 10.7560/IC51302 2

[15] M. Feng, E. Peck, and L. Harrison. Patterns and pace: Quantifying diverse exploration behavior with visualizations on the web. *IEEE transactions on visualization and computer graphics*, 25(1):501–511, 2018. doi: 10.1109/tvcg.2018.2865117 2

[16] A. Figueiras. How to tell stories using visualization. In *2014 18th International conference on information visualisation*, pp. 18–18. IEEE, 2014. doi: 10.1109/IV.2014.78 2

[17] E. Geva. Facilitating reading comprehension through flowcharting. *Reading Research Quarterly*, 18(4):384, 1983. doi: 10.2307/747375 2

[18] F. B. Gilbreth and L. M. Gilbreth. Process charts: First steps in finding the one best way to do work. *Journal of Fluids Engineering*, 43:1029–1043, 1921. doi: 10.1115/1.4058133 2

[19] F. Hohman, M. Conlen, J. Heer, and D. H. P. Chau. Communicating with interactive articles. *Distill*, 5(9):e28, 2020. doi: 10.23915/distill.00028 2

[20] J. Hullman and N. Diakopoulos. Visualization rhetoric: Framing effects in narrative visualization. *IEEE transactions on visualization and computer graphics*, 17(12):2231–2240, 2011. doi: 10.1109/TVCG.2011.255 2

[21] A. H. B. Jr. *Cubism and Abstract Art: Painting, Sculpture, Constructions, Photography, Architecture, Industrial Art, Theatre, Films, Posters, Typography*. Museum of Modern Art, 1936. https://archive.org/details/cubismabstractar0000muse. 2

[22] D. E. Knuth. Computer-drawn flowcharts. *Communications of the ACM*, 6(9):555–563, Sept. 1963. doi: 10.1145/367593.367620 2

[23] G. Kramer, B. Walker, T. Bonebright, P. Cook, J. Flowers, N. Miner, and J. Neuhoff. Sonification report: Status of the field and research agenda. *Faculty Publications, Department of Psychology, University of Nebraska*, 444, 1997. https://digitalcommons.unl.edu/psychfacpub/444/. 3

[24] S. Lenzi and P. Ciuccarelli. Intentionality and design in the data sonification of social issues. *Big Data & Society*, 7(2):2053951720944603, 2020. doi: 10.1177/2053951720944603 3

[25] S. McKenna, N. Henry Riche, B. Lee, J. Boy, and M. Meyer. Visual narrative flow: Exploring factors shaping data visualization story reading experiences. *Computer Graphics Forum*, 36(3):377–387, 2017. doi: 10.1111/cgf.13195 2

[26] J. C. Nesbit and O. O. Adesope. Learning from animated concept maps with concurrent audio narration. *The journal of experimental education*, 79(2):209–230, 2011. doi: 10.1080/00220970903292918 2

[27] J. Nielsen. Progressive disclosure. Nielsen Norman Group, 2006. https://www.nngroup.com/articles/progressive-disclosure/. 2

[28] Z. Pousman, J. T. Stasko, and M. Mateas. Casual information visualization: Depictions of data in everyday life. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1145–1152, Nov/Dec 2007. doi: 10.1109/tvcg.2007.70541 2

[29] J. D. Rawlins and G. D. Wilson. Agency and interactive data displays: Internet graphics as co-created rhetorical spaces. *Technical Communication Quarterly*, 23(4):303–322, 2014. doi: 10.1080/10572252.2014.942468 2

[30] A. Rind, M. Iber, and W. Aigner. Bridging the gap between sonification and visualization. In *Proc. AVI Workshop on Multimodal Interaction for Data Visualization (MultimodalVis)*, 2018. https://multimodalvis.github.io/papers/AVI_2018_paper_155.pdf. 3

[31] J. C. Roberts, P. Butcher, A. Sherlock, and S. Nason. Explanatory journeys: Visualising to understand and explain administrative justice paths of redress. *IEEE Transactions on Visualization and Computer Graphics*, 28(1):518–528, 2021. doi: 10.1109/tvcg.2021.3114818 2

[32] D. Scanlan. Structured flowcharts outperform pseudocode: an experimental comparison. *IEEE Software*, 6(5):28–36, Sept. 1989. doi: 10.1109/52.35587 2

[33] R. Schragis. Occupy wall street flowchart, 2011. https://www.rachelschragis.com/occupy. 2

[34] M. Sedlmair, M. Meyer, and T. Munzner. Design study methodology: Reflections from the trenches and the stacks. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2431–2440, 2012. doi: 10.1109/TVCG.2012.213 4

[35] E. Segel and J. Heer. Narrative visualization: Telling stories with data. *IEEE Transactions on Visualization and Computer Graphics*, 16(6):1139–1148, Nov/Dec 2010. doi: 10.1109/TVCG.2010.179 2, 9

[36] A. Siu, G. SH Kim, S. O'Modhrain, and S. Follmer. Supporting accessible data visualization through audio data narratives. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, pp. 1–19, 2022. doi: doi.org/10.1145/3491102.3517678 3

[37] A. Thudt, C. Perin, W. Willett, and S. Carpendale. Subjectivity in personal storytelling with visualization. *Information Design Journal*, 23(1):48–64, jul 2017. doi: 10.1075/idj.23.1.07thu 3

[38] J. Walny, S. Huron, C. Perin, T. Wun, R. Pusch, and S. Carpendale. Active reading of visualizations. *IEEE transactions on visualization and computer graphics*, 24(1):770–780, 2017. doi: 10.1109/TVCG.2017.2745958 2

[39] M. Whitelaw, S. Wassens, and A. Mackenzie. The sound of water: sensing a wetland intervention through interactive environmental audio. *cultural geographies*, p. 14744740231197813, 2023. doi: 10.1177/14744740231197813 3

[40] J. S. Yi, Y. ah Kang, J. Stasko, and J. A. Jacko. Toward a deeper understanding of the role of interaction in information visualization. *IEEE transactions on visualization and computer graphics*, 13(6):1224–1231, 2007. doi: 10.1109/TVCG.2007.70515 2