Eurographics Conference on Visualization (EuroVis) 2025
W. Aigner, N. Andrienko, and B. Wang
(Guest Editors)

COMPUTER GRAPHICS *forum*
Volume 44 (2025), Number 3

Instructional Comics for Self-Paced Learning of Data Visualization Tools and Concepts

M. Boucher[1,2], M. AlKadi[3], B. Bach[4] and W. Aigner[1,2]

[1]St. Pölten University of Applied Sciences, Austria, [2]TU Wien, Austria,
[3]University of Edinburgh, United Kingdom, [4]Inria, France

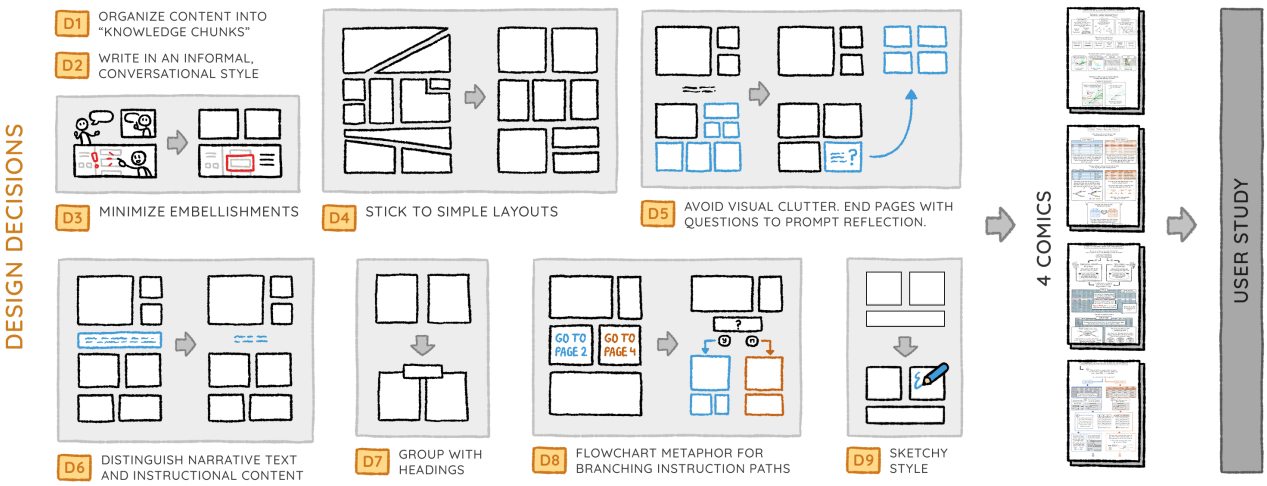

Figure 1: *An overview of the design decisions we made in the process of creating our set of four instructional comics before conducting a user study. Section 3.2 details the concepts we derived from literature and explains our reasoning behind the decisions.*

Abstract

In this paper, we introduce instructional comics to explain concepts and routines in data visualization tools. As tools for visual data exploration proliferate, there is a growing need for tailored training and onboarding demonstrating interfaces, concepts, and interactions. Building on recent research in visualization education, we detail our iterative process of designing instructional comics for four different types of instructional content. Through a mixed-method eye-tracking study involving 20 participants, we analyze how people engage with these comics when using a new visualization tool, and validate our design choices. We interpret observed behaviors as unique affordances of instructional comics, supporting their use during tasks and complementing traditional instructional methods like video tutorials and workshops, and formulate six guidelines to inform the design of future instructional comics for visualization.

CCS Concepts

• ***Human-centered computing*** → *Empirical studies in visualization;* • ***Social and professional topics*** → *Informal education;*

1. Introduction

Interactive software tools are essential for bringing the power of exploratory visualization to a broad audience. Various tools exist for visualization creation, interactive exploration, analysis, or storytelling [RSDB20]. However, like with any software, users must familiarize themselves with a tool's interface, features, and methodologies to form a mental model of its functionality. This includes understanding its visualizations, interactions, usage strategies, and more. As an example, interactive network exploration deals with complex data and diverse visualizations, such as matrices and timelines, and concerns users from varied domains such as history, archaeology, biology, or finance. Network visualization requires knowledge of network analysis, data formatting, and interpretation of diverse visual representations [ASSB*22, BMBH16]. Without proper onboarding—the process of training and guiding people through new tools [SGP*19]—powerful tools can fall short in gaining and retaining users: While newcomers need more explanations of higher-level visualization concepts and the interface, advanced users may need help recalling specific interactions, learning new features, or getting an overview of all available functions.

To support onboarding and guidance in visualization, there are many means catering to specific needs [SGP*19, LAC*23]. For example, hands-on workshops and individual tutoring can offer personalized support but are impractical for self-paced, informal learning. Textbooks cover general topics in depth but are often not tool-specific. User manuals, if available, can feel technical and text-heavy, making it difficult to quickly find relevant information. While video tutorials can help explain specific features, they often require patience to watch, are difficult to navigate for specific content, and are generally too fast to use alongside a tool without having to pause or rewind frequently.

Instructional materials and onboarding for visualization tools require a carefully crafted mix of visual explanations, textual guidance, and contextual cues to direct attention to key interface elements, illustrate interaction effects, and visually explain components of the highly data-driven UIs [SWG*ss]. Beyond UI widgets and interaction elements, users must also grasp fundamental data- and visualization-related concepts (e.g., data structures, chart types, and visual mappings), creating a broad set of interconnected knowledge prerequisites.

In this paper, we investigate **comics** for self-paced learning and onboarding to network visualization tools and concepts, aiming to offer a fresh, complementary alternative to the established instructional methods described above. There is strong evidence that static sequential images with text offer cognitive processing affordances that animated media do not [MHMC05], by making readers "fill in the blanks" between multiple static depictions, a notion also echoed in Scott McCloud's description of the comic medium [McC93].

Consequently, comics have a long history of being used in teaching [Tru21, MHSD21, Iss18], science communication [Mun23, Ico22, Wil22], and, most recently, to communicate features and use cases of new tools presented in scientific papers [KRHH23, PMCM23]. They have also already made appearances in the field of data visualization for data-driven *storytelling* [BRCP17] (see Section 2.2), but examples or studies on using them as instructional material for onboarding are still lacking. To determine if they are in principle a viable option for this purpose, we need to understand how the medium is used by learners and which reading and usage patterns occur. This led us to our research question **RQ:** *How do people engage with comics as an instructional medium, and can they effectively follow and understand the content while learning to use a visualization tool?* Our study makes a qualitative deep dive into design considerations, reading behavior, understanding, and qualitative user feedback.

This paper is structured to follow the steps we took to address this question: We first review related work to situate our research and carve out the distinction between data comics as an established genre and instructional comics in visualization (Section 2). Next, we classify the types of content that instructional comics can convey and outline the design process of four comics, explaining our design decisions which incorporate principles from instructional design and comic theory (Section 3). Then, we describe a mixed-method study with 20 participants (Section 4), using eye-tracking, think-aloud methods, semi-structured interviews, and observations. Participants read the comics and were tested to assess their comprehension. Our **hypothesis** was that comics can effectively convey each type of content we identified, with usage varying by context — for instance, we expected that a comic on procedural information would be more useful during a task than before.

Our results suggest instructional comics are indeed effective for helping to understand network data exploration. Additionally, our study revealed significant differences in reading behavior compared to studies on traditional entertainment comics. Finally, in Section 5, we discuss six guidelines derived from our findings on the design of instructional comics to support learning data visualization.

2. Related Work

2.1. Visualization Onboarding and Education

With the widespread use of visualization tools, it has become increasingly important to support users in adopting and making the most of them. This is the aim of visualization onboarding, which is defined as *"the process of supporting users in reading, interpreting, and extracting information from visual representations of data [in a visualization tool]"* [SGP*19]. Many approaches exist, such as step-by-step overlays, tutorial videos, interactive guided tours, or online manuals, all varying in whether they are embedded within the tool and whether onboarding occurs before or during usage [SWG*ss]. Some tools have even experimented with generating automated guided walkthroughs through data [LSSB*23].

However, effective onboarding involves more than just familiarizing users with where to click and how to interact with visualizations. Depending on the user's context, it may also include introducing fundamental visualization concepts to enhance their understanding of underlying principles [SWG*ss]. This extends into the area of visualization education, which has also recently seen increased interest in the community, as visible in dedicated education tracks [Eur24] and workshops [KHP*23] at visualization conferences. In this context, efforts have been made in measuring visualization literacy through tests [BRBF14, LKK17, GCK23] and in creating engaging and playful materials and activities [HA16, HCBF16, WDB19, BSK*24]. A key focus in this area, as highlighted in a recent paper addressing the grand challenges of data visualization education [BKR*23], is *Creating materials for informal and self-paced learning*.

The scope of contents in visualization education is broad; however, in this paper, we narrow our focus to network visualization as a use case. Unlike the interpretation of conventional business charts, the exploration of visual networks is not commonly taught throughout general education. At the same time, it is especially complex [ZMUB18]. Acquiring and effectively applying skills associated with network visualization exploration is a significant challenge and steep learning curve for users, during which they often encounter difficulties. AlKadi et al. [ASSB*22], for example, outline eight understanding barriers in network exploration, which emphasizes the need for guidance and tailored instructional approaches when facing these unique challenges (also see Section 3).

2.2. Comics and Data Visualization

Comics have been recognized for their ability to effectively communicate content through their unique combination of images and text, as well as their sequential nature of offering step-by-step explanations like a video, while leaving the pace of the content presentation to the reader [BBS*23], offering multiple points of contact with the field of data visualization. Data comics, as the most prominent example, make use of the spatial arrangement and narrative pacing in comics to tell stories about and guide readers through insights in data. Some use dialogues between characters acting in various scenarios (like some examples in [Dat]), others focus on breaking down complex facts, often not relying on characters at all (e.g., [BKH*16]). While the former evoke relatability and empathy [VDT*22, Far18], the latter prioritize a deeper understanding of factual details.

However, the relationship between comics and visualization extends beyond just data comics. While data comics represent just one approach to data-driven storytelling, the medium of comics offers numerous possibilities for visualization: For example, comic strips have been used to query temporal data [JS09] or to visualize data provenance [SS18]. More closely related to visualization education, comics have not only been looked at from the passive perspective, where people read and process their contents, but also from an active perspective, where people create their own comics as a way of processing or understanding data or concepts. For example, they have been used to support learning analytics [MAE*24], as a means for people to engage with and make sense of personal data [GOBK23], or as an activity to learn different data visualization techniques [BSK*24].

In the aforementioned examples, the main aim of comics is to *communicate insights and facts*. However, more recently, researchers have started to use comics for ***instructional*** purposes. For example, Visualization Cheat Sheets [WSMRB20] make use of comics to to explain the anatomy of visualization types, and some authors of scientific papers have adopted comics to present features or use cases of their presented tools (e.g., [KRHH23, PMCM23]).

2.3. Comics for Educational and Instructional Purposes

While many studies highlight the effectiveness of comics in education (see Section 1), targeted research on their teaching objectives and design implications remains sparse. Eisner [Eis08] classifies comics into two types: *entertainment-focused*, featuring fictional stories and engaging visuals, and *instructional*, emphasizing clear communication and process explanations. Within instructional comics, he distinguishes between *attitudinal* comics, which foster identification with a topic, and *technical* comics, which focus on explaining specific processes from a reader's perspective. Eisner also notes that while entertainment comics allow flexibility in narrative and visuals, instructional comics require precise organization of panels, speech bubbles, and text to clearly present information and engage readers, helping them bridge the gaps between panels through their experiences for deeper understanding.

Eisner's descriptions, however, leave specific design principles for instructional comics undefined, providing limited groundwork for creating own comics. Wessels-Compagnie [WC22] proposes 12 guidelines for translating academic information to comics, but acknowledges that the creation process requires many tacit skills. As a result, researchers creating educational comics are drawing insights from different disciplines such as information, web, or UX design [Fig11, WL20]. Similarly, we build on our team's experience as visualization designers, educators, and illustrators. It is important to note that this paper aims not to establish a definitive set of design guidelines, *but to investigate how instructional comics can communicate visualization knowledge* and assist in learning processes of digital tools.

3. Design Process

In this section, we describe our process and our decisions taken during the creation of four instructional comics for network visualization. Our process was iterative, consistently updating the content and designs by incorporating feedback from both experts and users, before moving on to our user study.

3.1. Defining the Content

As a representative tool for network visualization, we chose *The Vistorian* [SMBP*17, ASSB*22], an interactive tool for visualizing and exploring dynamic, multivariate, and geographic networks, which shares concepts and routines with other network visualization tools like Gephi [BHJ09] and NodeXL [SSMF*09]. It provides ten visualizations, all of which are highly interactive and can be manipulated through various features. Data must be uploaded in the form of tables following specific formatting rules. The Vistorian is representative of visual exploration tools but avoids overwhelming users with excessive features, making it well-suited for our study.

AlKadi et al. [ASSB*22] describe several understanding barriers novice analysts face when performing network exploration with the Vistorian. However, many of these challenges are unrelated to the tool itself: understanding the level of abstraction needed to set realistic exploration goals, modeling data into network abstractions like nodes and links, formatting data, selecting relevant items for exploration, importing data tables, assigning semantics to columns, or interpreting visual patterns in unfamiliar visualizations. Based on these barriers and our personal experience of teaching network visualization with the Vistorian, we created a list of questions that were often raised by learners, such as *What are nodes and links in a network? How do I prepare my data for visual exploration? What is the difference between entity (nodes) and relationship (links) in my data? What is the Vistorian and what can it do?* or *How do I upload my data to the Vistorian?*.

Using these questions as a basis, we investigated ways to structure the knowledge we wanted to convey through comics. As a first step, we referred to Bloom's Revised Taxonomy [AK01], a common framework in visualization education [KSK21]. However, since it focuses primarily on learning goals (the "what"), we found it too granular for organizing information in an onboarding context (the "how"). Hence, we examined classifications of knowledge in visualization onboarding and visual analytics: The model by Stoiber et al. [SGP*19], for example, describes domain, data, visual encoding, interaction, and analytical knowledge, while Federico et al. [FWR*17] distinguish between domain and operational knowledge and tacit and explicit knowledge. While both of these models served as valuable foundations, they were not perfectly tailored for structuring content in instructional comics.

Eventually, we analyzed how we as educators would answer each of the questions if they were asked by a student in a lecture. We created a list of *key points* we would explain, which was also informed by slide sets from an existing course on network visualization exploration with the Vistorian. We found that our answers would always either explain *a series of steps* to achieve a goal, or explain *general concepts*. Additionally, they were either *related to a specific tool*, or *generally applicable* in the domain of visualization. This led us to a more suitable approach of four categorical combinations that arise from the two orthogonal dimensions of tool-dependency and procedural nature:

TOOL-DEPENDENT vs. TOOL-INDEPENDENT: This distinction considers whether a piece of knowledge is specific to a particular visualization tool or universally applicable. Tool-dependent knowledge involves understanding how to perform tasks in a certain tool, such as creating a scatterplot in Tableau. On the other hand, tool-independent knowledge includes foundational concepts, such as knowing that a scatterplot uses positional encoding to show the relationship between two quantitative variables.

PROCEDURAL vs. NON-PROCEDURAL: This distinction refers to whether the knowledge is focused on a series of steps, or conceptual understanding. Procedural knowledge involves knowing how to accomplish a specific task, while non-procedural knowledge focuses on underlying concepts and principles of data visualization. Some examples of knowledge according to our categories are:

- TOOL-DEPENDENT + PROCEDURAL: *"How do I generate a Sankey diagram in Tableau using specific datasets?"*
- TOOL-DEPENDENT + NON-PROCEDURAL: *"Which kinds of data visualizations does Datawrapper support?"*
- TOOL-INDEPENDENT + PROCEDURAL: *"How do I normalize data before creating a data visualization?"*
- TOOL-INDEPENDENT + NON-PROCEDURAL: *"Which color palettes are suitable for quantitative variables?"*

This distinction enabled us to examine the advantages of instructional comics for both procedural (step-by-step, manual-like) explanations and non-procedural information. It also guides our understanding of the degree to which a comic should be specific (tool-dependent) or remain abstract about ideas (tool-independent) through the use of illustration and sketching.

3.2. Designing the Comics

For each comic, we followed the *four steps of designing data comics* described by Wang et al. [WDB19]. However, we anticipated some **design differences** between comics, such as tool-dependent content relying more on screenshots and requiring distinct panel sizes and layouts, or procedural and non-procedural

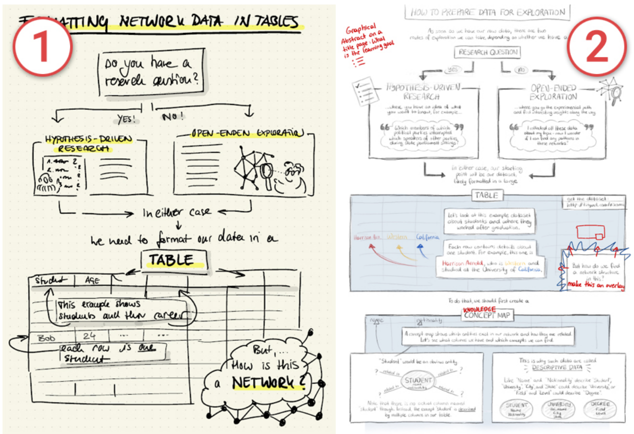

Figure 2: *The first two design stages of the comic "How to Prepare Data for Exploration". 1: A storyboard roughly showing where elements would be placed. 2: A first version of the same page, annotated with change instructions for the next iteration.*

comics differing in their use contexts. To explore these differences, we followed an iterative design process, refining our drafts at each step based on feedback from experts in teaching (network) visualization and comic illustration—similar to expert-based testing in interface design [Laz17].

In total, we created four comics (available in the supplementary material) on the following topics, representative of the four kinds of content described in 3.1. We refer to them as C1 - C4:

- **C1** (TOOL-DEPENDENT + NON-PROCEDURAL):
  What Can the Vistorian Do: A Feature Overview (3 pages)
- **C2** (TOOL-INDEPENDENT + NON-PROCEDURAL):
  Node Tables and Link Tables (2 pages)
- **C3** (TOOL-INDEPENDENT + PROCEDURAL):
  How to Prepare Data for Exploration (3 pages)
- **C4** (TOOL-DEPENDENT + PROCEDURAL):
  Uploading and Creating a Network with the Vistorian (4 pages)

We describe our process on the example of C3 - *"How to Prepare Data for Exploration"*. Along the way, we arrived at nine important design decisions (**D1**-**D9**), which are also visualized in Figure 1.

Step 1 – Define "Knowledge Chunks": Our first decision **D1** was to sort our lists of key points - our *main messages* [WDB19] - into easily digestible sequential segments. The significance of breaking down causal chains into smaller understandable points is emphasized by advocates of instructional design and helps prevent excessive cognitive processing, especially when introducing multiple interrelated concepts [CM16]. We further categorized our key points into main and sub-points, essentially forming "mini-chapters". For example, "How to form networks from the data" would be a main point, with the sub points "How to identify entities relevant to the research question", "Ways of mapping entities in the visualization" and "Why some mappings are better than others".

Step 2 – Write Scripts: In a second step, we wrote scripts for each comic, similar to those written for videos or stage plays, where

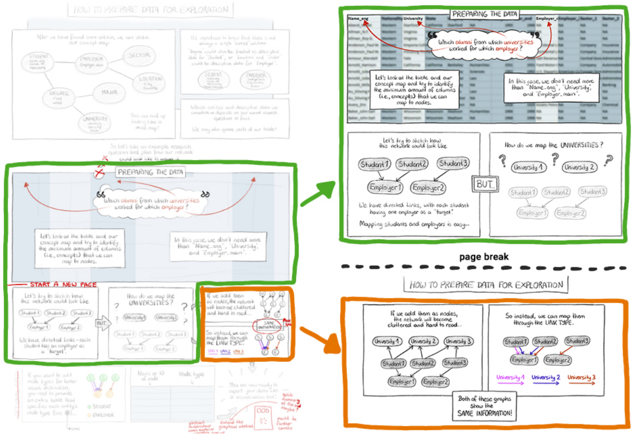

Figure 3: *Left side: The first version of the comic C3 was limited to two pages. Right side: Upon reconsideration of the logical segmenting and the cognitive load of the contents, we decided to split them and add another page, ending the page with a question to the reader before expanding the answer on the next page.*

we faced the question of the *tone and style* of the text. Traditional manuals generally adhere to formal step-by-step descriptions, however, in their work on instructional design principles, Clark and Mayer [CM16] argue that a conversational style triggers a social response in the reader and activates deeper cognitive processes, leading to a better learning outcome. Since a more personal tone and directly addressing the reader is customary in comics as well, we also opted for a conversational style (**D2**).

Step 3 – Storyboard: In the third phase, we developed storyboards (see Figure 2). While closely following our scripts for a seamless narrative, we sketched various panel compositions on scrap paper before aligning text, placeholders, and images in panels. For the "pacing", i.e., determining how many panels to dedicate to an explanation, we considered the natural flow of a lecture. We reviewed where pauses in speech would occur to allow time for reflection or emphasis. Similarly, when we would point to specific elements on a slide or interface during a lecture, we mirrored this by using multiple panels to "zoom in" on them while blending out the surroundings, a technique referred to as "greying out" in [WC22]. This phase contained two to three iterations for every comic, and encompassed a few important choices:

First, we chose to minimize decorative images in our instructional comics. While visual embellishments can enhance engagement and memorability in data visualizations [BMG*10], they also increase the risk of problematic metaphors in educational comics, potentially supporting misleading perceptions [WC22]. Wessels-Compagnie [WC22] further notes that readers generally approach comics with the expectation of being entertained, and that deliberately adding emotive content can reinforce this notion, leading readers to take the comic less seriously. Although her observations do not refer to the concept of characters as a whole, we have seen that (data) comics can be effective even without characters [BKH*16]. This is why we made the decision **D3** not to use characters to avoid distractions from the instructions and instead emphasize screenshots and visualizations, strengthening the connection between the comics, their usage context, and the tool itself.

Second, users of the Vistorian are both students and professionals and come from very different backgrounds, leading to highly varying levels of comic affinity among our comics' audience. For this reason, we aimed to keep the panel layout as simple as possible to avoid confusion. For example, an eye-tracking study by Kirtley et al. [KMVT23] identifies that panel blockages (panels that disrupt the customary reading path) and panels with corner angles different than 90° are common sources of confusion. This constituted decision **D4** visible in Figure 1. Applying the Gestalt principle of proximity, we then visually placed panels explaining each main point and its sub points, i.e., the "knowledge chunks", closer together, creating self-contained panel groups.

However, we faced a challenge when we attempted to connect these "knowledge chunks". In our script, they were ordered along the narrative, one chunk after another, linked through non-descriptive text. Incorporating this purely narrative text into the panel groups made it difficult to immediately see important information. Hence, we used a technique known as "bleeding", where content extends beyond panel boundaries into the surrounding space. In traditional comics, it is often used when a piece of text carries a message of special significance, where it adds both visual and narrative weight to the composition [McC93]. This resulted in a layout enabling readers to either follow a guided narrative or just quickly reference key information within a self-contained knowledge chunk, which formed our decision **D5** in Figure 1.

Next, we anticipated that learners would need to closely compare panels to grasp certain concepts. For instance, on the third page of C3 (see bottom right of Figure 3), two panels depict the same networks with different data mappings, requiring multiple comparisons. To highlight connections between such panels, we used overlapping text boxes with headings or keywords at the top or bottom. This decision forms design decision **D6** in Figure 1, particularly important in PROCEDURAL comics illustrating states like before-and-after interactions.

Overall, the panel layout of most comics changed little across iterations. However, in the second iteration of C3 - "How to Prepare Data for Exploration", we found the final point required a high cognitive load. To address this, we allocated more space by splitting the panels and adding a page (see **D7** in Figure 1 and Figure 3).

Lastly, storyboarding C4 (tool-dependent + procedural) revealed challenges due to the fact that the described process depended on the type of data users upload. While "Choose Your Own Adventure" comics, for example, allow for conditional storylines by prompting readers to flip to certain pages, this approach felt cumbersome. Instead, inspired by infographics which often use conceptual metaphors [PIB*24], we incorporated questions into the comic. For example, a panel might ask, "Do you know how to export your data as a .CSV file?". Following "yes" skips to the next step, while "no" leads to export instructions, before the paths converge again. While traditional comics rarely use visual elements like arrows to determine reading order, we added them to guide readers through branching paths and to support skipping steps. Additionally, we colored the two main paths of the Vistorian's upload process and

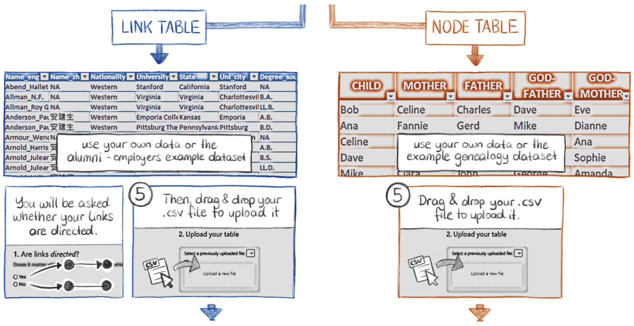

Figure 4: *An excerpt from the comic C4: "Uploading Data and Creating a Network Schema with the Vistorian", showing the split into separate instruction branches depending on the reader's situation. See the supplementary material for the full comic.*

presented them side by side to maintain the overview (see Figure 4 and decision (**D8** in Figure 1).

Step 4 – Final Layout and Design: Initially, we planned to create clean, vector-style comics using Figma, but two issues led us to reconsider. Firstly, Wood et al. [WII*12] show that sketchy styles lower the participation barrier. Secondly, the vectorized borders and computer fonts blended with the many software screenshots, while hand-drawn annotations contrasted well (see, e.g., Figure 3). This formed decision **D9** in Figure 1 The final comics were drawn on a 7th Generation iPad using Procreate.

Before moving on to the user study, we informally presented the comics to participants of a network visualization course. The response was very positive; learners found the comics engaging and even asked for additional comics on other course aspects. No changes were requested, but decision **D5** of moving some content on another page had an unexpected benefit: The first page now ended on a question and prompted readers to pause and reflect before turning the page, which was emphasized by almost every participant and also mentioned in other studies [WC22].

4. User Study

Addressing our research question **RQ** as well as validating the design decisions we took during our process required in-depth insights into actual reading behavior. While Wang et al. [WWF*19] propose having readers trace their paths with a pencil, this method is unsuitable for capturing rapid scanning or brief "look-aheads" [KMVT23]. For instance, validating design decision **D7** required observing if, and how much, participants compared panels, leading to our choice of using eye-tracking. It would also offer valuable data for design decisions **D6** and **D8** and allowed us to test our hypothesis that comic usage would vary with the type of knowledge conveyed (see Section 3).

Additionally, we assessed participants' comprehension of the comics' content through multiple-choice questions and practical assignments. To understand their thought processes, we asked them to think aloud. We also conducted short semi-structured interviews for qualitative feedback at the end, and noted significant observations during the study.

#	Questions for Comics
C1	Which visualization is not supported by the Vistorian?
	What is the technique where two or more visualizations are fully linked to be explored side by side?
C2	[image] Is this table a Node Table or a Link Table?
	[image] Is this table a Node Table or a Link Table?
C3	What is the purpose of a Concept Map?
	A Concept Map has visual similarities with...?

Table 1: *After reading each comic C1, C2, and C3, participants were asked the questions in this table. They were multiple choice and had four or five possible answers, except for those of C2.*

4.1. Participants

We recruited 20 participants via university mailing lists, including 7 female, 9 male, 3 non-binary individuals, and 1 person who preferred not to disclose their gender. The group included 8 employees from St. Pölten University of Applied Sciences with an HCI or data visualization background, 1 employee and 2 external participants without technical backgrounds, and 9 students or alumni from computer science related programs. The participants' age distribution was 18-24 (6), 25-34 (10), 35-44 (3), and 55-64 (1). All participants had normal or corrected-to-normal vision. We asked them to rate their experiences with relevant topics on a 5-step Likert scale (1 = low, 5 = high), which they reported as follows: Comics: 1 5 (Median: 3, Standard Deviation: 1.41), Spreadsheet Software 1 5 (M: 3.2, SD: 1.24), and Network Data Visualization: 1 5 (M: 2.25, SD: 1.21). Only one participant had used the Vistorian before, and another was familiar with the "Marie Boucher Dataset" used in the study.

4.2. Procedure

The study took place in the usability lab of the St. Pölten University of Applied Sciences in June 2023. Participants provided written consent for audio, video, and eye-tracking recordings, handled per GDPR regulations. Data was stored locally during the study, then archived on an external hard drive and deleted from the lab PC. The software used was iMotions 9.3 with a Tobii Pro Nano Eye Tracker.

Phase 1 - Reading Paths & Understanding: After eye-tracking calibration, participants viewed each comic page separately on a 25-inch high-resolution monitor in the following order: C1: Feature Overview, C2: Node and Link Tables, C3: Data Preparation, and C4: Uploading Data. The fixed order was due to the fact that each comic's content built upon the prior one. Participants announced when they finished reading a page, and we would display the next page without scrolling to maintain accurate eye-tracking data. After Comics C1 - C3, we displayed a questionnaire with two questions (see Table 1) alongside a scrollable version of the comic for reference. After C4, we moved on to Phase 2 instead. Eye-tracking data was continuously recorded in both phases.

Phase 2 - Exercise: After reading all comics, participants were presented with a practical task involving exporting a dataset as a

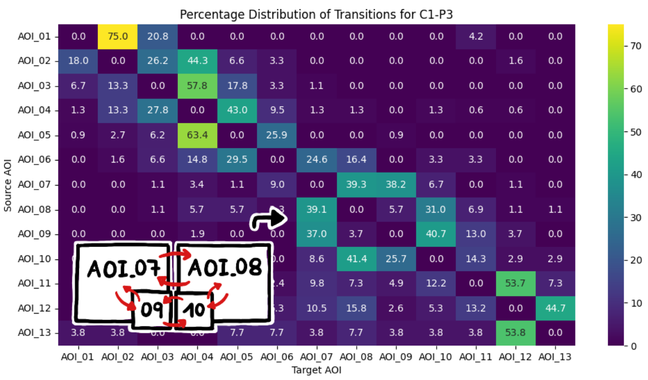

Figure 5: *A matrix visualization of the percentage of transitions between panels on page C1-P3. We can see a clear progression from AOI_01 to AOI_02, a regression from AOI_05 to AOI_04, and a loop around AOI_07 to AOI_10, which prompted more detailed comparison. Figure 6 shows the corresponding comic page.*

.CSV file from Excel, uploading it to the Vistorian, creating a Node-Link diagram, and searching for two insights: 1) Who had the most finance-related connections to Marie Boucher, and 2) Which person other than Marie Boucher had the most work-related connections. During the task, the screen was split, with the Vistorian on the right and a PDF reader with all four comics for reference on the left. Participants described their thought process aloud so we could understand their reasoning. Each participant's session concluded with feedback on the comics, guided by questions on what was unclear and what they especially liked. All sessions lasted 35–45 minutes.

4.3. Data Analysis

After the study, we manually highlighted areas of interest (AOIs) on each comic page so the software could render the eye-tracking metrics such as participants' dwell time, number of fixations, or revisit count. Generally, we treated each panel, heading, and panel-less text as one AOI, except in the very large panels of the comics C2 and C3, whose content we divided into multiple AOIs to obtain a more granular reading path.

To determine participants' average reading paths through each comic page, we extracted transition matrices from iMotions and converted them into pairwise transition tables with a Python Jupyter Notebook. For each AOI, we identified the next AOI with the most transitions, forming a chain. In cases of loops (e.g., AOI7 to AOI8 and back), we checked which AOI had the second most transitions and continued the process from there. We also created matrix visualizations of transition percentages (see Figure 5) to cross-verifiy the results visually, and manually annotated the comic pages with the reading paths, loops, and average dwell times on each AOI (see Figure 6). We then analyzed the average dwell time (marked in green on the annotated comics) and fixation counts to identify which panels required more time to understand. To verify loops in reading paths, we examined AOI revisits, with frequent revisits indicating panels that were often compared or referenced. Links to all interactive visualizations and annotated comics are included in the supplemental material.

We were also interested in how often and at which steps participants referred back to a comic during the practical exercise. For this, we divided the exercise into 18 steps (e.g., "Export CSV from Excel", "Create new network", "Find upload field"), allowing us to track whether participants completed or failed each step [TA13]. Using screen recordings with eye-tracking overlays, we manually counted how often participants paused to consult a comic, noting the frequency per task, participant, and comic. Additionally, we gathered statistics on the comics themselves, such as panel and word counts inside and outside panels, and the average words per panel, while also qualitatively analyzing the instructor's notes on participants' remarks.

4.4. Findings from the User Study

F1 – Participants understood explained concepts: The multiple-choice answers in Phase 1 indicate that the comics conveyed the content clearly: participants answered 96.67% of questions correctly (4/120 incorrect). In Phase 2, 16/20 participants successfully identified both target individuals in the visualized network, while 4 identified one correctly (90% correctness overall). However, think-aloud comments showed that these participants still followed the correct approach, identifying individuals with similar traits (e.g., the second or third most connections). This suggests all participants understood the information conveyed by the comics.

F2 – Images guide the reading path: Across all 12 comic pages, participants carefully studied the contents of all panels. Only one single panel in Comic 1, Page 1 (C1-P1) was often skipped initially and then revisited from the surrounding panels. This panel, one of three explaining different types of data, contained more text and lacked the larger images found in the others. We suspect that the absence of a prominent visual element led participants to gravitate toward the more image-heavy neighboring panels first, which is expected behavior in such a visually driven medium like comics.

F3 – Frequent panel comparisons for understanding: Participants frequently paused to compare panels, creating more *reading loops* than we anticipated. Figure 6 highlights examples in C1 (tool-dependent & non-procedural). At (1), panels merely intended as examples of different network structures caused unexpected significant loops, suggesting that participants were interested in studying the visual differences of clusters and highly connected nodes. Conversely, the loop at (2) aligned with our predictions, as the panels showed a before and after interaction state affording a closer comparison. At (3), another smaller unexpected loop involving logos likely reflected curiosity about the organizations behind the content. While regressions are common in entertainment comics, accounting for 35%-37% of transitions [FWC16, KMVT23], our study showed significantly higher rates (43% on average, ranging from 37.7%-48.4%; see Figure 5), indicating that instructional comics encourage more revisiting, comparison, and engagement.

Additionally, transition data revealed that the first few panels of a comic typically connected to only a few other panels, while later panels linked to a broader array; a pattern we observed at both page and comic level. To verify this, we calculated a Shannon entropy for each panel, where higher values indicate more connections [KSDK14]. Given the comics' varying panel counts, we also

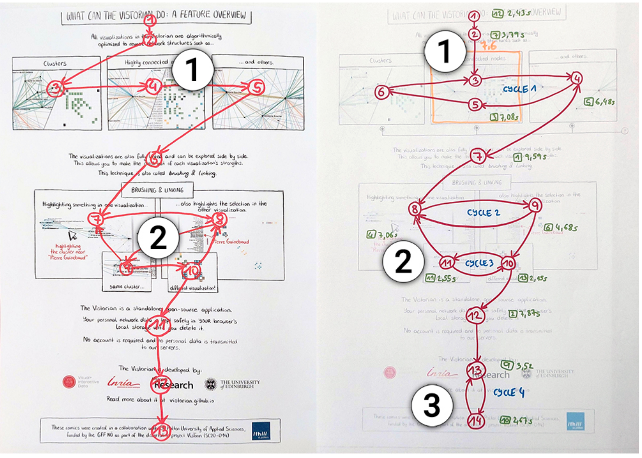

Figure 6: *Reading paths in C1-P3 – Left: The path we had intended readers to follow with our layout. Right: Readers' actual reading path, which exhibits more loops than we had anticipated.*

calculated mean entropy for each quarter of a comic: In the first quarter, transition numbers were rather uniform (H=1.82). From the second quarter onward, the number of transitions increased (Q2: H=2.23, Q3: H=2.16, Q4: H=2.24), suggesting participants were more likely to "trail off" while searching for or comparing content. While loops and high entropy could indicate understanding difficulties, comics' flexibility for self-paced comprehension - especially making comparisons across pages - is unmatched by traditional methods like manuals or videos. Therefore, we see these loops as a strong indicator of comics' suitability for instructions.

F4 – Participants used photographic recall to revisit information: While answering multiple-choice questions in Phase 1, most participants relied on memory and only referred back to the comics to confirm their answers before submitting. Eye-tracking data revealed that they used photographic recall, scrolling to the location where they remembered the relevant information, progressively narrowing down their scanning paths. This suggests participants had formed a mental map of the comic, echoing findings from a previous study on data comics [WWF*19]. Additionally, four participants mentioned in the interviews that the comic's organization into "chunks" helped them use these grouped panels as visual anchors during searches.

F5 – Procedural comics were only skimmed outside of the practical task: We hypothesized that comics with different types of content might prompt distinct usage patterns. In Phase 1, while reading C4 (procedural & tool-dependent, see Figure 4), four participants made remarks like *"Do I have to read this in detail now?" (P3)* and *"I guess I cannot try that right now" (P7)*, suggesting they were only skimming content with less intent of in-depth-understanding. We verified this by calculating the dwell time per word in each comic as a measure for the reading speed (see Table 2). We found that procedural comics had a lower dwell time per word, suggesting a lower level of concentration compared to non-procedural ones. At the same time, dwell times also decreased with each comic, so a general attention decline cannot be ruled out as a factor. During Phase 2, however, C4 (procedural & tool-dependent) was revisited more than any other comic, having been used in 138 tasks (38%) across all participants. The reading paths in C4 also differed between Phases 1 and 2. In Phase 2, participants followed the colored paths relevant for their current situation and ignored the others, while in Phase 1, they attempted to read the whole comic at once. Eye-tracking data also showed no consensus on the "correct" reading order in Phase 1, reinforcing our idea that procedural comics would be more useful during the task itself. We consider this finding a strong indicator of the effectiveness of procedural instructional comics in supporting hands-on tasks.

#	Knowledge Type		Pages	DTpW
C1	tool-dependent	non-procedural	3	470.6
C2	tool-independent	non-procedural	2	407.0
C3	tool-independent	procedural	3	379.5
C4	tool-dependent	procedural	4	281.3

Table 2: *Dwell Time per Word (DTpW), measured in milliseconds, for each comic in comparison to page number and knowledge type.*

F6 – Addressing the reader is especially engaging: A part of C3 explained how to map tabular data to a network structure and ended with a question directly testing the reader's understanding and application of the respective information (*"But, how do we map the universities?"*, see Figure 3). Of the 20 participants, 15 clearly expressed positive surprise when the question was resolved on the following page, making comments such as *"Oh, that's really clever!" (P2)*. This effect is similar to how teachers use direct questions to check students' understanding. It can also be used to pause the reader, prompt them to revisit previous panels (see F3, F4), or prepare them for upcoming instructions, interactions, or explanations.

5. Discussion

Our findings (F1-F6) indicate that instructional comics are a highly understandable medium for communicating both tool-dependent and tool-independent, as well as procedural and non-procedural information (F1). We did not find major differences between these four types, except that procedural comics were most effective during actual tasks (F5). We attribute this effectiveness to several factors: First, the concise combination of paced visual annotations (F2) makes it easier to follow the presented information. Additional qualitative feedback shows that readers found our comics 'especially engaging' and 'helpful' for explaining new concepts step-by-step. Second, the ability to easily compare information across panels or pages (F3); and lastly, how comics allow readers to rapidly revisit and revise information through mental maps of the visual content (F4). While directly addressing readers (F6) is not a technique specific to instructional comics, it can amplify these advantages.

5.1. Implications and Guidelines

Our findings also suggest that our design decisions in Section 3.2 were effective in bringing out the strengths of the medium. In this section, we discuss how these insights can further inform the design

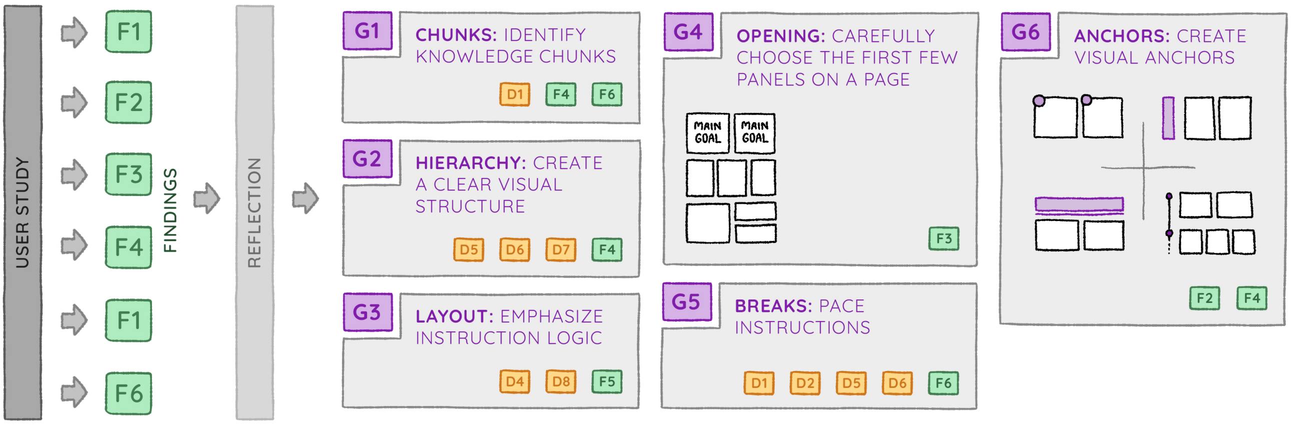

Figure 7: *An overview of the guidelines derived from validating our design decisions, as depicted in Figure 1. Each guideline is linked to the design decisions (D) and findings (F) it is based on. Section 5.1 provides a detailed explanation of each guideline.*

of instructional comics for explaining data visualization concepts and instructions. To that end, we propose six preliminary guidelines (G1–G6) for supporting understanding processes in data visualization (see Figure 7). While this set is not definitive, it represents an initial step toward generalizing design principles in this context.

G1—CHUNKS: Identify knowledge chunks. We define a "knowledge chunk" as a particular independent piece of information conveyed in a comic, such as a feature overview, a description of an interaction, or explanations of a visual encoding. Chunks determine the narrative pacing of a series of explanations and serve as "chapters" that guide readers not only in understanding, but also in locating and revisiting information in the comic (F4). They can be used for assessing understanding, e.g., through reflexive questions (F6). Chunks can be procedural or non-procedural, tool-dependent or tool-independent. Procedural information may impact panel layout and page structure differently than non-procedural information, as the former requires more comparisons or diverging paths. Tool-dependent information may require additional space due to large and potentially detailed screenshots.

G2—HIERARCHY: Create a clear visual hierarchical structure. Comics offer various ways to structure content visually; through pages, panel groups, individual panels with sub-panels, boxes and speech balloons, and chapters or individual comics. In instructional comics, visual hierarchy helps readers understand which information belongs together, judge the length of a series of instructions, and quickly retrieve specific details by enabling readers to form a mental map and employ searching strategies like we saw in our study (F4). Visual hierarchy can be emphasized by adjusting spacing between panels, aligning them on grids, separating instructional from guiding text (Figure 1-**D5**), moving content to different pages (Figure 1-**D6**, or using headlines (Figure 1-**D7**).

G3—LAYOUT: Use layout to emphasize instruction logic. Comics' layouts should accommodate the needs of different types of conveyed information, which users reference in distinct ways (see F5). For example, procedural information may follow a single path or involve forking decisions, alternative routes, or iteration cycles. The spatial structure of panels allows comics to easily adopt either an open or constrained panel layout [BWF*18] to illustrate the flow of a procedure. For non-procedural information, parallel panels, overview panels, or schemas can put information into context. However, these layouts should be kept as simple as possible, favoring the traditional Z-shaped reading path [Coh13] (Figure 1-**D4**), simple panel shapes, and clearly indicated diverging paths (Figure 1-**D8**). In the first three panels of Figure 6, most readers started with the center panel before moving to the neighboring ones. However, this was not an issue, as the information was non-procedural and the three panels were not intended for sequential reading but meant as independent information.

G4—OPENING: Carefully choose the first few panels of a page. Readers tend to give the first few panels of a comic page more focused attention before shifting to a more exploratory reading approach (F3). It is therefore beneficial to place key instructions or important concepts at the start of the page, outlining what the reader can expect and if they should continue reading. For instance, if the comic describes a procedure, it is helpful to provide a preview of the outcome or abbreviated version of the complexity of the procedure. If it offers a tool overview, one could begin with representative key features or results (see Figure 7-**G4**).

G5—BREAKS: Pace instructions. Use comics' inherent narrative and conversational style to guide the reader (e.g., Figure 1-**D1**, **D2**, **D5**, **D6**). In our study, we found that questions introduce breaks and reflection points which refresh attention, foster engagement, and structure content (F6). In procedural comics, they can also prompt readers to complete a task, such as uploading data or performing an interaction, before continuing.

G6—ANCHORS: Create visual anchors. While we did not explicitly study different visual anchors in our study, the reading and navigation behavior we observed suggests that they would be highly beneficial to facilitate the parallel use of comics during practical tasks. For example, images in panel corners could leverage that people are drawn to images (F2), and color-coded heading boxes or even a timeline with icons along the edge of a page could support readers building mental maps of the comic (F4) (Figure 1-**G6**).

5.2. Limitations & Future Work

Our study is the first to investigate instructional comics for data visualization. We chose a qualitative reading study to explore this promising medium and to assess whether these comics are both readable and informative, as well as how readers engage with instructions and information in comic form. Our study complements existing research on comic layouts and reading strategies [Coh13, KMVT23], extending the investigation into the specific context of visualization instructions. While we used the Vistorian as a concrete use case, we believe our findings extend beyond this specific tool. Just as established onboarding techniques apply across different software, our guidelines focus on the unique affordances of comics to communicate the different types of knowledge associated with visualization tools.

Future studies should examine the use of instructional comics in real-world settings, such as classrooms and workshops as well as (novice) analysts using tools for their actual analyses, rather than in a lab environment. This could provide insights into how people use instructional comics over an extended period, how much knowledge they retain, whether personal annotations on printed comics could aid understanding and memory, and how instructional comics compare to other onboarding methods and media. Most participants of our study, while novices in network data visualization, still had a technical background. While we are confident that our idea is generalizable, more diverse backgrounds might raise challenges we have not encountered. Our work also opens up further questions about using instructional comics for explaining visualization tools, processes, and concepts:

How to extend and improve instructional comics? Although our comics focus on a single network visualization tool, we believe that our considerations of knowledge and content types, design decisions, findings, and guidelines are broadly applicable. Similar types of information, such as explaining interactions, user interfaces, or providing feature overviews, are relevant in any interactive visualization analysis tool and possibly in visualization authoring tools as well. However, comics for visualization authoring tools may also need to address topics like best design practices and user-centered design research; a promising avenue for future research.

Likewise, while our study and guidelines focus on static comics, animated media have strong engaging factors [MHMC05] and may outperform static media in certain contexts [AGR24]. We see potential for media-transcending comics that combine the cognitive benefits of static images and text with the engaging qualities of animation, particularly for demonstrating user interface routines.

What visualization concepts are people generally missing, and which do they struggle with? There is still limited understanding of how people learn visualization [BKR*23,ASSB*22] and how we define novice users [BLC*23]. By examining instructional comics from the perspective of people with no prior visualization knowledge, we can observe which learning strategies, such as scaffolding, learning by analogy, or concreteness fading [SWG*ss], work well when encountering unfamiliar foundations.

How can we integrate instructional comics for onboarding and guidance directly into tools? Introducing interactivity to instructional comics [WRC*22] could not only provide details on demand but also bridge the gap between comics and the tools they describe. Integrated directly into a tool's interface, comics could offer in-situ guidance for tasks, such as explaining general features [CYC*23] or visual patterns in visualization [SPT*24]. In this context, questions about personalization and tailoring comics to match specific tasks, tools, environments, and user skill levels remain open. Future research could build on studies of explorable explanations [Bre11], exploranations [YLT18], and various onboarding methods [SWG*ss, SWG*21]. We can also envision authoring tools for instructional comics that could, for example, export screenshots and routines directly from a visualization tool, potentially in a (semi-)automated manner.

6. Conclusion

In this paper, we introduced and studied the concept of instructional comics for data visualization. We created four comics and detailed our design rationale, drawing from comic theory and instructional design. We categorized knowledge in visualization into four categories that served as a framework for the content and structure of our comics. In a comprehensive mixed-method study, we validated our design decisions and deduced six preliminary guidelines for the design of instructional comics. We uncovered findings into how readers read and use this novel format and how the behavior differs from other comic formats. The consistently high correctness rates and positive qualitative feedback reinforce the effectiveness of instructional comics in visualization education. We aim for our research to pave the way for further exploration and utilization of the medium of instructional comics and to open avenues for future research in this emerging field.

Acknowledgements

This work was funded by the Austrian Science Fund as part of the Vis4Schools project (10.55776/I5622), by the GFF NÖ as part of the dissertation project VisToon (SC20-014), as well as by the Austrian Federal Ministry of Labour and Economy, the National Foundation for Research, Technology and Development, and the Christian Doppler Research Association. For the purpose of open access, the author has applied a CC BY public copyright license to any Author Accepted Manuscript version arising from this submission.

References

[AGR24] AMABILI L., GRÖLLER M. E., RAIDOU R. G.: Show Me the GIFference! Using data-GIFs as Educational Tools. In *WSCG 2024 Proceedings* (2024). doi:10.24132/CSRN.3401.7. 10

[AK01] ANDERSON L. W., KRATHWOHL D. R. (Eds.): *A Taxonomy for Learning, Teaching, and Assessing. A Revision of Bloom's Taxonomy of Educational Objectives*, 2 ed. Allyn & Bacon, New York, 2001. 3

[ASSB*22] ALKADI M., SERRANO V., SCOTT-BROWN J., PLAISANT C., FEKETE J.-D., HINRICHS U., BACH B.: Understanding barriers to network exploration with visualization: A report from the trenches. *IEEE TVCG* (2022), 1–11. doi:10.1109/TVCG.2022.3209487. 2, 3, 10

[BBS*23] BOUCHER M., BACH B., STOIBER C., WANG Z., AIGNER W.: Educational Data Comics: What can Comics do for Education in Visualization? In *EduVis Workshop* (Melbourne, Australia, Oct. 2023), IEEE, pp. 34–40. doi:10.1109/EduVis60792.2023.00012. 3

[BHJ09] Bastian M., Heymann S., Jacomy M.: Gephi: an open source software for exploring and manipulating networks. In *Proc. of the international AAAI conference on web and social media* (2009), vol. 3, pp. 361–362. 3

[BKH*16] Bach B., Kerracher N., Hall K. W., Carpendale S., Kennedy J., Henry Riche N.: Telling stories about dynamic networks with graph comics. In *Proc. of CHI 2016* (NY, USA, 2016), ACM, p. 3670–3682. doi:10.1145/2858036.2858387. 3, 5

[BKR*23] Bach B., Keck M., Rajabiyazdi F., Losev T., Meirelles I., Dykes J., Laramee R. S., AlKadi M., Stoiber C., Huron S., Perin C., Morais L., Aigner W., Kosminsky D., Boucher M., Knudsen S., Manataki A., Aerts J., Hinrichs U., Roberts J. C., Carpendale S.: Challenges and Opportunities in Data Visualization Education: A Call to Action. *IEEE TVCG* (2023), 1–12. doi:10.1109/TVCG.2023.3327378. 2, 10

[BLC*23] Burns A., Lee C., Chawla R., Peck E., Mahyar N.: Who do we mean when we talk about visualization novices? In *Proc. of CHI 2023* (2023), pp. 1–16. 10

[BMBH16] Börner K., Maltese A., Balliet R. N., Heimlich J.: Investigating aspects of data visualization literacy using 20 information visualizations and 273 science museum visitors. *Information Visualization 15*, 3 (2016), 198–213. 2

[BMG*10] Bateman S., Mandryk R. L., Gutwin C., Genest A., McDine D., Brooks C.: Useful junk? the effects of visual embellishment on comprehension and memorability of charts. In *Proc. of CHI 2010* (NY, USA, 2010), ACM, p. 2573–2582. doi:10.1145/1753326.1753716. 5

[BRBF14] Boy J., Rensink R. A., Bertini E., Fekete J.-D.: A principled way of assessing visualization literacy. *IEEE TVCG* (2014), 1963–1972. 2

[BRCP17] Bach B., Riche N. H., Carpendale S., Pfister H.: The emerging genre of data comics. *IEEE CG&A 37*, 3 (2017), 6–13. doi:10.1109/MCG.2017.33. 2

[Bre11] Bret V.: Explorable Explanations, 2011. Accessed: 2024-09-07. URL: https://worrydream.com/ExplorableExplanations/. 10

[BSK*24] Boucher M., Stoiber C., Keck M., De-Jesus-Oliveira V.-A., Aigner W.: The comic construction kit: An activity for students to learn and explain data visualizations. In *Proc. of IEEE VIS 2024* (St. Pete Beach, Florida, 2024). 2, 3

[BWF*18] Bach B., Wang Z., Farinella M., Murray-Rust D., Henry Riche N.: Design patterns for data comics. In *Proc of CHI 2018* (NY, USA, 2018), ACM. URL: https://doi.org/10.1145/3173574.3173612. 9

[CM16] Clark R. C., Mayer R.: *e-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning*, 1 ed. Wiley, Mar. 2016. doi:10.1002/9781119239086. 4, 5

[Coh13] Cohn N.: Navigating comics: An empirical and theoretical approach to strategies of reading comic page layouts. *Frontiers in Psychology 4* (2013). URL: https://www.frontiersin.org/articles/10.3389/fpsyg.2013.00186. 9, 10

[CYC*23] Chundury P., Yalçin M. A., Crabtree J., Mahurkar A., Shulman L. M., Elmqvist N.: Contextual in situ help for visual data interfaces. *Information Visualization 22*, 1 (2023), 69–84. 10

[Dat] Data comics gallery. https://datacomics.github.io/. Accessed: 2023-11-20. 3

[Eis08] Eisner W.: *Comics and sequential art: principles and practices from the legendary cartoonist*. The Will Eisner library. W.W. Norton, New York, 2008. 3

[Eur24] Eurovis 2024 education track collection, 2024. Eurographics Digital Library. URL: https://diglib.eg.org/handle/10.2312/3607002. 2

[Far18] Farinella M.: The potential of comics in science communication. *Journal of Science Communication 17*, 01 (2018), 0. URL: https://jcom.sissa.it/archive/17/01/JCOM_1701_2018_Y01. 3

[Fig11] Figueiredo S.: Building Worlds for an Interactive Experience: Selecting, Organizing, and Showing Worlds of Information Through Comics. *Journal of Visual Literacy 30*, 1 (2011). doi:10.1080/23796529.2011.11674686. 3

[FWC16] Foulsham T., Wybrow D., Cohn N.: Reading without words: Eye movements in the comprehension of comic strips. *Applied Cognitive Psychology 30*, 4 (July 2016), 566–579. URL: https://onlinelibrary.wiley.com/doi/10.1002/acp.3229, doi:10.1002/acp.3229. 7

[FWR*17] Federico P., Wagner M., Rind A., Amor-Amoros A., Miksch S., Aigner W.: The role of explicit knowledge: A conceptual model of knowledge-assisted visual analytics. In *2017 IEEE VAST Conference* (Phoenix, AZ, Oct 2017), IEEE, p. 92–103. doi:10.1109/VAST.2017.8585498. 4

[GCK23] Ge L. W., Cui Y., Kay M.: Calvi: Critical thinking assessment for literacy in visualizations. In *Proc. of CHI 2023* (New York, NY, USA, Apr. 2023), ACM, p. 1–18. doi:10.1145/3544548.3581406. 2

[GOBK23] Gómez Ortega A., Bourgeois J., Kortuem G.: Personal Data Comics: A Data Storytelling Approach Supporting Personal Data Literacy. In *Proc. of CLIHC 2023* (Puebla Mexico, Oct. 2023), ACM, pp. 1–8. doi:10.1145/3630970.3630982. 3

[HA16] He S., Adar E.: Vizit cards: A card-based toolkit for infovis design education. *IEEE TVCG 23*, 1 (2016), 561–570. doi:10.1109/TVCG.2016.2599338. 2

[HCBF16] Huron S., Carpendale S., Boy J., Fekete J.-D.: Using viskit: A manual for running a constructive visualization workshop. In *Pedagogy of Data Visualization Workshop at IEEE VIS 2016* (Baltimor, MD, US, 2016), HAL, pp. 2–5. 2

[Ico22] Icon Books: Introducing Books - Graphic Guides. https://www.introducingbooks.com/graphic-guides/, 2022. Accessed: 2023-06-25. 2

[Iss18] Issa S.: Comics in the English classroom: a guide to teaching comics across English studies. *Journal of Graphic Novels and Comics 9*, 4 (2018), 310–328. URL: https://www.tandfonline.com/doi/full/10.1080/21504857.2017.1355822. 2

[JS09] Jin J., Szekely P.: QueryMarvel: A visual query language for temporal patterns using comic strips. In *VL/HCC* (2009), IEEE. URL: http://ieeexplore.ieee.org/document/5295262/. 3

[KHP*23] Keck M., Huron S., Panagiotidou G., Stoiber C., Rajabiyazdi F., Perin C., Roberts J. C., Bach B.: EduVis 2023: Workshop on Visualization Education, Literacy, and Activities. *IEEE VIS* (2023). URL: https://arxiv.org/abs/2303.10708, doi:10.48550/ARXIV.2303.10708. 2

[KMVT23] Kirtley C., Murray C., Vaughan P. B., Tatler B. W.: Navigating the narrative: An eye-tracking study of readers' strategies when reading comic page layouts. *Applied Cognitive Psychology 37*, 1 (Jan. 2023), 52–70. doi:10.1002/acp.4018. 5, 6, 7, 10

[KRHH23] Kim H., Rossi R., Hullman J., Hoffswell J.: Dupo: A mixed-initiative authoring tool for responsive visualization. *IEEE Transactions on Visualization and Computer Graphics* (2023), 1–10. doi:10.1109/TVCG.2023.3326583. 2, 3

[KSDK14] Krejtz K., Szmidt T., Duchowski A. T., Krejtz I.: Entropy-based statistical analysis of eye movement transitions. In *Proceedings of the Symposium on Eye Tracking Research and Applications* (Safety Harbor Florida, Mar. 2014), ACM, pp. 159–166. doi:10.1145/2578153.2578176. 7

[KSK21] Keck M., Stoll E., Kammer D.: A Didactic Framework for Analyzing Learning Activities to Design InfoVis Courses. *IEEE Computer Graphics and Applications 41*, 6 (Nov. 2021), 80–90. URL: https://ieeexplore.ieee.org/document/9556143/, doi:10.1109/MCG.2021.3115416. 3

[LAC*23] Liu X., Alharbi M. S., Chen J., Diehl A., Rees D., Firat E. E., Wang Q., Laramee R. S.: Visualization resources: A survey. *Information Visualization 22*, 1 (Jan. 2023), 3–30. doi:10.1177/14738716221126992. 2

[Laz17] Lazar J.: *Research methods in human computer interaction*, 2nd edition ed. Elsevier, Cambridge, MA, 2017. 4

[LKK17] Lee S., Kim S.-H., Kwon B. C.: Vlat: Development of a visualization literacy assessment test. *IEEE TVCG 23*, 1 (2017), 551–560. doi:10.1109/TVCG.2016.2598920. 2

[LSSB*23] Li W., Schöttler S., Scott-Brown J., Wang Y., Chen S., Qu H., Bach B.: Networknarratives: Data tours for visual network exploration and analysis. In *Proc. of CHI 2023* (2023), pp. 1–15. 2

[MAE*24] Milesi M. E., Alfredo R., Echeverria V., Yan L., Zhao L., Tsai Y.-S., Martinez-Maldonado R.: "it's really enjoyable to see me solve the problem like a hero": Genai-enhanced data comics as a learning analytics tool. In *Extended Abstracts of CHI 2024* (Honolulu HI USA, May 2024), ACM, pp. 1–7. doi:10.1145/3613905.3651111. 3

[McC93] McCloud S.: *Understanding comics: The invisible art*. Tundra Pub, Northampton, MA, 1993. 2, 5

[MHMC05] Mayer R. E., Hegarty M., Mayer S., Campbell J.: When Static Media Promote Active Learning: Annotated Illustrations Versus Narrated Animations in Multimedia Instruction. *Journal of Experimental Psychology: Applied 11*, 4 (2005), 256–265. doi:10.1037/1076-898X.11.4.256. 2, 10

[MHSD21] Matuk C., Hurwich T., Spiegel A., Diamond J.: How Do Teachers Use Comics to Promote Engagement, Equity, and Diversity in Science Classrooms? *Research in Science Education 51*, 3 (2021), 685–732. 2

[Mun23] Munroe R.: xkcd. https://xkcd.com/, mar 2023. 2

[PIB*24] Pokojná H., Isenberg T., Bruckner S., Kozlíková B., Garrison L.: The Language of Infographics: Toward Understanding Conceptual Metaphor Use in Scientific Storytelling, July 2024. arXiv:2407.13416 [cs, math]. URL: http://arxiv.org/abs/2407.13416. 5

[PMCM23] Pérez-Messina I., Ceneda D., Miksch S.: Guided visual analytics for image selection in time and space. *IEEE TVCG* (2023), 1–10. doi:10.1109/TVCG.2023.3326572. 2, 3

[RSDB20] Ridley A., Schöttler S., Dadzie A.-S., Bach B.: The vistools marketplace: An activity to understand the landscape of visualisation tools. In *Proc. of the VIS 2020 Workshop on Data Vis Activities* (Oct. 2020), IEEE. URL: https://www.research.ed.ac.uk/en/publications/the-vistools-marketplace-an-activity-to-understand-the-landscape-. 1

[SGP*19] Stoiber C., Grassinger F., Pohl M., Stitz H., Streit M., Aigner W.: *Visualization Onboarding: Learning How to Read and Use Visualizations*. preprint, Open Science Framework, Aug. 2019. URL: https://osf.io/c38ab, doi:10.31219/osf.io/c38ab. 2, 4

[SMBP*17] Serrano Molinero V., Bach B., Plaisant C., Dufournaud N., Fekete J.-D.: Understanding the Use of The Vistorian: Complementing Logs with Context Mini-Questionnaires. In *Visualization for the Digital Humanities* (Phoenix, United States, Oct. 2017). URL: https://inria.hal.science/hal-01650259. 3

[SPT*24] Shu X., Pister A., Tang J., Chevalier F., Bach B.: Does this have a particular meaning? interactive pattern explanation for network visualizations. In *2024 IEEE VIS* (2024). URL: https://arxiv.org/abs/2408.01272, doi:10.48550/ARXIV.2408.01272. 10

[SS18] Schreiber A., Struminksi R.: Visualizing the Provenance of Personal Data Using Comics. *Computers 7*, 1 (2018). URL: http://www.mdpi.com/2073-431X/7/1/12. 3

[SSMF*09] Smith M. A., Shneiderman B., Milic-Frayling N., Mendes Rodrigues E., Barash V., Dunne C., Capone T., Perer A., Gleave E.: Analyzing (social media) networks with nodexl. In *Proc. of the 4th international conference on Communities and technologies* (2009), pp. 255–264. 3

[SWG*21] Stoiber C., Walchshofer C., Grassinger F., Stitz H., Streit M., Aigner W.: Design and comparative evaluation of visualization onboarding methods. In *Proceedings of VINCI'21* (NY, USA, 2021), ACM. doi:10.1145/3481549.3481558. 10

[SWG*ss] Stoiber C., Wagner M., Grassinger F., Pohl M., Stitz H., Streit M., Potzmann B., Aigner W.: Visualization Onboarding Grounded in Educational Theories. In *Visualization Psychology*. Springer Nature, tba., in Press. URL: http://arxiv.org/abs/2203.11134. 2, 10

[TA13] Tullis T., Albert B.: *Measuring the user experience: collecting, analyzing, and presenting usability metrics*, second edition ed. Elsevier/Morgan Kaufmann, Burlington, Massachusetts, 2013. 7

[Tru21] Trușcan M.-S.: How to successfully integrate the multi-modal learning in english classes using comics. https://edcomix.eu/2021/08/11/how-to-successfully-integrate-the-multi-modal-learning-in-english-classes-using-comics/, mar 2021. 2

[VDT*22] Vacca R., DesPortes K., Tes M., Silander M., Matuk C., Amato A., Woods P. J.: "I happen to be one of 47.8%": Social-Emotional and Data Reasoning in Middle School Students' Comics about Friendship. In *Proc. of CHI 2022* (New Orleans LA USA, Apr. 2022), ACM, pp. 1–18. doi:10.1145/3491102.3502086. 3

[WC22] Wessels-Compagnie M.: Designing an Information Comic. In *Seeing across Disciplines: The Book of Selected Readings 2022*, Lee J., Beene S., Chen X., (Eds.). International Visual Literacy Association, 2022, pp. 1–35. URL: https://ivla.org/wp-content/uploads/2022/05/1-Designing-a-Information-Comic.pdf, doi:10.52917/ivlatbsr.2022.011. 3, 5, 6

[WDB19] Wang Z., Dingwall H., Bach B.: Teaching Data Visualization and Storytelling with Data Comic Workshops. In *Extended Abstracts of CHI 2019* (NY, USA, 2019), ACM, p. 1–9. 2, 4

[WII*12] Wood J., Isenberg P., Isenberg T., Dykes J., Boukhelifa N., Slingsby A.: Sketchy Rendering for Information Visualization. *IEEE TVCG 18*, 12 (2012), 2749–2758. URL: http://ieeexplore.ieee.org/document/6327281/. 6

[Wil22] Williams I.: What is "Graphic Medicine"? https://www.graphicmedicine.org/why-graphic-medicine/, 2022. Accessed: 2023-06-25. 2

[WL20] Watkins R., Lindsley T.: Sequential Mapping: Using Sequential Rhetoric and Comics Production to Understand UX Design. *Technical Communication Quarterly 29*, 3 (2020). doi:10.1080/10572252.2020.1768292. 3

[WRC*22] Wang Z., Romat H., Chevalier F., Riche N. H., Murray-Rust D., Bach B.: Interactive Data Comics. *IEEE TVCG 28*, 1 (2022), 944–954. URL: https://ieeexplore.ieee.org/document/9552591/. 10

[WSMRB20] Wang Z., Sundin L., Murray-Rust D., Bach B.: Cheat sheets for data visualization techniques. In *Proc. of CHI 2020* (NY, USA, 2020), CHI '20, ACM, p. 1–13. doi:10.1145/3313831.3376271. 3

[WWF*19] Wang Z., Wang S., Farinella M., Murray-Rust D., Henry Riche N., Bach B.: Comparing effectiveness and engagement of data comics and infographics. In *Proc. of CHI 2019* (NY, USA, 2019), CHI '19, ACM, p. 1–12. doi:10.1145/3290605.3300483. 6, 8

[YLT18] Ynnerman A., Lowgren J., Tibell L.: Exploranation: A new science communication paradigm. *IEEE CG&A 38*, 3 (May 2018), 13–20. doi:10.1109/MCG.2018.032421649. 10

[ZMUB18] Zoss A., Maltese A., Uzzo S. M., Börner K.: Network visualization literacy: Novel approaches to measurement and instruction. In *Network Science In Education*. Springer International Publishing, 2018, pp. 169–187. URL: https://doi.org/gpsvw4, doi:10/gpsvw4. 2