Comparing Effectiveness and Engagement of Data Comics and Infographics

Comparing Effectiveness and Engagement of Data Comics and Infographics

Zezhong Wang[1] **Shunming Wang**[1,2] **Matteo Farinella**[3] **Dave Murray-Rust**[1] **Nathalie Henry Riche**[4] **Benjamin Bach**[1]

[1] University of Edinburgh [2] Peking University [3] Columbia University [4] Microsoft Research

zezhong.wang@ed.ac.uk shunming.wang@pku.edu.cn {bbach, d.Murray-Rust}@inf.ed.ac.uk nath@microsoft.com mf3094@columbia.edu

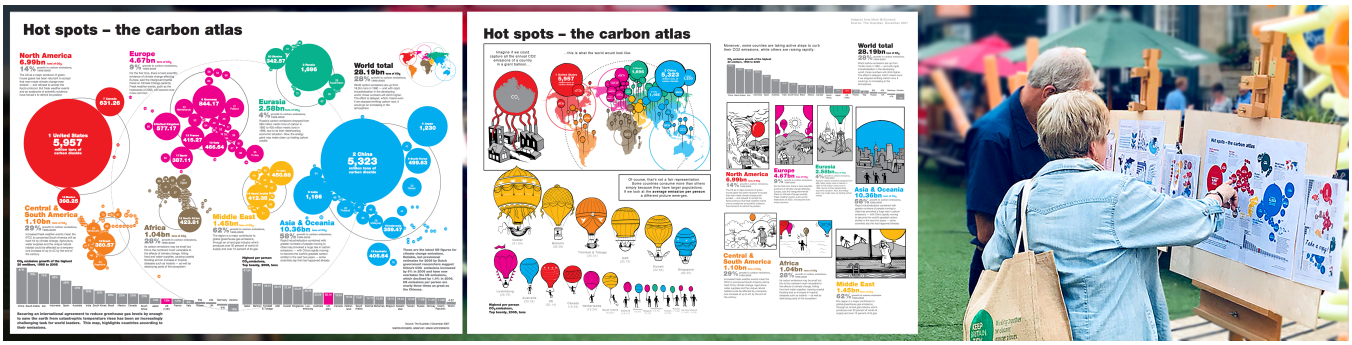

Figure 1: Two stories were presented in the wild in both Infographic and Comic form, for an empirical observation study conducted with pedestrians, measuring reading time, interactions (i.e. pointing and talking) and opinions as evidence for engagement and enjoyment.

ABSTRACT

This paper compares the effectiveness of data comics and infographics for data-driven storytelling. While infographics are widely used, comics are increasingly popular for explaining complex and scientific concepts. However, empirical evidence comparing the effectiveness and engagement of infographics, comics and illustrated texts is still lacking. We report on the results of two complementary studies, one in a controlled setting and one in the wild. Our results suggest participants largely prefer data comics in terms of enjoyment, focus, and overall engagement and that comics improve understanding and recall of information in the stories. Our findings help to understand the respective roles of the investigated formats as well as inform the design of more effective data comics and infographics.

KEYWORDS

Visualization, Comics, Effectiveness, Engagement

ACM Reference Format:

Zezhong Wang, Shunming Wang, Matteo Farinella, Dave Murray-Rust, Nathalie Henry Riche, Benjamin Bach. 2019. Comparing Effectiveness and Engagement of Data Comics and Infographics. In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019), May 4-9, 2019, Glasgow, Scotland, UK.* ACM, New York, NY, USA, Paper 253, 12 pages. https://doi.org/10.1145/3290605.3300483

1 INTRODUCTION

Data-driven storytelling is concerned with effective communication around data through visualization [26, 38]. It covers a multitude of formats to match the diversity of audiences, messages, contexts, data, and communication media [44]: magazine style, annotated charts, partitioned posters, flowchart, comic strips, sideshows and videos. Many of these formats can be seen as complementary, in that they support specific media, might be more attractive to specific audiences, have different ways of supporting a specific message, and involve specific skills and tools for creation.

CHI 2019, May 4–9, 2019, Glasgow, Scotland Uk

ACM ISBN 978-1-4503-5970-2/19/05…$15.00
https://doi.org/10.1145/3290605.3300483

In this paper, we are interested in *data comics* [3, 54], a relatively new and underexplored format. Data comics draw from the tradition of comics, and combine techniques from infographics, data visualization, journalism, and other formats of visual explanations. They are based on the notion of a sequence of panels [32] with each panel being a combination of text and picture to illustrate a particular message the author wants to convey. For sequential explanations in general, many studies have shown benefits (e.g., [13, 36], summarized in [18]). Generally the use of comics in classroom education and health-related communication appears to improve the reader's comprehension and engagement. While these results may encourage the use of data comics, generalizing existing study results to data comics is challenging due to varying content, visual representations, audiences, and purposes.

As a step towards a better understanding, we provide the first structured investigation into the effectiveness of data comics. We compare data comics with the two closest popular alternatives: infographics and texts accompanied by visualizations (illustrated texts). While there are numerous differences between these three formats, we focus our comparison on *i)* the degree to which an explicit *reading order* is given, and *ii)* how close the *integration of text and picture* is (Section 3). While data comics typically have a highly structured reading order and text closely integrated pictures, illustrated texts and infographics exhibit a varying degree in each of these dimensions. We compared these techniques in a controlled lab study, where 36 participants read the same 3 stories, each presented in a different format (Section 4). We collected empirical and subjective data on understandability, recall, preferences, and engagement. To complement this controlled study, we observed 50 groups of visitors engaging with comics and infographics in an open public space (Section 6, Figure 1).

Based on a variety of collected data including questionnaires, interviews, think-aloud protocols, explanations, memory-recall, and visitor observation, we found that data comics are seen as more fun, help readers to stay focused, and are overall more engaging. Quantitative results suggest that data comics improve understanding for most cases, and were generally rated high for enjoyment and engagement. In addition, subjective feedback collected gives a richer picture of the respective merits and drawbacks of each format. With these results, we aim to encourage professional communicators to explore the use of data comics for explanation, as well as to better inform the design of future data comics and communicative graphics. Study materials for the Lab study, in the wild study, questions, some interview quotations and examples of reading sequence record, can be found online: http://datacomics.net.

2 BACKGROUND

This section overviews previous studies on illustrated texts, infographics and other related data storytelling media.

Texts and Pictures

Textual descriptions (printed and spoken words) and graphical depictions (photography, drawings, paintings, maps and videos) are the basic forms of representation [43, 51]. Information is remembered better when it is supported with pictures [28], even more so when presented through both channels at the same time [6, 13, 36, 48]. Data visualizations have been found less memorable than natural scenes [11], yet adding embellishments and unique presentations can improve memorability [7, 11]. Studies comparing comics and other visual formats [27] with text-only material [1] and illustrated texts [31] confirm these trends, and show increased memorability. For storytelling in general, the use of sequence has been found to increase recall, facilitated by information being split into chunks [10]. Psychological studies have investigated the effectiveness of the panel layouts [14, 15] used in traditional comics through eye-tracking [19]. Other studies have found that in cases where text is unnecessary, closely integrating text and picture can distract the reader and hinder learning [12, 40], while providing inappropriate graphics can impede understanding [29].

Comics for Explanation

Comics are becoming increasingly popular for explaining complicated processes [18, 49]. They offer a set of unique characteristics for communication and optimal understanding, being highly accessible to a large audience, compatible with many different media, do not require a presenter and can be read at one's own pace [53]. Comics can blend explanation (e.g. schemata, illustrations, data visualization) with narration, characters and dialogue. From a structural point of view, a notion central to comics is the *panel*, which encapsulates a specific *message* (or information) represented as an integrated combination of text and picture [32]. The (mostly) linear order of panels creates a sequence of viewpoints which together can build a deeper understanding in the readers' mind [46].

Comics, and related formats such as juxtaposed annotated pictures, have consequently been used for explaining a range of phenomena, blending schematic drawings and illustrations with the narration and characters of traditional comics. Empirical evidence from using comics as classroom material [21, 45, 47] as well as for health-related communication [16, 17, 33, 50] suggests that comics may be more engaging and easier to comprehend, especially for non-expert readers.

Recently, comics have also been applied to the communication of insights from data, resulting in a format called *data*

comics [3, 4, 54], where comic strip elements are combined with data visualization techniques. A growing number of data comics have been created for networks [2, 54], geography [8, 34], personal data and scientific experiments [4], summarized online [5]. While research highlighted design patterns [4], authoring tool-support [25], and workshop formats [52] for creating data comics, several factors prevent a wider distribution and exploration of data comics: the novelty of the format as well as the lack of a better understanding of the effectiveness of the format.

In fact, while most of the evidence from previous studies supports a strong motivation for the use of comics, the effects were observed in traditional or scientific comics and may or may not generalize to *data* comics. In particular, graphics in data comics focus more on abstract data visualization [3], require visualization knowledge and largely deal with concepts requiring data literacy such as relations, temporal change, and quantities. For example, Qu and Hullman point to the importance of consistency in creating sequences of visualizations [37], a factor that very likely influences the acceptability and usability of data comics. Given the popularity of infographics and traditional visualisation formats, as well as the body of expertise built up around their creation and use, it would be wrong to simply assume there will be enhanced understanding and engagement with data comics. Our study aims to support the further investigation, application and creation of data comics through empirical results on their effectiveness. As far as we are aware, ours is the first study to address this gap.

Infographics and Illustrated Texts

Two popular alternatives to data comics are *infographics* and *illustrated texts* ("magazine style" [44]). Both are text-picture combinations, differing in how these elements are combined. Infographics strongly emphasize the visual content, often using visual embellishments to stimulate attractiveness and memory [7]. They tend to be open-ended, inviting the reader to explore the content without any specific direction. For more structured narrative content, e.g., in journalism and scientific papers, texts illustrated with visualizations have become the common option: a text for the main narration, referring to visualizations as needed.

All three formats (comics, infographics, and illustrated texts) are expressions of different combinations of reading order and text-picture integration. Current studies are not conclusive and say little about these three formats ability to support understanding and memory as well as how engaging each format appears to potential readers.

3 STUDY DESIGN SPACE

Infographics, illustrated texts, and data comics vary in a range of characteristics and it is not easy to precisely define each format. Thus, to inform our baseline techniques for the study, we focus on two characteristics across these formats:

1 **Text-Picture-Integration** is the *spatial distance between the verbal message and the visualization* [3]. In their general form, comics exhibit a high integration of text and picture; one piece of text is related exactly to one image, both supporting the same information within the panel. A low integration would mean that text and picture are presented in parallel with occasional implicit or explicit references such as found in scientific and news articles.
2 **Reading Guidance** is *how strong the reader is guided while reading the story* [3, 4]. While exceptions exist [4], comics provide a high guidance through an explicit order of panels. Low guidance can be found in most infographics where text and pictures are usually not organized in a linear order but can be read in a non-linear way.

We use these dimensions to map out a design space for visual storytelling formats for our study (Figure 2). *Comics* are located high on both dimensions, with tight text-picture integration and strong reader guidance. *Infographics* provide a less strong integration of textual and pictorial content because the same picture is usually annotated with several textual information and the specific scope of the text, with respect to the picture. Infographics provide low reading guidance as the content can usually be read in any order. *Illustrated Texts* are by visualizations, sometimes referenced in the text. This format provides a low integration of text and picture, a higher reading guidance than infographics, but less than comic as it is up to the reader to switch between text and picture.

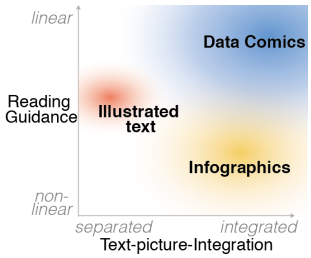

Figure 2: Design space

To investigate the effectiveness and engagement of these formats, we opted to perform two complementary studies: one in laboratory settings and one in the wild.

4 LAB STUDY

Our first study aimed to compare comics, infographics, and illustrated text in a controlled lab study. We were generally interested in how each of the dimensions, laid out in the previous section, influences comprehension, recall, and engagement with the formats. More specific questions concerned how people read each format, which configurations they found helpful or confusing, how well did they understand the communicated stories, as well as how much of the content do participants remember after a while. To that

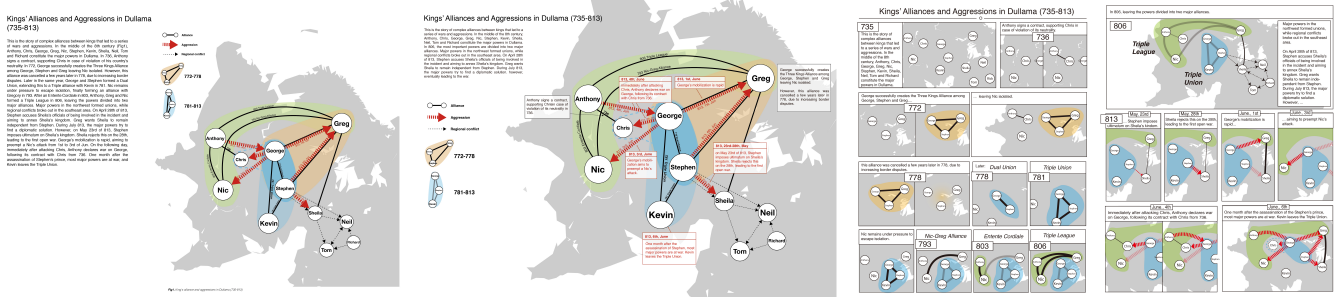

Figure 3: Samples of ALLIANCES in the lab study. ILLUSTRATEDTEXT (left) ; INFOGRAPHIC (center); COMIC (right).

end, we invited participants to read a series of stories in each of the formats, answer questions related to content understanding, and report their subjective impressions about each format. Prior to the study, we carried out a pilot with three visualization-experienced participants to ensure the suitability of our material and techniques. The full material (including all questions and results) is found in the supplementary material.

Stories

During the study, participants read three data stories, a number we chose with respect to how long we expected participants to remain attentive and remember story content. Our main criteria in finding appropriate stories for a controlled lab study were (i) comfortably presentable on A3 paper and (ii) requiring little previous knowledge. To extend the variation among the study examples, we selected different types of common visualizations including multivariate data, dynamic networks, and geological distribution. To ensure realistic stories, we selected three existing infographics (see below). For two of the stories, the labels, text, and data were changed to prevent users relying on prior knowledge.

- **ENERGY:** ***Renewables' Mix in Power Generation in Europe*** talks about the production and distribution of renewable energy among European countries. The visualization was found in the Energy Atlas [9]. Bars on each country showed production in 2011 and 2017 respectively. Texts describe features of the distribution (Figure 4-left).
- **ALLIANCES:** ***Kings' Alliances and Aggressions in Dullama*** (Figure 3) was based on a graph comic on dynamic networks *European Alliances before World War I* [2]. Dates were changed and the story was transposed into a fictitious medieval kingdom. Country names were replaced by common names and the background map was altered.
- **ECONOMICS:*Global Interest Rate And Tax Burden*** was taken from Hans Rosling's TED talk [41], featuring a dynamic scatterplot of country indicators over time [20](Figure 4-right). We changed axes labels to *Interest rate* and *tax burden* respectively, implying no specific meaning. The narration was guided by the changes to specific countries over time.

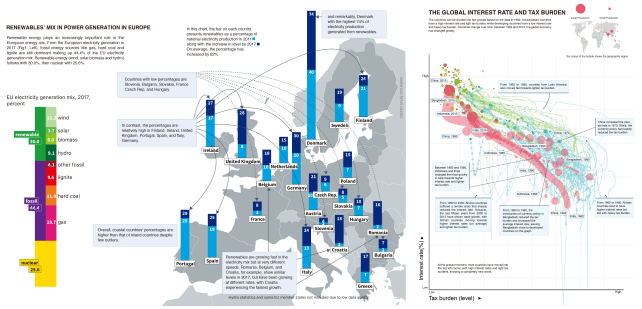

Figure 4: Infographics: ENERGY (left) and ECONOMICS (right).

While we tried to keep stories to an equal level of complexity (e.g., number of panels, number of messages per panel, expected commonness of visualizations and difficulty of understanding visualizations), all three participants in the pilot study gave the same ordering in terms of increasing complexity: ENERGY, ECONOMICS, and ALLIANCES.

Techniques

The techniques in the lab study are the three techniques mentioned in Section 3. As boundaries between the formats are blurred, we settled on the following criteria to create the material for our comparison. Fig. 3 shows the three formats for ALLIANCES. The full material for the other stories is available in supplementary material.

- **ILLUSTRATEDTEXT**: One or two narrative paragraphs were placed right below the title, followed by the legend below or on the right. Text and pictures were visually separated, captions and essential names were added on the pictures referring to the text description.
- **INFOGRAPHIC**: Besides a 1-2 sentence summarization under the title, texts were shown in text boxes, placed close to the visual information they referred to. Leader lines sometimes connected text to visual elements. No explicit visual hint implied a specific reading sequence.
- **COMIC**: All text and visuals were placed into 16-18 panels in an unambiguous linear left-right, top-down order. Visuals were adapted to support the text, e.g., focusing on

specific information, highlighting important and removing unimportant information. We made no other changes to visual encoding or text.

We ensured everything was readable comfortably from 40cm distance, printed on A3 paper format. Texts were kept the same across formats, except from minor adjustments to the format. For example, we added *"see figure x"* for IllustratedText and simplified few longer sentences to fit the panels in Comic. We created all materials through several iterations to make sure they were readable and understandable and to lower confusion; at each stage we discussed in depth across the authors and asked for feedback from three external comic artists as well as two external colleagues. The pilot study identified minor problems in understanding and design and we consequently modified several ambiguous expressions in the stories and the questionnaires. To provide a high-resolution and minimize the operational distractions such as panning and zooming, we printed each story on one-side A3 paper instead of showing them on a monitor.

Hypotheses

We developed our hypotheses based on the existing literature, and the two dimensions of our design space.

- **H-Accuracy**: We expect participants *to have a more correct understanding of the messages after reading Comic than Infographic, and least with IllustratedText*. We believe that making a connection between visual and verbal for each message improves understanding. Comics with messages embedded in individual panels will be more effective than combined information in Infographic and separated text and pictures.
- **H-Engaging**: we expect *Comic and Infographic to be rated as more engaging than IllustratedText*. This means that people are more willing to spend time with Comic and Infographic and believe they are more fun to read.
- **H-Memorability**: We expect Comic to increase retention of information compared to the other formats due to the separation of information into clear chunks, supported through tightly integrated texts-and-pictures, presented in a clear reading order [31].

Data Collection

Seven types of data were collected during the lab study: (1) error rate from multiple-choice questions to measure understanding of each story and format (including four answer possibilities and "I'm not sure"); (2) story recall scores, coded by the experimenter and explained in Section 5; (3) reading paths drawn onto the material by the participants; (4) subjective scores, and (5) qualitative feedback from participants on all three formats for the same story (shown at the end of the study) gathered through semi-structured interviews. Questions included *"Compared to the other formats of same story, how would you judge these formats?"* and *"Do you have any preference among these formats and why?"*. Subjective ratings were collected through a questionnaire after participants saw the three formats of all stories. While engagement is hard to define and measure [30], we assessed aesthetic feeling, willingness of spending time to explore, enjoyment, attention, engagement and preference using 7-point Likert scales, inspired by existing frameworks [35, 42].

Participants

We recruited 38 participants through mailing lists of a Western-european university. One subject was eventually denied participation due to missing English language proficiency and one subjects results were invalidated as she did not complete phase 1. Of the remaining 36 participants, 19 were male, ages ranged between 18 and 35 years, 1 A-level, 9 undergraduates and 20 graduates, 4 computer science doctoral students, 1 research associate in computer science and 1 lecturer of Linguistics and English Language. Participants' backgrounds included Design, Art, Computer Science, Engineering, Linguistics, Philosophy and Psychology. We had 16 Europeans, 15 Asians, 3 North American and 2 African; 34 had lived in an English speaking country for more than 1 year, the other 2 had scores in English language test equal to B2 level of Common European Framework of Reference for Languages.

To assess participants' level of reading ability, comic and visualization literacy, self rated questions were filled in before the study. For text reading ability, 13 read illustrated texts daily and 13 indicated weekly; 11 read scientific text-only articles daily and 12 read them weekly. For infographics, 20 read them weekly and 7 daily. Familiarity with data visualizations was rated differently (**1** **7**). For comic literacy, 8 read comics daily, 7 weekly, 4 monthly, 9 few times year, 3 yearly and 5 of them have never read comics with 20 of them having first read comics aged between 6 and 12 years old. 12 participants had experience in drawing comics, but mostly only a few times and for less than one year. Participants reported on their preferred learning method: verbal (spoken or written) media (6), visual stimuli (8), combined visual and verbal media (17). Repetition was a popular strategy mentioned by 8 participants. Participants were paid a compensation of $7.

Procedure

Our study employed a mixed design. For both stories and techniques we employed an within-design, i.e., every participant read all stories and all formats. However, as we could not provide the same story twice to the same participant, we employed an in-between design for story-format conditions, i.e., every participant read each story using a different format. We used a Latin-square randomization to assign stories to

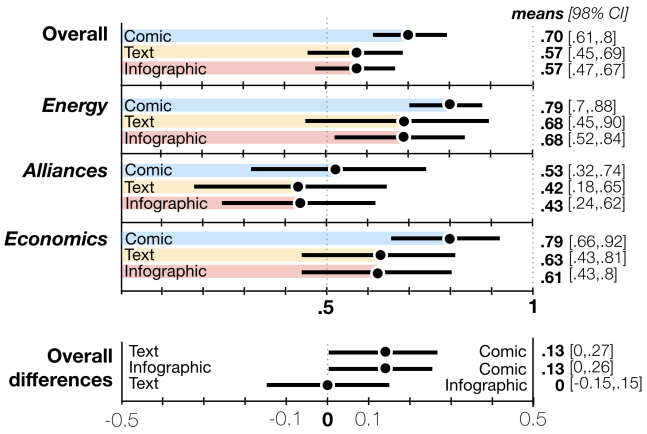

Figure 5: Results for *(top)* understanding including means and 98% CIs and *(bottom)*: overall effect sizes with 98% CIs.

formats. With 36 participants each seeing 3 presentations, each of the 9 story-format combinations

5 LAB STUDY RESULTS

All 36 participants completed the study, with each session lasting just below 1h. For each of the 9 story-format combinations, we obtained true or false answers to 6 questions from 12 participants. We collected all video materials and annotated print outs from each participants, available in the supplementary material.

Understanding

Understanding was measured as accuracy for the questions from the questionnaire in step (4). Error per question was binary, i.e., participants selected the right or a wrong answer. For each participant we calculated the mean accuracy score across all the answers per story. Using D'Agostino's K-squared test, we found accuracy scores for two stories to be *not* normally distributed. Below and in Figure 5 we report on mean values, confidence intervals (CIs), and effect sizes. Using Bonferroni correction for multiple comparisons, we report on 98% CIs for our three comparisions ($1 - 0.05/3$). P-values are indicated for pair-wise comparisons yielding significance at the respective 0.02 level or close, using a Mann-Whitney-U test.

Across Stories we found Comic (mean=.70) to be more accurate than Infographic and IllustratedText ($p<.006$). No difference was found between IllustratedText and Infographicwith the same mean accuracy of .57. Effect sizes between techniques are reported in Figure 5-bottom. Our effect sizes represent the overall improvement (or decrease) in understanding averaged for each participant, i.e. for each participant we calculated differences between formats and averaged these values. Differences between Comic and the other techniques amounts to .13 points in understanding, implying that comics are on average 23% more accurate than both IllustratedText and Infographic.

For **Energy** we found Comic (mean=.79) more accurate then Infographic (mean=.68). However, leading to the same mean accuracy than Infographic, IllustratedText was not found different from the other two techniques and showed much wider CIs. For one question, we could find a real difference between techniques; the question asked for spatial distribution of countries. As this information was highlighted explicitly in one panel in the comic, we believe it was easier for participants to understand and remember.

For **Alliances** we could not find any clear differences, while Comic (mean=.52) was still the most accurate on average but with largely overlapping CIs. Infographic and IllustratedText had similar mean values (.42 and .43). Again, we found a difference for one question asking about the meaning of a specific visual encoding in the visualization (*"What does the black dashed relation represent?"*); Comic was significantly worse (mean=.25) than the other two formats (IllustratedText=.66, Infographic=.83). We believe participants overlooked this information in the comic as they might have paid less attention to this particular—not explicitly highlighted—detail. We attribute the good performance of Infographic to the fact that a respective text was placed close to these lines to explain their meaning.

For **Economics** we found similar results to Energy; Comic showed a slightly higher accuracy (mean=.79) while Infographic(mean=.61)($p<.036$) and IllustratedText (mean=.62) ($p<.04$) were similar. As with the other stories, we found a difference for a question on time (*"What is the characteristic of the countries in 1962?"*). Here, Comic was more accurate (mean=.91)($p<.015$) then any of the other formats (IllustratedText=.58, Infographic=.33). We conjecture that the bad performance of Infographic can be related, again, to the missing temporal visualization, while Comic showed that information in a single panel. While the explanation should indicate a similar bad performance for IllustratedText, the average here was slightly higher. However, this particular infographic has been described as very cluttered by participants, which may explain some of the poor performance.

Recall

After reading the stories on the first day, participants were required to retell the story in their own words. We took notes of each explicitly presented fact they mentioned (11 for Energy, 14 for Economics, and 17 for Alliances). Self discovered messages, i.e., those not being mentioned in the texts, were not considered. On the second day, participants were asked to again retell the story with their own words. Following

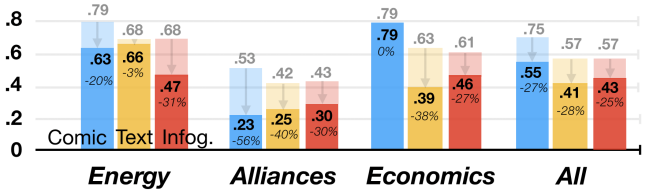

Figure 6: Mean results for understanding after one 1-4 weeks. Upper numbers indicate original values (as shown in Fig 5), lower numbers indicate correct results after 1-4 weeks with change in percent (Comic=blue, IllustratedText=yellow, Infographic=red).

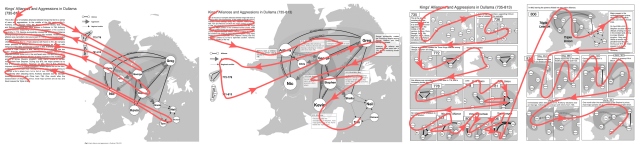

Figure 7: Examples of users' traces while reading the same story (Alliances) in different formats. Percentages in brackets indicate fraction of users showing comparable traces. Left: IllustratedText (67%), center: Infographic (75%), right: Comic (100%).

the methodology by Bateman et al. [7], we coded the difference between both versions as follows: 3 points for every correct fact (e.g., correct values), 2 points for remembering general trends (e.g., increase, type of temporal change), 1 point for vaguely remembering (e.g., mentioning type of information) and 0 points for not or wrongly recalling. Two of the authors independently coded all of the recordings, then discussed until reaching consensus. We found Comic to yield slightly more precise results on average (35%), compared to IllustratedText (32%) and Infographic (30%).

After one to four weeks, we sent the questionnaire from step (4) again to all participants (Figure 6): Overall, Comic caused participants to remember most on average (55%, down from 75%), followed by Infographic (43%, down from 57%) and IllustratedText (41%, also down from 57%). Participants lost around 1/3 of their performance. However, values varied across stories, with each format performing best for one story (see Figure). In two cases, mean understanding rates did remain the same (IllustratedText for Energyand Comic for Economics).

Reading Strategy

By asking for the reading sequence of the story, we simulated an "eye tracking" phase (step (9)) in our study. In the pilot study, we found participants walking us through their reading order more accurate and informative for our purpose than actual eye-tracking. Figure 7 shows example traces, drawn by participants, while explaining their reading order.

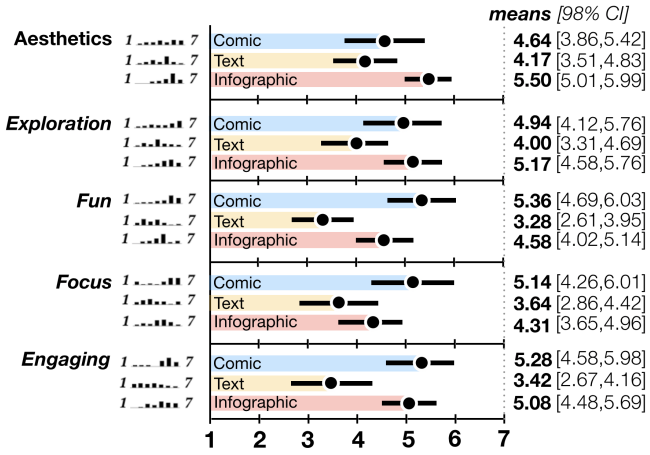

Figure 8: Subjective measurement from the lab study in step (2) of the 2nd session including means and 98% CIs. Distributions of the answers are shown on the left.

With Comic, all participants followed the panel order, reading both text and looking at figures in each panel except 1 participant who read the Comic of Energy in a right-left order from the second row. 16 participants (44.4%) jumped back to previous panels to make comparisons. For Infographic, most participants (83%) started with title and abstract, the others started with figures. We found no specific sequence in which participants read text-boxes in Infographic, i.e. no prevalence for left-right or top-down order. We found reading sequence was guided by the layout of text boxes, e.g., clock-wise or randomly in Economics and Alliances. Generally, participants were guided by text boxes and only then looked at the figure to obtain more information. All participants checked the legend in Alliances and Economics. In IllustratedText, most participants (83%) started with the text, few (17%) started with pictures. 28% checked figures in the end, while a majority (72%) checked the figures during reading (2-3 times), especially when they found specific values in the text.

Subjective Feedback

Subjective results from the preference questionnaire (step 7) are summarized in Figure 8, following the same conventions and analysis as Figure 5. We found Comic to be highest rated (averages) on three measures (*fun*, *engaging*, and allowing people to stay *focused*) while scoring slightly less then Infographic for *aesthetics* and *exploration*. While, differences between Comic and Infographic are minor and not significant, Comic is generally ranked higher as shown in the respective distribution (small bar charts left side of Figure 8). IllustratedText was rated generally least across all measures with huge differences to the two other techniques for the measures *engaging* and *fun*. Infographic was rated as

aesthetically pleasing, with opinions being more equally distributed for Comic. Asked which format participants would chose next time, we found similar results: Comic rated best by 47% (**worst ▁▃▅ best**), IllustratedText rated least by 64% (**worst ▅▃▁ best**) and Infographic in the middle (**worst ▁▅▃ best**). In the following, we report on participants' feedback during the interview in step (8). Frequencies of issues raised are reported by the numbers in brackets. Full material and an overview table with the reported merits and drawbacks of each technique can be found in the supplementary material.

Comic—Comics were appreciated for their clear reading order (33%) and their ability to break down the complexity into pieces (28%). Reading order was found use support memory (6%)(*"[...] because the important information is repeated all the time, which helps [...] memorize."*,*"Comic makes a story in your head"*) and were found to facilitate understanding: *"just follow the sequence. It is logic and well organized"*, especially for temporal content (39%) (*"just because [Alliances] is so complicated and chronological"*). Breaking down complexity into individual pieces has been found useful for the same reasons (*"You have the option to see the information by steps, you can easily have your memory when it is happened (sic). It is like the same way we remember history when I was a child."*"*is quite easier to memorize"*. Additionally, participants liked that comics could group higher-level messages into rows and potentially pages. Participants also commented on the ability to quickly overview information and find/recall the information they wanted (*"If I don't have time, I'll go for data comic"*). In fact, during recall 4 participants used their hands to air-point to where the respective panel was located.

On the downside of Comic, visual repetitions were distracting for 2 participants, indicating too much information to process: *"every time I see new pictures (panels) I expect something new"*,*"I need to compare to define what is new"*. There is a tension here, as building a new message is on the basis of previous messages uses repeated visual elements, causing redundancy. For Energy, one participant mentioned *"I think it is unnecessary to have that kind of level to break down, because it is simple enough to understand the image by just looking at the whole picture and explore it."*. This story indeed featured a high degree of visual repetition (the map of Europe) as it was hard to break down the content into simpler images. Again, other people explicitly preferred a more open format (*"I can only read the comic step by step, it is hard to find the part that I am interested in"*) and found that an overview picture was missing. The same participant was found to jump between panels. Looking at the comic the first time, one participant noted *"This one can be confusing, considering there are all types of graph. It seems a little much at first glance"*.

Infographic—Infographics were rated highly for exploration (33%) by providing overview and detail at the same time which helped making comparisons (6%). Some participants (31%) liked the strong connection between text and picture. (19%) participants found Infographic easier for spatial relations and (17%) mentioned understanding time was harder. (28%) found a clear reading order lacking.

IllustratedText—Some participants liked the cleanness and familiarity of IllustratedText (11%) and reported that they would use the text to understand the story, and could look up information on demand. However, the majority found jumping between text and picture negative (42%) as they had to create their own connections (14%), complaining about the high density of the text (31%) (*"Along with the high density of text, and hard time of bridging verbal and visual"*).

Summary

Our lab study yielded consistent and conclusive results: comics helped understanding while there was no difference between the other two formats, thus partially confirming H-Accuracy. Differences across questions highlighted specific aspects of each format. Eventually, all participants found comics more engaging, thus mostly confirming H-Engaging. Subjective feedback revealed more precise information about the respective advantages and drawbacks of each format. We could not find evidence to fully support H-Memorability.

While this evidence was collected in a controlled lab setting, the question remains of how comics and infographics compare in more ecologically valid settings, and how well each format is able to keep readers engaged who are not paid and asked to answer questions after reading. For example, our comics did not involve characters or elaborate artistic styles, nor could they feature actual topics and information. To complement our initial results, we thus designed a in-the-wild study.

6 IN-THE-WILD STUDY

The in-the-wild study was carried out during an international art festival where visitors varied in age, interest, and cultural origin, enabling us to study a more diverse set of participants compared to using standard mailing list recruiting. The study focused on the attraction of each format, how people engaged with each format and for how long, and their preferences for consuming information. To that end, we observed and coded people's behavior as well as conducting semi-structured interviews with some of the readers.

Techniques—We only used Infographic and Comic in this study. Two comics were created from existing infographics, using the same process as the lab study. Presented topics were chosen for public interest, but unrelated to any of the surrounding exhibitions to mitigate potential confounds on the respective audience attracted by our visualization. To increase attractiveness of the material for the public space, we were more free with visual presentation. Comics were

drawn by hand by an experienced comic artist and co-author of this paper. The basic visual encodings in the infographic such as colors, height and size for data variations were preserved, while also using metaphors and sketch styles from data comics (Figure 1). We used material on two subjects:

- **Hot spots—The Carbon Atlas (CarbonFootprint)** [39] shows global carbon dioxide emission by country, using bubbles of different size to indicate the amount of produced carbon dioxide, colored by region.
- **The Global Water Print (WaterUsage)** [24] indicates the volume of water needed for production and human services, showing of amount of freshwater available, the highest consumption, renewable water sources and the highest usage in food production.

Study Design—An A0 sized copy of an Infographic about CarbonFootprint and a Comic about WaterUsage were placed on a pair of easels in the street, with take-away copies of the comics and Infographic attached (Figure 1). After 1h, we exchanged the respective material to show an Infographic about WaterUsage and a Comic about CarbonFootprint. The study was conducted twice on the same Saturday, once between 11:30am-1:30pm and again from 2pm-4pm. Two study instructors were seated approx. 10 meters distant from the easels, tracking audience behavior. Visitors who read both formats were approached for an interview after they turned away from the graphics.

Data Collection—The time visitors spent at each format was measured, with talking and pointing interactions counted manually. When we interviewed visitors, we asked four questions: why did they stop? Did they finish reading? Was there anything they did not understand? and Which format they found easiest to understand?

Results

During the 4 hours a total of 43 groups stopped for more than 10 seconds to view the graphics. Most **visitors** came in groups of 2 to 4 with a wide age range from adolescent to elderly. From this, we interviewed 8 groups including 14 people of which 11 were adults, 2 elders and 1 adolescent.

We did not not find any differences in time spent on either format or story. CarbonFootprint comic was read 13 times while Infographic was read 15 times; For WaterUsage , both the comic and infographic format was read 14 times. Viewers spend between 8 and 132 seconds reading each story, with averages ranging between 37 and 48 seconds across formats. We did not find significant difference in reading time.

Counting visitors **interactions** with the material through pointing and discussing each format, we found slightly more engagement with Infographic (8 groups for Comic vs. 12 groups for Infographic). This could be seen as an indicator that the more exploratory nature of infographics prompts people wanting to share and discuss their observations, while comics focus the reader on understanding the message.

Asked about what attracted them to our graphics in the first place, 4 groups replied *topic*, 1 replied *color*, 2 replied *illustration* in the comic, 1 replied *data*. Asked about which format provided **better understanding** of the content, 6 groups preferred Comic, 1 group preferred Infographic and 1 group didn't find any difference. Reasons for preferring comics the way it visualized, the grouped messages, the metaphor, and the easy-to-follow layout. Consequently 12 people reported that Comic were their overall choice, while 1 adult and one adolescent from different groups would chose Infographic (WaterUsage). This supports the evidence from the Lab Study results, that readers find comics more "fun and enjoyable" even if this may not necessarily translate to longer reading time or improved memorability.

Participants took away slightly more copies of CarbonFootprintin comic format compared to infographics format (20 vs 16). However, this is not the case for WaterUsage, for which participants took 16 copies of each.

7 DISCUSSION

This section summarizes our findings, design implications for data comics, as well as limitations and future work.

Main Study Findings

Data Comics improve understanding and engagement—In general, data comics led to more correct answers on average. Data comics have been rated more engaging and more enjoyable, more easy to stay focused, and received better overall ratings. The reasons for these results may be explained by a variety of factors. For example, clear sequencing increases the readers ability to focus and navigate spatial-temporal information, while panels help to divide information into easy memorable chunks, with rows grouping individual messages into higher level messages. From analyzing specific questions, we found that comics performed better for some information that was explicitly shown and highlighted in panels, such as some temporal events (Alliances) or distributions (Energy). On the contrary, not highlighting important information in comics, such as visual encoding (Alliances) can lead to participants overlooking details. These results suggest that increased text-picture integration and more reading guidance (c.f. the design space in Section 3) can lead to better understanding.

Large text-picture distance impairs understanding and increases cognitive load—While illustrated texts were seen as clean and simple, some participants complained about the higher cognitive load required by the constant switching between text and figures. This can explain why participants preferred formats minimizing that distance.

Infographics foster exploration and overview—Infographics are well suited to represent spatial content and are good at delivering both overview and detail. Participants liked the way they allow for comparison, and were more likely to want to share their discoveries with other viewers. We believe techniques from data comics and infographics can be seamlessly integrated with each other, depending on data and message.

Designing Data Comics

Our results can be used to discuss and inform the design of data comic (e.g., [52]). Below, we illustrate some of the complexity of designing good data comics, often requiring multiple trade-offs.

Balancing repetition and highlighting—while most of our results point to an increase in understanding with comics, subjective feedback highlighted potential problems with excessive repetition and sequencing. Too much (visual) repetition and redundancy between panels can lead to confusion as readers struggle to notice the differences. Possible solutions include explicitly highlighting changes, using a cut-out pattern [4] to emphasize small changes, or combining several messages into one panel by using elements from infographics such as annotations. Complicated information could be explained in a large-picture pattern [4] to serve as a mental map, before individual changes are explained in detail.

Balancing sequence and overview—Sequences support temporal and complex causal information, while overviews support comparison and spatial (non-temporal) information and help readers to keep a mental map. The lack of overview has been criticized in data comics, especially if panels show details of the general visualization (e.g., map, scatter plot). However, repetition can be distracting, as mentioned above. A solution could be to carefully pace overview pictures and to make sure zoomed-in content is understood within the larger context. Where necessary, larger pictures (especially for spatial and detailed visualizations) can incorporate elements from infographics, such as annotations.

Using the layout to structure information—A comic layout provides several means to visually structure information and the story, using panels, panels inside panels, rows and potentially pages. Panel size, number and layout [4] can be used to group and relate messages, to pace reading and attention, as well as to demonstrate importance. A clear page layout, potentially including overview panels, can support information look-up and relation during reading.

Reducing visual complexity—Comics can quickly become visually overwhelming when seen at a glance, as mentioned by some participants. While we designed our comics with this issue in mind, panels full of abstract information remain a natural source of visual clutter, especially if small. Possible solutions include creating larger panels (and hence less panels per page) when panel content gets visually complex. Consistency and repetition of visual information [37] can be another solution to keep the overall visual clutter low, if the respective changes between panels are highlighted properly, as mentioned above. Yet, we could not confirm that visual complexity at a first glance actually impacts participants performance negatively.

Limitations and Future work

Type of stories and visualization—Clearly, the type of story and visualization presented in the studies may influence the the reading experience. We chose maps, networks and scatter plots as representative examples of visualizations.

Future studies need to evaluate whether our findings hold for other visualization types including simpler (e.g. bar charts, line charts) as well as more complicated and less familiar visualizations such as parallel coordinate plots, matrices or tree maps. Such types of visualizations require careful explanations to be understood and used in a storytelling context. We further believe that comics could be successful in achieving this, given their sequential nature and tight integration of textual and pictorial information and we see significant potential for data comics to explain complex data as well as contribute to aspects of visualization and data literacy.

Style and design choices—In creating panels in our data comics, we made specific design choices. Different sequences and pacing could potentially lead to different results [23] and further studies are required, e.g., in order to determine the appropriate pacing or the amount of redundancy between text and visualization. Similarly, comics may adopt different drawing styles and visualization strategies. For our lab-study, we decided on a simple, neutral style that used the same visuals and colors of the infographics, to allow for a direct comparison. For the in-the-wild study, we opted for a more visually elaborate presentation to catch people's attention on the street. Hence, Infographic and Comic were slightly more different in their visual appeal (Figure 1). However, interviews revealed that visitors were attracted mainly by the presented topics (CarbonFootprint, WaterUsage) rather than the visuals. It still is possible that introducing more elaborate drawings, characters and metaphors, will affect readers' engagement and attention [18].

Context and Audience—Our results are naturally limited by the study context and audience. While the audience of our in-the-wild study included a wide range of ages, interests, cultures, and pre-knowledge about visualizations and the presented topics, people may have been reticent to engage with the material at all, whether due to lack of interest or external distraction. Feedback and insights into people's behaviour may also vary in other contexts (e.g., students focused on studying with textbook) but our setup appears

to align with the general public's consumption of infographics, as echoed by online news article reading behaviors such as reported in Amanda Cox' talk at IEEE VIS 2011 about consumption of New York Times online articles.[1]

Story Formats—Our design space in Section 3 was chosen to motivate and structure our study. For both axes different solutions are possible and there is no unique measure that locates a specific solution. In designing our comics, we made certain choices in panel layout, sizes, style, message chunking, highlighting, text and picture redundancy, which might have had an impact on our results. Moreover, in our first experiment (Section 4), story and texts were the same across techniques, in real settings one could be more specific and add more text in infographics. Eventually, as pointed out by Bach et al. [4] data comics and infographics span a continuum with terminological and conceptual boundaries not clearly defined. Given our design space, we can adopt the same argument of fluidity for illustrated texts [3]. For example, text plus pictures can include several pictures, pictures can be linked to places inside the text, infographics can contain several pictures, can have more or less linearity, even involve features from comics. Thus, rather than comparing prototype formats, we compared *locations* in our design space. Our study aims to provide some clarity about the usage and impact of each dimension on understanding and engagement. Future designs should take the best of both worlds, i.e., using sequential, narrative, and metaphorical elements from comics, combined with exploratory and image-focused elements from infographics. Gaining more insights into design decisions will be the major challenge for future studies.

Finally, infographics, illustrated texts and comics can be compared along other dimensions and for different contexts: picture size, type of visualization and information, audience and etc [22]. Eventually, comparison with other formats for data-driven storytelling (videos, interactives, physicalizations, etc. [27]) can yield more insights in the respective drawbacks and merits of each format. Better understanding of the potentials of data comics will lead to better authoring support and education.

8 CONCLUSION

The new genre of data comics combines many features with the potential of making data-driven stories accessible and understandable. In order to verify the comics' effectiveness on reader's understanding, memorability and engagement, we conducted two experiments comparing data comics with infographics and illustrated texts. Our results are encouraging for the use of data comics, especially for complex spatio-temporal data, which are naturally hard to visualize in infographics. Our results also lead to valuable implications for designing future comics.

[1] http://ieeevis.org/year/2011/keynote/visweek/how-editing-and-design-changes-news-graphics

ACKNOWLEDGEMENTS

We wish to thank all the participants in this study, including the visitors in the in-the-wild study, and the colleagues who gave us feedback on the study materials.

REFERENCES

[1] Paul A Aleixo and Krystina Sumner. 2017. Memory for biopsychology material presented in comic book format. *Journal of Graphic Novels and Comics* 8, 1 (2017), 79–88.

[2] Benjamin Bach, Natalie Kerracher, Kyle Wm Hall, Sheelagh Carpendale, Jessie Kennedy, and Nathalie Henry Riche. 2016. Telling stories about dynamic networks with graph comics. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI)*. ACM, 3670–3682.

[3] Benjamin Bach, Nathalie Henry Riche, Sheelagh Carpendale, and Hanspeter Pfister. 2017. The Emerging Genre of Data Comics. *IEEE computer graphics and applications* 38, 3 (2017), 6–13.

[4] Benjamin Bach, Zezhong Wang, Matteo Farinella, Dave Murray-Rust, and Nathalie Henry Riche. 2018. Design patterns for data comics. In *Proceedings of ACM SIGCHI Conference on Human Factors in Computing Systems (CHI)*. ACM, 38.

[5] Benjamin Bach, Zezhong Wang, Matteo Farinella Nathalie Henry Riche, Dave Murray-Rust, Sheelagh Carpendale, and Hanspeter Pfister. 2018. online: retrieved from http://datacomics.net.

[6] Alan D Baddeley. 1997. *Human memory: Theory and practice*. Psychology Press.

[7] Scott Bateman, Regan L Mandryk, Carl Gutwin, Aaron Genest, David McDine, and Christopher Brooks. 2010. Useful junk?: the effects of visual embellishment on comprehension and memorability of charts. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*. ACM, 2573–2582.

[8] Arnd Bernaerts. 2006. Booklet on Naval War changes Climate. (2006).

[9] Rebecca Bertram and Radostina Primova. 2018. *Energy Atlas 2018: Figures and Facts about Renewables in Europe*. Heinrich Böll Foundation.

[10] John B Black and Gordon H Bower. 1979. Episodes as chunks in narrative memory. *Journal of verbal learning and verbal behavior* 18, 3 (1979), 309–318.

[11] Michelle A Borkin, Azalea A Vo, Zoya Bylinskii, Phillip Isola, Shashank Sunkavalli, Aude Oliva, and Hanspeter Pfister. 2013. What makes a visualization memorable? *IEEE Transactions on Visualization and Computer Graphics* 19, 12 (2013), 2306–2315.

[12] Paul Chandler and John Sweller. 1991. Cognitive load theory and the format of instruction. *Cognition and instruction* 8, 4 (1991), 293–332.

[13] James M Clark and Allan Paivio. 1991. Dual coding theory and education. *Educational psychology review* 3, 3 (1991), 149–210.

[14] Neil Cohn. 2013. *The Visual Language of Comics: Introduction to the Structure and Cognition of Sequential Images*. A&C Black.

[15] Neil Cohn. 2014. The architecture of visual narrative comprehension: the interaction of narrative structure and page layout in understanding comics. *Frontiers in Psychology* 5 (2014). https://doi.org/10.3389/fpsyg.2014.00680

[16] C. Delp and J. Jones. 1996. Communicating information to patients: the use of cartoon illustrations to improve comprehension of instructions. *Academic Emergency Medicine: Official Journal of the Society for Academic Emergency Medicine* 3, 3 (March 1996), 264–270.

[17] Judy Diamond, Julia McQuillan, Amy N. Spiegel, Patricia Wonch Hill, Rebecca Smith, John West, and Charles Wood. 2016. Viruses, Vaccines and the Public. *Museums & Social Issues* 11, 1 (Jan. 2016), 9–16. https://doi.org/10.1080/15596893.2016.1131099

[18] Matteo Farinella. 2018. The potential of comics in science communication. *Journal of Science Communication* 17, 01 (2018), Y01–1.

[19] Tom Foulsham, Dean Wybrow, and Neil Cohn. 2016. Reading without words: Eye movements in the comprehension of comic strips. *Applied Cognitive Psychology* 30, 4 (2016), 566–579.

[20] Ola Rosling Hans Rosling and Anna Rosling RÃűnnlund. [n. d.]. online: https://www.gapminder.org, [last accessed: 17 Aug 2018].

[21] Jay Hosler and KB Boomer. 2011. Are comic books an effective way to engage nonmajors in learning and appreciating science? *CBEâĂŤLife Sciences Education* 10, 3 (2011), 309–317.

[22] Jessica Hullman and Nick Diakopoulos. 2011. Visualization rhetoric: Framing effects in narrative visualization. *IEEE transactions on visualization and computer graphics* 17, 12 (2011), 2231–2240.

[23] Jessica Hullman, Steven Drucker, Nathalie Henry Riche, Bongshin Lee, Danyel Fisher, and Eytan Adar. 2013. A deeper understanding of sequence in narrative visualization. *IEEE Transactions on visualization and computer graphics* 19, 12 (2013), 2406–2415.

[24] US Infrastructure. 2010. online: retrieved from http://aquadoc.typepad.com/waterwired/water_quantity/page/121/. Original website not available anymore..

[25] Nam Wook Kim, Nathalie Henry Riche, Benjamin Bach, Guanpeng A Xu, Matthew Brehmer, Ken Hinckley, Michel Pahud, Haijun Xia, Michael McGuffin, and Hanspeter Pfister. 2019. DataToon: Drawing Dynamic Network Comics With Pen + Touch Interaction. In *Proc. of ACM Conference of Human Factors in Computing Systems (CHI)*.

[26] Robert Kosara and Jock Mackinlay. 2013. Storytelling: The next step for visualization. *Computer* 46, 5 (2013), 44–50.

[27] Stephanie A. Kraft, Melissa Constantine, David Magnus, Kathryn M. Porter, Sandra Soo-Jin Lee, Michael Green, Nancy E. Kass, Benjamin S. Wilfond, and Mildred K. Cho. 2016. A randomized study of multimedia informational aids for research on medical practices: Implications for informed consent. *Clinical Trials* 14, 1 (Sept. 2016), 94–102. https://doi.org/10.1177/1740774516669352

[28] W Howard Levie and Richard Lentz. 1982. Effects of text illustrations: A review of research. *ECTJ* 30, 4 (1982), 195–232.

[29] Huifen Lin and Tsuiping Chen. 2007. Reading authentic EFL text using visualization and advance organizers in a multimedia learning environment. (2007).

[30] Narges Mahyar, Sung-Hee Kim, and Bum Chul Kwon. 2015. Towards a taxonomy for evaluating user engagement in information visualization. In *Workshop on Personal Visualization: Exploring Everyday Life*, Vol. 3. 2.

[31] Richard E. Mayer and Joan K. Gallini. 1990. When is an illustration worth ten thousand words? *Journal of Educational Psychology* 82, 4 (1990), 715–726. https://doi.org/10.1037/0022-0663.82.4.715

[32] Scott McCloud. 1993. Understanding comics: The invisible art. *Northampton, Mass* (1993).

[33] Sarah McNicol. 2017. The potential of educational comics as a health information medium. *Health Information & Libraries Journal* 34, 1 (2017), 20–31.

[34] Antoni B. Moore, Mariusz Nowostawski, Christopher Frantz, and Christina Hulbe. 2018. Comic Strip Narratives in Time Geography. *ISPRS International Journal of Geo-Information* 7, 7 (2018). https://doi.org/10.3390/ijgi7070245

[35] Heather L O'Brien and Elaine G Toms. 2010. The development and evaluation of a survey to measure user engagement. *Journal of the American Society for Information Science and Technology* 61, 1 (2010), 50–69.

[36] Allan Paivio. 1990. *Mental representations: A dual coding approach*. Oxford University Press.

[37] Zening Qu and Jessica Hullman. 2018. Keeping multiple views consistent: Constraints, validations, and exceptions in visualization authoring. *IEEE Transactions on Visualization and Computer Graphics (TVCG)* 24, 1 (2018), 468–477.

[38] Nathalie Henry Riche, Christophe Hurter, Nicholas Diakopoulos, and Sheelagh Carpendale. 2018. *Data-driven Storytelling*. CRC Press.

[39] Simon Rogers and Mark Mccormick. 2010. online: retrieved from http://image.guardian.co.uk/sys-files/Guardian/documents/2007/12/17/CARBON_ATLAS.pdf. Original website not available anymore..

[40] Gertjan Rop, Anne Schüler, Peter PJL Verkoeijen, Katharina Scheiter, and Tamara Van Gog. 2018. The effect of layout and pacing on learning from diagrams with unnecessary text. *Applied Cognitive Psychology* (2018).

[41] Hans Rosling. [n. d.]. Some cool motion sensor stuff. https://www.ted.com/talks/hans_rosling_shows_the_best_stats_you_ve_ever_seen#t-230391

[42] Bahador Saket, Alex Endert, and John Stasko. 2016. Beyond usability and performance: a review of user experience-focused evaluations in visualization. In *Proceedings of the Sixth Workshop on Beyond Time and Errors on Novel Evaluation Methods for Visualization*. ACM, 133–142.

[43] Wolfgang Schnotz and Maria Bannert. 2003. Construction and interference in learning from multiple representation. *Learning and instruction* 13, 2 (2003), 141–156.

[44] Edward Segel and Jeffrey Heer. 2010. Narrative visualization: Telling stories with data. *IEEE transactions on visualization and computer graphics* 16, 6 (2010), 1139–1148.

[45] Jeremy C. Short, Brandon Randolph-Seng, and Aaron F. McKenny. 2013. Graphic Presentation An Empirical Examination of the Graphic Novel Approach to Communicate Business Concepts. *Business Communication Quarterly* 76, 3 (Sept. 2013), 273–303. https://doi.org/10.1177/1080569913482574

[46] Nick Sousanis. 2015. *Unflattening*. Harvard University Press, Cambridge, Massachusetts.

[47] Amy N Spiegel, Julia McQuillan, Peter Halpin, Camillia Matuk, and Judy Diamond. 2013. Engaging teenagers with science through comics. *Research in science education* 43, 6 (2013), 2309–2326.

[48] Nicole Sultanum, Michael Brudno, Daniel Wigdor, and Fanny Chevalier. 2018. More Text Please! Understanding and Supporting the Use of Visualization for Clinical Text Overview. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, 422.

[49] M Tatalovic. 2009. Science comics as tools for science education and communication: a brief, exploratory study. *Jcom* 8, 4 (2009), A02.

[50] Redda Tekle-Haimanot, Preux Pierre-Marie, Gerard Daniel, Dawit Kibru Worku, Hanna Demissie Belay, and Meron Awraris Gebrewold. 2016. Impact of an educational comic book on epilepsy-related knowledge, awareness, and attitudes among school children in Ethiopia. *Epilepsy & Behavior: E&B* 61 (Aug. 2016), 218–223. https://doi.org/10.1016/j.yebeh.2016.05.002

[51] Barbara Tversky. 2011. Visualizing thought. *Topics in Cognitive Science* 3, 3 (July 2011), 499–535. https://doi.org/10.1111/j.1756-8765.2010.01113.x

[52] Zezhong Wang, Harvey Dingwall, and Benjamin Bach. 2019. Teaching Data Visualization and Storytelling with Data Comic Workshops. In *Proc. of ACM Conference of Human Factors in Computing Systems (CHI), Extended Abstracts*.

[53] Gene Yang. 2008. Graphic Novels in the Classroom. *Language Arts 85.3* (2008), 185.

[54] Zhenpeng Zhao, Rachael Marr, and Niklas Elmqvist. 2015. Data Comics: Sequential Art for Data-Driven Storytelling. *Tech. report* (2015).