A Study of the Effects of Narration on Comprehension and Memorability of Visualisations

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Abstract

Information visualisation researchers have posited that author-driven narratives will allow information to be conveyed efficiently and argue for the adoption of storytelling techniques in information visualisation. However, limited work has been done to date to concretely examine the effects of author-driven narratives in users' comprehension and memorability of visualisations, and their associated benefits and limitations in relation to interactive visualisations (devoid of author narratives). Recommendations for author-driven visualisation stories are largely based on anecdotal reports and/or research from journalism, and not on factual user studies in information visualisation. To investigate these issues, we carried out a confirmatory user study that compared purely author-driven narratives with interactive visualisations devoid of author narratives, in terms of comprehension and short-term and long-term memorability. We found that the presence of narration in author-driven stories significantly aided the understanding of information but had no significant effect on the long-term recall of information from visualisations.

Keywords: visualisation, experiment, storytelling, presentation, comprehension,

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memorability

1. Introduction

Research in the field of information visualisation has highlighted the barriers encountered by users in engaging with visualisations [1, 2]. These studies mainly identify users' challenges in understanding and interpreting visualisations. Consequently, new approaches are emerging to tackle these issues.

A promising approach is the adoption of narrative visualisation - the combination of information visualisations with storytelling mechanisms. Throughout history, storytelling has been an effective way of conveying information and knowledge, as stories provide the causal link between facts that make them memorable [3].

Narrative visualisation (or visualisation story) is an ordered sequence of steps, each of which can contain words, images, visualisations, video, or any combination thereof [3]. Narrative visualisation consists of two different approaches; author-driven and reader-driven approaches. In an author-driven narrative, a strictly linear path is followed in presenting the data visualisation and leaves no room for interactivity. This approach relies on the author to communicate findings from the data visualisation to the audience in an accessible manner e.g., presentation videos, live presentations [4]. A good demonstration of an author-driven approach is Hans Rosling's Gapminder presentation at the 2006 TED conference (`http://tiny.cc/x181sy`) [3, 5]. On the other hand, a reader-driven narrative has no defined path and is highly interactive, and relies on the audience to interact with the data visualisation, interpret it and gain insights by themselves e.g., interactive visualisation graphs created in the form of slideshows.

Borrowing from research in the arts and journalism that depict stories as engaging and memorable [6, 7], visualisation researchers have posited that author-driven narratives will allow information to be conveyed efficiently and argue for the adoption of storytelling techniques in information visualisation [8, 3, 9]. Others have suggested that visualisations presented in the form of narrative

stories are "psychologically efficient" [4] and call for its advancement as a primary way of communicating information visualisation [10, 11, 12, 13]. The recent increase in data journalism has also served to promote interest in narrative visualisation [14, 15].

Moreover, limited work has been done to concretely examine the effects of author-driven narratives in users' comprehension and memorability of visualisations[16], and their associated benefits and limitations in relation to interactive visualisations (devoid of author narratives) [3]. Recommendations for author-driven visualisation stories are largely based on anecdotal reports and/or research from journalism, and not on factual user experiments in information visualisation [17, 18].

To investigate these issues, we carried out a confirmatory user study to examine the effects of author-driven narration in user comprehension and short-term and long-term memorability of visualisations, using interpretation and recall accuracy as measures. We do not propose our study to be final and immutable in its current form; instead, we present our work as one of the early steps in unravelling users perspectives on narration in information visualisation. We also aim to contribute a nuanced point of view to the current discussion in the narrative visualisation community concerning the appropriateness, benefits and limitations of narration in visualisation.

The main contributions of this study and its findings include:

1. we carried out a controlled confirmatory study comparing performance in understanding and recalling information using author-driven narratives in relation to interactive visualisations (devoid of author narratives)
2. we discovered a significant improvement in user comprehension of the visualisation when engaged with author-driven narratives
3. we found no significant difference in long-term recall of information when using either author-driven narratives or interactive visualisations
4. There is a fine line between complete data control and increased cognitive load in the presentation of visualisation stories to a target audience

5. Users are concerned about the subjectivity of narratives in the presentation of visualisations

After discussing related literature in the next Section, we underscored our motivation for the user study in Section 3. We describe the design of our user study in Section 4. In Section 5, we discuss the results of the user study and their relevance in information visualisation, threats to validity and the control techniques we applied, and also outline direction for future work. Finally, we conclude the paper in Section 6.

2. Related Literature

2.1. Narrative Visualisation

Information visualisation, the graphical representation of data [19], serves two broad purposes - 1. exploratory i.e., discovering insight from data, and 2. communicative i.e., presenting the discovered insights to others [20, 19, 21]. Since the seminal work on narrative visualisation by Gershon and Page [8], researchers have begun to pay attention to the communicative aspect of visualisation and the adaptation of storytelling mechanisms [9, 4, 11, 10, 18, 22].

Although the earliest ideas of narrative visualisations were proposed by Gershon and Page [8], their work does not offer a concrete framework for creating visualisations using the mechanisms of traditional narratives, nor a structure for understanding the intersection between the two. However, they did make a profound case for the adoption and advancement of narrative visualisations. Using a hypothetical military exercise scenario, they explored various methods to convey narrative events such as continuity, setting the mood and time in place, and filling gaps. They also argued for the application of the "psychologically - efficient" format of stories to information visualisation, a perspective further supported by other researchers [10, 11, 12, 13]. Our study tests these suggestions of the benefits of storytelling within the context of information visualisation and contributes an empirical perspective to the narrative visualisation literature.

Segel and Heer [4] analysed 58 narrative visualisations from different sources including news media, academia, and online journalism. Their work highlights 7 genres of narrative visualisations - magazine style, annotated charts, infographics, flow charts, comic strips, slideshows and videos. Moreover, their framework for designing narrative visualisation places it on a spectrum of author-driven and reader-driven approaches. In an author-driven approach, there is heavy messaging, a strictly linear path is followed and there is no room for interactivity. On the other hand, a reader-driven approach has little or no messaging, no defined path, and is highly interactive. Both approaches to narrative visualisations contribute to the exploratory and communicative goals of visualisations and part of our research seeks to examine how the two approaches affect the comprehension and memorability of visual narratives in terms of accuracy and recall.

More focused studies have explored the role of rhetorical techniques in narrative visualisations and how they influence the interpretation of visualisations [23]. These techniques which are external to the visualisations have the potential to help visualisation designers and researchers design multilayered and engaging visualisations while encouraging an intended interpretation on their target audience. This suggests that narrative visualisations are beyond visualisations alone and can be correctly categorised as multimedia artefacts, with the designers knowingly or unknowingly influencing their target audience' interpretation of the presented information. However, this does not come as a surprise, as conventional stories typically utilise a combination of persuasive and linguistic techniques to convey ideas and information; and visualisation designers think of the analysis process in terms of a presentation [24]. Part of our study aims to show users' perspective on the application of rhetorical techniques in the delivery of a visualisation story by an author.

More recently, Boy et al. [18] carried out a study to learn if the use of narrative visualisations engages users to explore data. They discovered from their three web-based field experiments that annotating exploratory visualisations with preliminary narratives does not necessarily lead to an increase in user-engagement in data exploration. We build on this by going beyond user-

engagement and examining the effects of narration on user comprehension and recall of visualisations.

While these studies have broadened our knowledge on the authoring processes and structures of narrative visualisations and effects of rhetorical techniques none of these studies have examined the contradistinctions between a purely author-driven and reader-driven narratives, in terms of comprehension and memorability, and how viewer generated narratives compare to author intended narratives. We aim to fill this gap with the insights from our user study.

2.2. Comprehension and Memorability of Visualisations

Extensive work has been carried out in the area of visualisation comprehension [3, 1, 25, 26, 27]. However, these are focused on elementary static charts without interaction because interactivity engages many more layers and levels of cognitive processes, and are difficult to study [28]. In this context, comprehension is measured as a trend and/or value reading in experiments [16, 29]. Four factors impacting chart comprehension amongst users have been identified: chart formats [1], visual characteristics, knowledge about charts and knowledge about content [1, 25].

Bateman et al. [16] carried out an experiment to compare embellished charts (i.e., charts with added visual imagery) with plain charts and measured the results in terms of comprehension and long-term memorability. There were no significant differences between comprehension results for embellished charts and plain ones. Remarkably though, participants' long-term memorability scores for embellished charts were significantly better than plain charts. Also, participants notably preferred embellished charts over plain charts. In a follow-up study, Li and Moacdieh [29] introduced time constraints to investigate whether time limit affects comprehension and memorability. Their results did not vary from Bateman et al.'s [16] - embellished charts were more attractive and memorable, and did not hinder the comprehension of the presented data. Haroz, Kosara and Franconeri [30] found a related result - pictographs embedded as part of data visualisations are beneficial for aiding user engagement and comprehension of

visualisations.

From a memorability perspective, Borkins et al. [31] examined factors that make a visualisation memorable. Their findings suggest that visualisations with high visual densities and human recognisable objects are more memorable than their minimalistic counterparts. Embellished visualisations were better remembered than simple visualisation types such as bar charts. However, they also noted that better memorability does not necessarily translate to a better comprehension of the presented information. Further evidence from a follow-up study [32] reports that visualisations that are memorable are also capable of increasing user comprehension; and redundancy - a rhetorical technique frequently used in storytelling, aids the effective communication of presented information [32, 23]. Nonetheless, a similar study [33] has shown that while visual embellishments are effective tools for recalling information shown in visualisations, they can have a negative impact on the speed of visual search and lead to a potential increase in user's processing time.

The aforementioned studies [31, 32, 33, 29, 16] provide valuable insight into comprehension and memorability of visualisations, but these studies are focused on static charts (both embellished and plain) that lack interactivity, even though interactivity has been shown to improve the analytical experience of users [34, 35]. Our confirmatory study examines the effects of author-driven narratives using data presentation videos in relation to interactive visualisations (devoid of author narratives) in terms of comprehension, and short-term and long-term memorability. We also explore users' perspective on issues of bias, cognitive load, and preferences in both author-driven narratives and interactive visualisations.

3. Motivation for the Study

Author driven visualisation stories typically comprise a collection of story items i.e., facts based on data. These story items are then visualised to promote certain value messages. The value messages can be derived from the trend

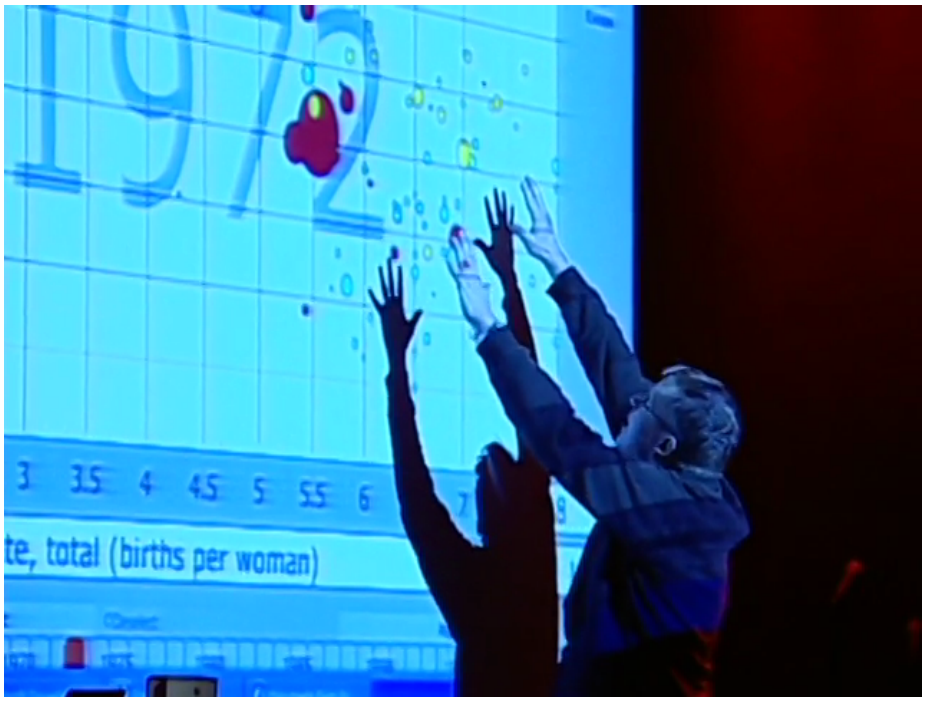


Figure 1: A sample screenshot taken from an author-driven presentation video with a narrator providing commentary on the visualisation.

and patterns of the facts. The author emphasizes these value messages and then presents the collection of story items in a logical order to support his/her presentation goals [5].

Moreover, cognitive science posits the presence of two memory types: semantic memory for understanding and recalling basic facts, and episodic memory for collecting and contextualising facts over time and place [9]. Episodic memory also associates facts with emotions, an attribute that conventional stories exploit. By presenting visualisations as stories, supporting one or more value messages and delivered in a logical sequence, visualisations can take advantage of episodic memory and organise themselves as a unified and coherent whole. Thus, narrative visualisation stories have the potential of enhancing user comprehension and recall of information visualisations, as have been suggested in the literature [10, 11, 12, 13, 4].

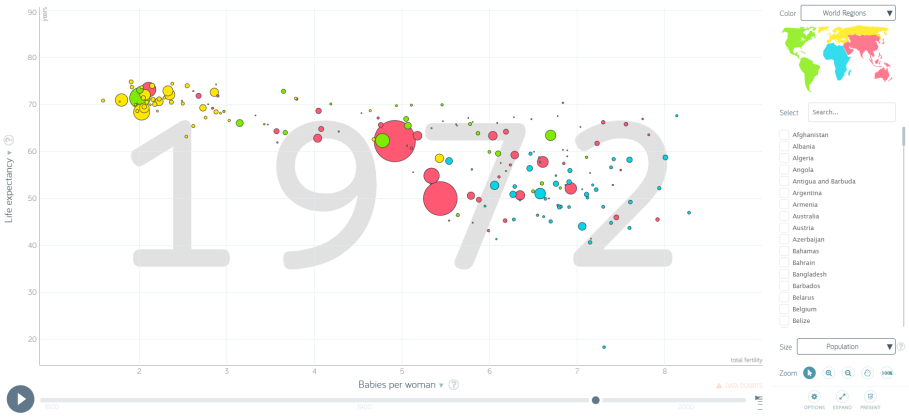


Figure 2: A sample screenshot of a fully interactive visualisation (devoid of narration) created to match the one shown in the presentation video in Figure 1 above.

However, while stories, as utilised in the arts, have been shown to be effective [6, 7], there is no empirical evidence to support this claim in the field of information visualisation because the information content and narrative communicated in visualisations are not just entertainment as in the arts but the communication of much more complicated and complex information. We present this work as one of the early steps in unravelling how author-driven narratives of visualisations affect user comprehension and recall of information visualisations. We also aim to test the general assumptions of the literature on the benefits of author-driven narratives and contribute a nuanced perspective to the current discussions in the narrative visualisation community.

4. Experimentation

4.1. Context Selection

The context of the experiment can be characterised as offline - it was run in a university research lab with 73 percent of student participants (both undergraduates and postgraduates) from 3 universities, and 27 percent industry professionals. It addresses a real challenge i.e. the role of author-driven narratives in user comprehension and memorability of information visualisations, and

also explores users' perspective on the use of rhetorical techniques by authors in the delivery of visualisation stories. The limitation of the experiment context to the generalisability of the results is presented in Subsection 5.6.

4.2. Hypothesis

In order to examine the effects of narration on the comprehension and recall of visualisations, we investigated the following 6 hypotheses for the user study:

H1: Author-driven narratives based on the presentation videos would better aid the comprehension of facts based on the data than interactive visualisations (devoid of author narratives).

H2: Author-driven narratives based on the presentation videos would better aid the comprehension of value messages and trends based on the data than interactive visualisations (devoid of author narratives).

H3: In the short-term, author-driven narratives based on the presentation videos would better aid the recall of facts than interactive visualisations (devoid of author narratives).

H4: In the short-term, author-driven narratives based on the presentation videos would better aid the recall of value messages and trends than interactive visualisations (devoid of author narratives).

H5: In the long-term, author-driven narratives based on the presentation videos would better aid the recall of facts than interactive visualisations (devoid of author narratives).

H6: In the long-term, author-driven narratives based on the presentation videos would better aid the recall of value messages and trends than interactive visualisations (devoid of author narratives).

4.3. Variable Selection

4.3.1. Independent Variables

The independent variables are

1. Time
   (a) 5 minutes interval (for short-term recall)
   (b) 2 - 3 weeks interval (for long-term recall)
2. Type of Visualisation artefacts
   (a) Interactive visualisation
   (b) Video presentation

4.3.2. Dependent Variables

The dependent variable is

Accuracy

(a) Comprehension accuracy
(b) Recall accuracy

4.4. Selection of Subjects

We recruited a total of 40 participants (32 male and 8 female) to participate in the user study. The limitation of the gender skew is addressed in Subsection 5.6.2. Of the 40 participants, there were 11 industry professionals in diverse fields and the remaining 29 were a mix of both undergraduate and postgraduate university students from 3 different universities studying different courses covering arts and humanities, design and architecture, and sciences and engineering disciplines. In order to increase the diversity in demographics of participants, we contacted them through flyers on notice boards across campuses, mailing list and Facebook group announcements.

All participants had basic computer skills and were aged between 18 and 50 years old. Their self-reported data analysis and visualisation skills ranged from *Not familiar (1)* to *Very familiar (4)* on a 4-point Likert scale.

There was no financial compensation for study participation. All participants voluntarily participated in the study and there were no conflicts of interest.

4.5. Experiment Design

We formulated a confirmatory within-subject user study (with the ethics board approval) to examine the benefits and limitations of author-driven narratives using presentation videos in relation to interactive visualisations (devoid of author narratives), in terms of comprehension and memorability. We chose a within-subject experiment design because it provides a good control of the individual differences in our subjects and allows for good statistical power. Also, the experiment uses a balanced design i.e. that there is the same number of persons in each recall category (20 participants each in both long-term and short-term category).

4.6. Instrumentation

4.6.1. Data

The data used for the study is from the United Nations Common Database [36]. Our choice of this data was partly influenced by a high quality study carried out by Robertson et al. [24], and also because the data is readily available in the Gapminder tool.

4.6.2. Visualisation Artefacts

For our presentation videos, we created 8 excerpts from 8 Han's Roslings' data visualisation talks [37] (See Figure 1). We chose Hans Rosling' talks because the underlying data and Gapminder tool are readily available to recreate the visualisations with all the features (e.g., animation) used in the talks. Moreover, Rosling's data visualisation talks are good examples of author-driven stories [3, 5]. The video excerpts contain visualisations created using the Gapminder software [38] with the presenter describing the visualisation elements and providing a specific value message based on the trend of the data over time. The presenter also emphasized facts that are based on the data. The presentation thus serves as a commentary on the visualisations.

For each of the presentation videos, we created a fully interactive visualisation **similar** to the one in the video using the Gapminder software, with the same data

and graph elements e.g., same y-axis, x-axis (See Figure 2). A play/pause button is present at the bottom left of each visualisation. This allows participants to animate changes in trends over time. There is also a time-slider which enables participants to step through the visualisation over time as they deem fit. Participants were able to interact with the interactive visualisation, examine data values and observe trends over time in a manner similar to the presenter in the presentation video. There were 8 presentation videos and 8 interactive visualisations.

Throughout the rest of this paper, both the presentation videos and interactive visualisation will be jointly referred to as ***visualisation artefacts***.

4.7. Operation

4.7.1. Pilot Study

Prior to beginning the user study, we carried out a pilot study with 2 external participants (not from our 40 participants) and used the feedback to improve the experiment instruments before carrying out the main experiment with the 40 participants. As a result of the pilot study, we carried out the following adjustment:

1. Overlapping task questions were removed
2. The number of task questions was reduced. This also led to a reduction in the time taken to complete the user study (from approximately 100 minutes to approximately 70 minutes)
3. Ascertained that all task questions can be answered from both their interactive visualisations and their author-driven presentation video counterparts

4.7.2. Apparatus

The user study was conducted using a desktop computer running Microsoft Windows 7, a 23-inch LCD monitor and standard peripheral devices - keyboard and mouse.

4.7.3. Data Collection Instruments

Both demographic and main experiment data were captured using online questionnaires. The survey instruments can be found in the supplementary materials. Each experiment session was facilitated on-site by investigators. Although participants were allowed to ask clarification questions and get more information from investigators, they were not allowed to refer to materials (either offline or online) beyond the survey instruments delivered to them.

4.7.4. Procedure

The user study was carried out in 2 phases: a comprehension phase and a recall phase. Participants were not informed about the recall phase in order to avoid active memorisation during the comprehension phase. They were only told that there is a second phase of the study to be carried out at a later time. Participants were randomly placed in one of two recall groups (short-term recall or long-term recall), with 20 participants in each group. Members of the short-term recall group were engaged in an off-topic non-related discussion for about 5 minutes to clear their visual-linguistic memory before proceeding to the recall task. Of the total 40 participants, only one participant reported to have seen a Hans Rosling talk before the study.

Participants were informed of the purpose, benefits and voluntary nature of the user study and were asked to sign a consent form before the session began. An investigator then explained the comprehension task and how participants were expected to carry them out. Participants completed a demographics pre-survey and reported on their background with data analysis and visualisation before the main test began.

During the user study, we presented both the presentation videos and inter active visualisations to participants. All participants saw either a presentation video or interactive visualisation for each task question. In order to prevent confounding effects in the order of presentation and task questions in our within-subject experiment design, we counterbalanced the order of the presentation videos and interactive visualisations for all participants.

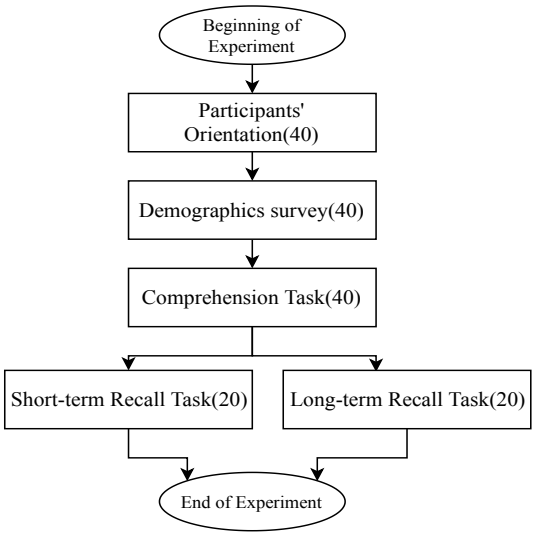


Figure 3: Experiment procedure steps. Numbers in brackets represent number of participants in that step.

In addition, the entire experiment takes approximately 70 minutes to complete - 40 minutes for the comprehension phase and 30 minutes for the recall phase. A summary diagram of the experiment procedure is shown in Figure 3.

4.7.5. Execution

Comprehension Phase. The comprehension phase commenced by showing participants a counterbalanced presentation of the interactive visualisations (devoid of author narratives) and the presentation videos. There were 3 questions associated with any of the interactive visualisations or presentation videos, making it a total of 24 questions in the comprehension task. The first and second questions are multiple choice questions (MCQ) about related facts - the approximation of a data point or set of data points or categories that meet a set attribute criteria while the third question is an open-ended question about the value message - the primary narrative of the visualisation. The task questions were motivated by questions addressed by Hans Rosling in his talks [37, 24] and related studies [16, 24].

Participants were encouraged to watch the presentation videos and interact

with the visualisations before attempting the task questions. Each participant saw 4 presentation videos and 4 interactive visualisations. The order of the presentation videos and interactive visualisations was counterbalanced for all participants so as not to confound the order in which the task is performed with the experimental treatment. For instance, participant P1 may see an interactive visualisation for the first question while participant P2 may be shown a presentation video for the same question. They were also advised to answer the task questions based on the information from only the interactive visualisations and presentation videos and not on preconceived beliefs. The comprehension task questions are marked compulsory. Below are sample comprehension task questions:

1. In the 1960's, what two regions had predominantly more babies and shorter life expectancy?
   (a) Asia, Europe
   (b) Asia, Africa
   (c) Africa, The Americas
   (d) Others (Please specify)
2. By the early 2000's, what's the estimate of countries with life expectancy above 50 years?
   (a) Approximately 50%
   (b) Less than 30%
   (c) More than 90%
   (d) Others (Please specify)
3. What's the main message being communicated by the author of this visualisation artefact?

After completing the comprehension phase task questions, participants completed an open-ended survey about the knowledge gained from the visualisations and the challenges they encountered while completing the task.

Recall Phase. Upon the successful completion of the comprehension phase, participants were assigned to one of two recall groups (short-term or long-term recall). Each group had 20 members. Participants in the short-term recall group completed the recall task 5 minutes after the comprehension phase while those in the long-term recall group completed the recall task in 2 to 3 weeks' time. Both groups of participants were not aware of the recall task during the comprehension phase although they were told there would be a second phase of the user study that is closely related to the comprehension phase. This was done to prevent participants from active memorisation during the comprehension phase.

The main recall task began by asking participants to write down in the spaces provided on the survey and describe the contents of the visualisations they saw in the comprehension phase with as many details as they could remember, including graph elements (e.g., y-axis, x-axis etc.), the value messages and narratives of the visualisations. Points were awarded to correctly stated visualisation subjects, displayed categories and value messages [16, 29]. They were told that they do not have to remember the visualisations in the order in which they appeared in the comprehension phase. However, they were advised to note the source of each visualisation they recall by selecting one of the following options; *presentation video*, *interactive visualisation*, or *I do not remember*. (It is important to note here that the investigators matched participants' recollection of the perceived source of visualisations with the true source of the visualisations shown to them during their own individual session of the comprehension phase). Long-term and short-term memorability questions are the same. Below are sample recall task questions:

A. Describe each of the visualisations you remember (including y-axis, x-axis, title) from the previous stage of the survey. Comment on what the visualisation is about and also on whether the visualisation shows any changes and describe these changes.

   Note: It does not have to be in the order you were shown in the previous survey. Please enter "I Don't Remember" in the answer area provided if

you no longer remember a visualisation.

B. The source of the visualisations I remembered and described above are:

Table 1: Single row matrix question in the survey. Displayed here as a table.

	Video Presentation	Interactive Visualisation	I Don't Remember
Visualisation 1			
...	...	...	...
Visualisation 8			

Note: This should correspond to the order of the answers described above e.g. description of Visualisation 1 above should correspond to Visualisation 1 radio button.

At the end of the recall phase for both recall groups, participants completed a subjective preference questionnaire indicating their leaning towards the author-driven narrative based on the presentation videos or the interactive visualisations (devoid of author narratives) by answering a set of questions related to the comprehension and recall of the visualisations.

4.7.6. Data Validation

Data was originally collected for 51 participants. After the completion of the experiment, data from 11 participants was removed because these participants did not return to complete the second phase of the study. As a result, only data from 40 participants was used for statistical analysis and interpretation of results.

5. Results and Discussion

We present the outcomes of the user study related to the effects of narration on user comprehension and recall of visualisations. The data distribution is not wholly symmetric. However, because both groups of samples (author-driven narratives and interactive visualisations) are drawn from the same approximately

Table 2: Summary of pair-wise t-test results between presentation videos (with author narratives) and interactive visualisations (devoid of author narratives). * indicates significant differences ($p < 0.05$)

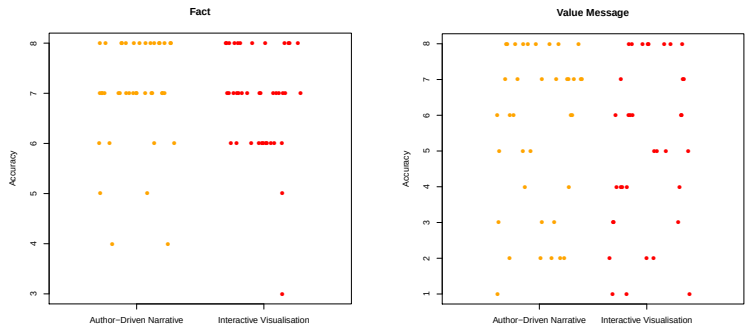
Question type	p-value	t-value
Comprehension (Fact)	0.36	0.92
Comprehension (Value message)	0.04	2.08*
Short-term recall (Fact)	0.04	2.15*
Short-term recall (Value message)	0.3	1.06
Long-term recall (Fact)	0.19	1.37
Long-term recall (Value message)	0.77	0.29

normal distributions with similar variances, the pair-wise t-test is fairly robust to the underlying data distribution and appropriate for analysis [39, 40]. Also, because the sample size in each group is not too small, there is no danger of a type 1 error.

We applied the pair-wise t-test ($alpha = 0.05$) for all our analysis in contrasting the author-driven narratives based on presentation videos and interactive visualisations (devoid of author narratives) covering comprehension, short-term and long-term recall. A pair-wise t-test is appropriate here because this is a within-subject experiment and each participant served as their own control. A two-tailed t-test was utilised in the places where we sought to examine if either the presentation videos (with author-driven narratives) was significantly better or worse than interactive visualisations (without author narratives). Our results also show the benefits and limitations of author narration in the presentation of information visualisations. The summary of the t-test results is shown in Table 2.

5.1. Comprehension

We carried out pair-wise t-tests to examine whether the presence of narration in the presentation videos improved participants' understanding of related facts based on the data and the value message over interactive visualisations (without



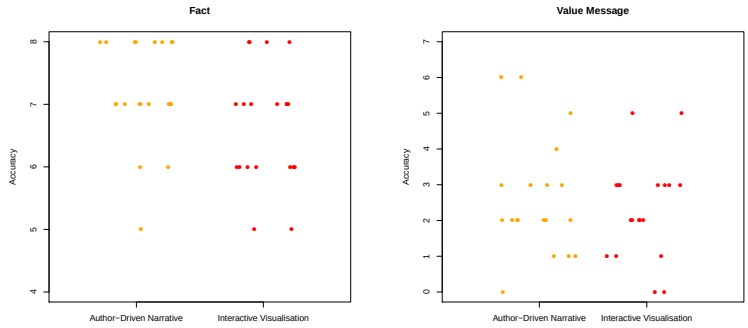
(a) Fact comprehension (b) Value message comprehension

Figure 4: Accuracy scores of fact and value message comprehension.

author narratives). Although the averages of the scores of presentation videos were higher than their interactive visualisations counterparts (See Figure 4), we found no significant differences ($t_{40} = 0.92, p = 0.36$) between the scores of facts-related questions for both the presentation videos and interactive visualisations. This result refutes hypothesis H1. However, there was a significant difference ($t_{40} = 2.08, p = 0.04$) in the scores of the value messages between the presentation videos and interactive visualisations (See Figure 4). Participants understood the value messages of the presentation videos better than their interactive visualisation counterparts, thereby confirming hypothesis H2.

5.2. Recall

We carried out t-tests to examine whether or not the author-driven narration present in the presentation videos was more effective in helping participants to recall facts based on the data and the value messages than interactive visualisations (devoid of author narratives). In the short-term recall group (See Figure 5), there was a significant difference ($t_{20} = 2.15, p = 0.04$) in recall scores of facts-related questions, with higher scores from the presentation videos than interactive visualisations. This result supports hypothesis H3. There was, however, no difference in the scores of value messages ($t_{20} = 1.06, p = 0.3$) between

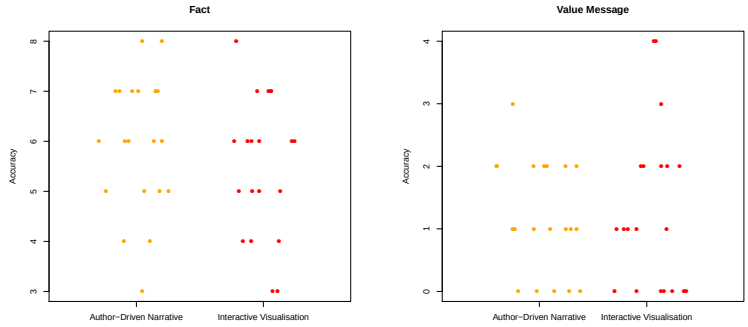


(a) Fact recall (b) Value message recall

Figure 5: Fact and value message scores for short-term recall.

the presentation videos and interactive visualisations. This refutes hypothesis H4.

In the long-term recall group (See Figure 6), there were no significant differences ($t_{20} = 1.37, p = 0.19$) in the recall scores of facts-related questions between presentation videos and interactive visualisations. Neither were there any significant differences ($t_{20} = 0.29, p = 0.77$) in the recall scores of value messages between the presentation videos and interactive visualisations. These results also refute hypotheses H5 and H6.



(a) Fact recall (b) Value message recall

Figure 6: Fact and value message scores for long-term recall.

5.3. Subjective Preferences

After the end of the recall phase, participants completed a subjective preference questionnaire indicating their leaning towards the presentation videos or interactive visualisations for an array of questions. We analysed the preference data using the chi-squared goodness-of-fit test because the variables under investigation are categorical and each variable had an expected frequency count of a minimum of 5. The results are summarised in Figure 7. Results of the chi-squared goodness-of-fit tests performed on these data showed that presentation videos (with author narratives) were faster to describe than interactive visualisations (devoid of author narratives), $X^2(1, N = 40) = 8.10, p = 0.004$. Not surprisingly, participants chose the presentation videos (with author narratives) as easier to understand, $X^2(1, N = 40) = 4.90, p = 0.027$. The results also showed that participants found interactive visualisations more accurate to describe than presentation videos, $X^2(1, N = 40) = 6.40, p = 0.011$. The other questions did not show any significant differences between the presentation videos and interactive visualisations.

5.4. Discussion

There are 6 main findings from this study:

- There were no significant differences in the comprehension of facts between presentation videos (with author narratives) and interactive visualisations (devoid of author narratives).
- The presence of author narration in the presentation videos significantly aided the comprehension of value messages than interactive visualisations (devoid of author narratives).
- After a 5-minute break, presentation videos (with author narratives) significantly aided recall of facts than interactive visualisations (devoid of author narratives).

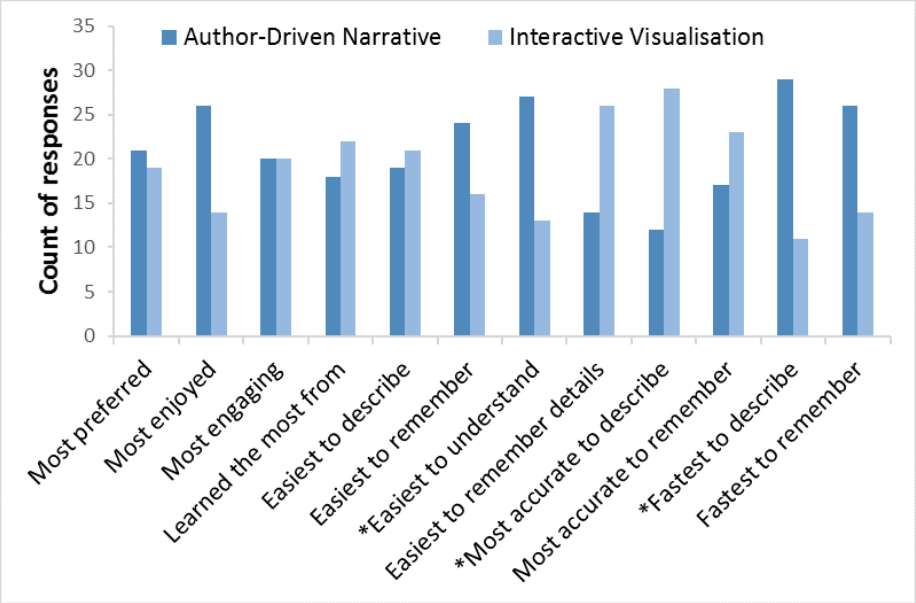


Figure 7: User responses to the subjective preference questionnaire: * denotes a significant difference between presentation videos (with author narratives) and interactive visualisations (devoid of author narratives) from the chi-squared goodness-of-fit test at $a = 0.05$.

- After a 5-minute break, there was no significant difference in the recall of value messages between presentation videos (with author narratives) and interactive visualisations (devoid of author narratives).

- After a 2-3 weeks break, there were no significant differences in the recall of facts and value messages between presentation videos (with author narratives) and interactive visualisations (devoid of author narratives).

- Participants found the presentation videos (with author narratives) both easier to understand and faster to describe and found the interactive visualisations (devoid of author narratives) more accurate to describe.

In short, the presence of author narration in the presentation videos significantly aided the understanding of the value messages and short-term recall of facts but had no significant effect in the long-term. In the following sections, we present the discussion of the results and feedback from participants.

5.4.1. Control of Data and Cognitive Load

For participants, selecting the data attributes and interacting with the interactive visualisation provides a concrete understanding of the presented data. Hence it is more accurate to describe. Although this requires more hands-on manipulation, they have access to all attributes of the data, learn facts based on the data and tailor the narrative according to their own experiences and understanding without the limitation of being restricted to the author's narrative in the presentation videos. For example, several participants noted, "Interactive visualizations itself is self-explanatory", "You can control what data you see", "interactive graph is easier to get specific information", "I can also see some interesting pieces of information I was not looking for".

However, complete access to the interactive visualisations increases cognitive load for participants as several of them reported difficulty in interpreting the interactive visualisations. For instance, a participant reported to be "overwhelmed by the data displayed" and another commented, "I found it was making me think too much to be able to answer the questions". This is not the case when they encountered the presentation videos as they found that their understanding of the facts and value messages of the data came primarily from the narrative in the presentation video and found it easy and straightforward to understand. Two participants commented, "I understand more clearly" and "I feel like I understand the information better when someone is explaining it to me".

The trade-off between complete data control and increased cognitive load has to be rightly guided by the author of the visualisation story depending on the data visualisation literacy of the targeted audience and the presentation goals.

5.4.2. Comprehension of Context and the Big Picture

The presence of author narration in the presentation videos significantly aided the comprehension of the value messages of the presented data than the interactive visualisations (devoid of author narratives). This result validates the general assumptions of the benefits of narration in the literature. In consonance with this result, it was generally more difficult for participants to understand

the social context of the data using the interactive visualisations even though the data was comprehensive, because they were devoid of narratives.

Different trends might be observable for different attributes and subset of the data but the reasons are not always obvious. Participants noted that the value messages were not clearly understood in the interactive visualisations compared to the presentation videos and could not guess the social events that could have triggered certain changes in trends. For example, one participant noted that "while interactive graphs were great to look at things, there was trouble understanding it without further elaboration" and another commented, "Although I know how to operate the Gapminder because it is intuitive, getting insights from it is a bit hard".

On the other hand, the presentation videos provided a better understanding of the big picture underlying the data through the presenter's narrative. Hence it was faster to describe than interactive visualisations. By having a narrator explicitly state their assumptions (e.g., that certain changes in trends were due to certain social reasons), it allows the users to consider whether the assumptions are correct rather than implicitly making assumptions about causality.

The presenter's narrative provides a synopsis of the value messages of the data as well as plausible explanations for certain observations in the data. As one participant notes, the presentation videos "explains the big picture and helps connect with the data presented" and another commented, "The narrator can present information and ideas/context, enriching the level of knowledge gained". However, while the presentation video allows plausible explanations for patterns in the data for easy comprehension of the value messages, in a strictly author-driven scenario such as this, it limits access to the data and is susceptible to subjective bias in interpretation. Subjectivity and bias are discussed in the next Subsection 5.4.3.

5.4.3. The Subjectivity of Narratives in the Interpretation of Visualisation Stories

The manner in which data is presented influences the comprehension and interpretation of the communicated message. This is evident in the rhetorical

techniques employed in communication media [4, 23]. This can be very effective when the story is appropriately crafted and is delivered by a presenter skilled in the art of storytelling. The result is an intended message delivered in an engaging style but with a subjective interpretation. For example, a participant reported, "The speaker puts the facts in a good manner".

The presentation videos were engaging but participants felt that the narrator may have been biased in his narrative and may have led them to certain conclusions. For instance, two participants reported, "it gives the interpretation of the data but somehow subjective", "narrator guides the viewers towards the desired perspective by steering their attention towards certain points."

Both the presentation videos and interactive visualisations were designed for convincing a targeted audience based on statistical evidence, but the narration present in the presentation videos takes a more active approach to accomplishing this goal. A danger in this approach is that users become passive and may not scrutinise the facts of the presented message especially when the narration is done by a skilled presenter. This is captured in a participants' comment, "sometimes I got caught up in the story and forgot to think for myself what the data was showing".

It may be tempting to think that interactive visualisations are free of bias, but the *Information Access Rhetoric* [23] suggests otherwise. Through rhetorical techniques such as omission (thresholding values or omitting exceptional cases) and obscuring (sizing transformations for the purpose of exposing salient points), the authors of interactive visualisations can directly influence the interpretation of interactive visualisations by their target audience.

The interactive visualisation may feel more objective than its presentation video counterpart. However, the interactive visualisation author can select axes, scales, overlays and other visualisation elements that lead the user to the exact same conclusion as if watching a presentation without the user being aware of the motivation of the interactive visualisation author.

As in journalism, there is a need for objectivity and impartiality in the communication of information in the field of information visualisation. An

information visualisation story should be both accurate and engaging. Facts, results and statistical evidence should be portrayed as accurately and clearly as possible and in a way that is engaging to the users. It is the duty of the author of the visualisation story to demonstrate the authenticity of the data and visualisation to his/her audience. This can be achieved using provenance strategies such as citing and/or linking data sources, additional references, methodological choices and relevant facts, as well as annotating exceptions and corrections [23]. This communicates respect for the users and affirms the integrity of the author.

5.5. Beyond Subjectivity in Visualisation Storytelling

Human beings (experts included) do not have the capacity for absolute objectivity and impartial reasoning [41, 42, 43]. This cognitive characteristic easily lends itself to the engagement and comprehension elements of conventional stories, which are typically considered to be subjective. Even for a reasonably objective author, the target audience may be less impartial and approach the visualisation story with a deeply subjective perception. Rather than dwelling too much on achieving absolute objectivity (which is unattainable) in the presentation of visualisation stories, authors should focus on managing these cognitive biases by applying provenance strategies (see Section 5.4.3) in order to keep them in check. This is a useful and practical approach because information needs to be contextualised and interpreted, and facts without context or a value message are meaningless.

Author-driven stories may not be effective in the recall of information visualisation in the long-term. However, they do serve the purpose of informing a target audience of a primary value message based on empirical evidence, aids the comprehension of the presented message in the short-term and thus persuade and influence decision-making - a foremost purpose of communicating information visualisation in the first place.

Table 3: Summary of validity evaluation.

Threat	Category	Status
Instrumentation - 1	Internal	Addressed
Instrumentation - 2	Internal	Addressed
Selection	Internal	Partially addressed
Maturation	Internal	Addressed
Population sample - 1	External	Partially addressed
Population sample - 2	External	Partially addressed
Settings	External	Partially addressed
Design issues - 1	Construct	Addressed
Design issues - 2	Construct	Addressed
Qualitative inference	Construct	Addressed
Statistical test	Conclusion	Addressed

5.6. Threats to Validity

We have taken precautions to minimise and control threats to validity and their effects in this study. Nonetheless, there are threats that may have affected our results and conclusions. We briefly highlight these threats and the control techniques applied to them. A summary of the validity evaluation is shown in Table 3.

5.6.1. Internal Validity

Instrumentation - 1. Although the survey instruments were simplified and participants were encouraged to ask questions during the experiment session, participants may have been hesitant to ask questions and therefore responded based on their understanding of the questions. This may have affected participants' experience of the experiment. However, participants did not raise concerns regarding instrumentation including survey forms and visualisation artefacts.

Instrumentation - 2. A potential threat to instrumentation is the use of videos for author-driven narratives instead of a live presentation, as a live presentation

may produce different impact e.g. an investigator posing as the presenter while following a script. However, this might have introduced variability in the presentation of the author-driven visualisation narrative e.g. change in mood, voice tempo, and pace of the presenter for different participants. We made an experimental design choice to standardise all experimental instruments, hence, we opted to use videos for author-driven narratives. Consequently, all participants had the same experience of the author-driven narratives.

Selection. There is a selection threat to the internal validity of the experiment. Participants were not chosen randomly, instead a convenience-based sampling was applied i.e. university students who made themselves available were recruited to participate. We partially addressed this threat by also recruiting working professionals as participants.

Maturation. There is a risk of boredom and lack of interest from participants as the experiment progressed over time. They may have considered their participation in the experiment a waste of time. However, investigators made a strong effort to motivate participants. Also, in an attempt to limit this risk, participants were advised that they are under no obligation whatsoever to complete either phases of the experiment and could leave whenever they wanted to.

5.6.2. External Validity

Population sample - 1. We aimed to get a representative population of participants - a cross section of industry professionals and students. However, due to the difficulty in recruiting professionals in a 2-part study, only 11 of our total 40 participants were industry professionals and the remaining 29 participants were made up of both undergraduates and postgraduate students from 3 different universities studying a wide range of courses. This may potentially affect the generalisation of our results.

Moreover, related studies have varying number of participants. For instance, Bateman et al. [16] has 20 participants, Li and Moacdieh [29] has 15 participants, Robertson et al. [24] has 18 participants and Borkin et al. [32] has 33 participants.

And these do not make a distinction between the qualifications of participants. Three of these studies [16, 29, 24] carried out their experiments with only student participants. Our recruitment of industry professionals is an attempt to cover a more diverse demographics and limit selection validity.

Population sample - 2. We recognise that the study population is skewed towards male. Although previous studies have highlighted gender differences in 3D environments navigation and end-user programming [44, 45], we did not observe any significant variation between the results of male participants and the limited female participants in our study. Thus, we believe that the impact of this on the generalisability of our results is limited. However, given the low number of females in our study, further experiments will be required to validate this.

Settings. The context of the experiment is a university research lab. The lack of an industry working context is a threat to external validity. However, we minimised this threat by using realistic experiment instruments - the data is a real world data provided by the United Nations, and the visualisations and author-driven narrative presentation videos are taken from real talks that were presented to audiences in several venues.

5.6.3. Construct Validity

Design issues - 1. Our measurement approach for comprehension and recall accuracy are based on and accepted in the visualisation literature [16, 29, 31, 32]. Hence, threat to our measurement approach is limited.

Design issues - 2. It is important that participants were not aware of the second (recall) phase of the study in order to prevent active memorisation during the first (comprehension) phase of the study. We controlled for this threat by deliberating keeping participants in the dark as regards the details of the second phase of the study and only told them that the second phase of the study is related to the first phase but not how. Almost all the participants showed surprise on learning that they were to recall visualisations from the first phase when they began the second phase of the study.

Qualitative inference. Due to the nature of the user study, certain inferences were drawn from the qualitative comments and subjective feedback from the participants to provide an explanation for recurrent patterns observed in the study. However, we made every attempt to stay true to the data and supported every claim with quotes from participants where necessary.

5.6.4. Conclusion Validity

Statistical tests. We checked and confirmed the statistical tests utilised in our user study to validate their accuracy. Thus and to the best of our knowledge, there are no statistical miscalculation errors threatening the validity and accuracy of our results.

5.7. Future Work

In our study, we utilised presentation videos (which engages the audio-visual senses) as an example of a strictly author-driven narrative. But how does a text-based visualisation narrative (which engages the visual senses) or a live presentation compare to an interactive visualisation (devoid of author narratives) and how do they differ from presentation videos in terms of comprehension and memorability?

In addition, in this study, participants could interact with the visualisations for as long they wanted within the overall time limit of the user study. Investigating how the introduction of different time constraints will affect user comprehension and memorability is another area for future work.

Finally, it might also be interesting to see how author-driven visualisation stories and interactive visualisations (devoid of author narratives) affect users' emotions and their impact on decision making based on the type of visualisation.

6. Conclusion

Many information visualisation researchers have suggested the application and adoption of the format of stories to information visualisation with the aim of effectively communicating information. While author-driven storytelling may

be effective in other fields such as journalism, the same level of effectiveness is not necessarily achieved in the field of information visualisation. To investigate this, we conducted a confirmatory user study that explored the benefits and limitations of author-driven narratives based on presentation videos in relation to interactive visualisations (devoid of author narratives) in terms of comprehension and memorability, using interpretation accuracy and recall as measures.

We found that the presence of narration in the presentation videos significantly aided the understanding of the value messages and short-term recall of facts from the visualisations but had no significant effect on the long-term recall of facts or value messages, confirming only two out of our six hypotheses. In addition, the results show that users can quickly describe the information contained in the presentation videos; and users overwhelmingly chose interactive visualisations as more accurate to describe. Not surprisingly, users found the information content in the presentation videos easier to understand.

Also, while author-driven narratives provide a better context for understanding the data domain, users do want access and control of the data at the risk of an increased cognitive load. Moreover, subjectivity and bias are issues that users are concerned about when they are presented with information visualisation stories which should be both accurate and engaging. More importantly, it is the duty of the author to demonstrate authenticity and integrity by adopting provenance strategies and policies.

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