Pontifícia Universidade Católica
do Rio de Janeiro

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Visualizing Data Facts: A Comparative Study of Annotation Techniques and Their Impact on Users' Perceptions

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Dissertation presented to the Programa de Pós–graduação em Informática of PUC-Rio in partial fulfillment of the requirements for the degree of Mestre em Informática.

Advisor: Prof[a]. Simone Diniz Junqueira Barbosa

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I dedicate this work, first of all, to my mother, who is my biggest supporter (I love you, mom). To my dear brother (in memoriam) and my father (in memoriam), who unfortunately cannot physically celebrate this so important achievement of my life.

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Abstract

Jack Freire Braga, Dieinison; Diniz Junqueira Barbosa, Simone (Advisor). **Visualizing Data Facts: A Comparative Study of Annotation Techniques and Their Impact on Users' Perceptions**. Rio de Janeiro, 2023. 118p. Dissertação de Mestrado – Departamento de Informática, Pontifícia Universidade Católica do Rio de Janeiro.

A growing number of visualization systems have been developed both commercially and within the research community. While these tools can aid in building charts, they can also present challenges for non-expert analysts. One particular challenge is providing support to visually highlight data facts in graphs. The manual effort employed by non-expert analysts or designers (without programming skills) to create annotations can be complex and time-consuming. In this research, we investigate visual representations of data facts in supporting non-expert analysts to explore and communicate insights through data. To address these challenges, we developed a conceptual model relating visualizations, data facts, and their visual representations. We implemented it into a visualization tool named VisStoryMaker, which allows generating annotated charts without requiring specialized knowledge. To benchmark its perceived value, we conducted a mixed-methods user study comparing it to Tableau Public. Overall, VisStoryMaker provides an easy-to-use approach to highlight facts visually, and the use of visual annotations in data visualizations can support non-expert users in data exploration and communication. However, their use must be carefully considered and designed to avoid visually cluttering the charts.

Keywords

Visualization System; Visualization Recommender System; Visual Data Fact Annotation.

Resumo

Jack Freire Braga, Dieinison; Diniz Junqueira Barbosa, Simone. **Visualizando Fatos de Dados: Um estudo comparativo das técnicas de anotação e seu impacto sobre as percepções dos usuários**. Rio de Janeiro, 2023. 118p. Dissertação de Mestrado – Departamento de Informática, Pontifícia Universidade Católica do Rio de Janeiro.

Um número crescente de sistemas de visualização tem sido desenvolvido tanto comercialmente quanto na comunidade de pesquisa. Embora estas ferramentas possam ajudar na construção de gráficos, elas apresentam desafios para analistas não especialistas. Um desafio em particular é o de prover suporte para destacar visualmente fatos de dados em gráficos. O esforço empregado por analistas não especialistas ou designers (sem conhecimento de programação) para realizar anotações visuais pode ser complexo e demorado. Nesta pesquisa, investigamos representações visuais de fatos de dados para apoiar analistas não especialistas na exploração e comunicação de insights através dos dados. Para endereçar estes desafios, nós tornamos operacional um modelo conceitual que relaciona visualizações, fatos de dados e suas representações visuais. Implementamos o modelo em uma ferramenta de visualização chamada VisStoryMaker, que permite gerar gráficos anotados sem exigir conhecimento especializado. Para avaliar o seu valor percebido, conduzimos um estudo de métodos mistos com usuário comparando com o Tableau Public. No geral, a VisStoryMaker oferece uma abordagem fácil de usar para destacar visualmente fatos sobre dados, e o uso de anotações visuais de fatos sobre dados nas visualizações podem apoiar usuários não especialistas na exploração e comunicação por meio de dados. Entretanto, seu uso deve ser cuidadosamente considerado para evitar poluir visualmente os gráficos.

Palavras-chave

Sistema de Visualização; Sistema de Recomendação de Visualização; Anotação Visual de Fator de Dados.

Table of Contents

1 Introduction **1**

2 Fundamentals **4**
2.1 Visualization Tasks 4
2.2 Visualization Recommendation 5
2.3 Annotations 5

3 Literature Review **8**
3.1 Procedure 8
3.2 Execution 9
3.3 Discussion 11
3.3.1 SQ1: What visualization recommender systems have been developed, including their design space, approaches, and visualizations used? 11
3.3.1.1 Knowledge-based recommender engines 13
3.3.1.2 Data-driven recommender engines 14
3.3.1.3 Hybrid recommender engines 14
3.3.2 SQ2: How were these visualization recommender systems evaluated? 15
3.3.3 SQ3: What are important open issues and future lines of work concerning visualization recommender systems? 16
3.4 Related Work 16
3.4.1 Visualization Recommendation 17
3.4.2 Computing Data Facts 19
3.4.3 Visualization Annotation 20
3.4.4 Considerations 21

4 VisStoryMaker **23**
4.1 Requirements 23
4.2 Model of Data Facts, Visualizations, and Visual Annotation Cues 24
4.3 User Interface 27
4.4 Implementation Details 28
4.4.1 Technologies Used 28
4.4.2 Available Visualizations 28
4.5 Considerations 30

5 Evaluation **31**
5.1 Participants and Experiment Design 31
5.2 Procedure 32
5.3 Material 33
5.4 Users' Perceptions Feedback 36
5.4.1 Visual Annotations of Data Facts to Aid Exploration and Communication 36
5.4.2 Benchmark of Perceived Usefulness and Ease of Use 38
5.4.3 Additional Feedback Regarding Visual Annotations of Data Facts 44

5.5 Discussion 44
5.5.1 *RSQ2: What are the positive and negative aspects of visually annotating data facts in charts?* 45
5.5.2 Limitations 46

6 Conclusions 47
6.1 Contributions 47
6.2 Future Work 47

Bibliography 48

Secondary Bibliography 53

A Study Material 56
A.1 Free and Informed Consent 57
A.2 Participant Profile Characterization Questionnaire 60
A.3 Document summarizing the dataset *employee performance* 66
A.4 Document summarizing the dataset *covid vacination* 68
A.5 VisStoryMaker's Task 70
A.6 Tableau Public's Task 73
A.7 Post Task Evaluation VisStorymaker 76
A.8 Post Task Evaluation Tableau Public 83
A.9 Interview Script 89

B Interview Responses 91

List of Figures

Figure 1.1 A sample recommended visualizations grouped by a question in VisMaker (de Araújo Lima and Barbosa, 2020). 2

Figure 2.1 Taxonomy of interactive dynamics for visual analysis (Heer and Shneiderman, 2012). 6
Figure 2.2 Sample data fact (correlation) visually annotated in a visualization designed in VisStoryMaker. 7

Figure 3.1 Overview of our sistematic literature review. 9
Figure 3.2 The ranking of alternative visualizations of *Show Me* (Mackinlay et al., 2007). 13
Figure 3.3 Main user interface of Tableau (Mackinlay et al., 2007). 17
Figure 3.4 The *Compass* visualization recommendation engine (Wongsuphasawat et al., 2016). 18
Figure 3.5 VisMaker's main user interface, with its four panels: (A) variables, (B) visual encodings, (C) main chart area, (D) related recommended questions and corresponding visualizations (de Araújo Lima and Barbosa, 2020) 18
Figure 3.6 Sample feed items for the average weight (in lbs), as well as range (in lbs) (Cui et al., 2019). 19
Figure 3.7 *Voder*'s main user interface: (A) Visualization specification and data fact tier selection, (B) Active visualization, (C) System-generated data facts observable in the active visualization, (D) Starred data facts for the active visualization, (E) System-generated data facts related to a different configuration of the active visualization's attributes, (F) Data fact query panel, and (G) Supported visualizations. 20
Figure 3.8 An annotated visualization produced by *Contextifier* (Hullman et al., 2013). 21
Figure 3.9 Sample annotated charts from taxonomy of overlays (Kong and Agrawala, 2012). 22

Figure 4.1 Illustration of our model's operation for visually annotating data facts in visualizations 25
Figure 4.2 *VisStoryMaker*'s prototype interface. 27
Figure 4.3 A dual-axis chart that layers area for temperature and line for precipitation; each layer uses an independent y-scale. 29
Figure 4.4 Available visualizations (de Araújo Lima and Barbosa, 2020) 30

Figure 5.1 Flowchart of study procedure 33
Figure 5.2 Distribution of results per question 37
Figure 5.3 Distribution of VisStoryMaker's results per question 39
Figure 5.4 Distribution of Tableau Public's results per question 40

List of Tables

Table 3.1 Search queries per database. 10
Table 3.2 Amount of resulting documents per database. 10
Table 3.3 Overview of visualization recommender systems. 12
Table 3.4 Main contributions from related work compared to our work. 22

Table 4.1 *VisStoryMaker*'s non-functional requirements 23
Table 4.2 *VisStoryMaker*'s functional requirements 23
Table 4.3 Tasks and statistical functions currently available in *VisStoryMaker*. 24
Table 4.4 Model of data facts, visualizations, and visual annotations cues. 26

Table 5.1 Experimentation scenarios according to dataset and tool. 32
Table 5.2 Results of Wilcoxon matched-pairs test 41
Table 5.3 Positive and negative aspects of VisStoryMaker's modules. 45

List of Abbreviations

InfoVis – Information Visualization

ML – Machine Learning

SLR – Systematic Literature Review

TAM – Technology Acceptance Model

VSM – VisStoryMaker

TP – Tableau Public

1
Introduction

It is well known that data visualization has become an essential medium for scientists, journalists, and anyone else who needs to communicate information through data. In fact, the vital importance of visualization in our daily lives can be demonstrated by the myriad visualizations used by scientists and journalists to warn us about the threats of the COVID-19 pandemic.[1] This real-world case exemplifies that research on visualization has critical importance to society and thus "well-designed visualizations often are the simplest and the most powerful effective way to describe, explore, and summarize data" (Tufte, 2001, pp. 7).

There are several challenges for designing visualizations by novice analysts[2] during data exploration, to name a few: choosing visual mappings and interpreting the visualizations (Grammel et al., 2010). Some visualization recommender systems aim to support generate visual mappings, such as these VisMaker's visualization recommendations presented in Figure 1.1 (de Araújo Lima and Barbosa, 2020). As we may notice, there is no explicit visual linkage between the title (question) and visualizations, and possible misalignment between visualization and text affects understanding, and thus the credibility of the information presented (Kong et al., 2019). Unfortunately, the manual effort employed by non-expert analysts or designers (without programming skills) to create annotations can be difficult and time-consuming (Cairo, 2012).

However, results obtained by Silva and Barbosa (2022) point out annotations as a future line of work to aid novice analysts in understanding charts. Indeed, a prior work presented the effects of visual embellishment in chart memorability and recall (Bateman et al., 2010), and researchers are instigating to investigate strategies for providing more accessible graphics through reader-friendly annotations (Jeffrey Heer, 2019; Munzner, 2014).

Given this context, we defined our main research question: *How can we support non-experts analysts through charts and visual annotations of data*

[1] See, for instance, `https://www.nytimes.com/2020/04/02/learning/7-ways-to-explore-the-math-of-the-coronavirus-using-the-new-york-times.html`

[2] In this work, in line with Heer and Shneiderman (2012), we adopt the term *analyst* to refer to those who use visualization tools in any capacity, not limited to a specific person or role.

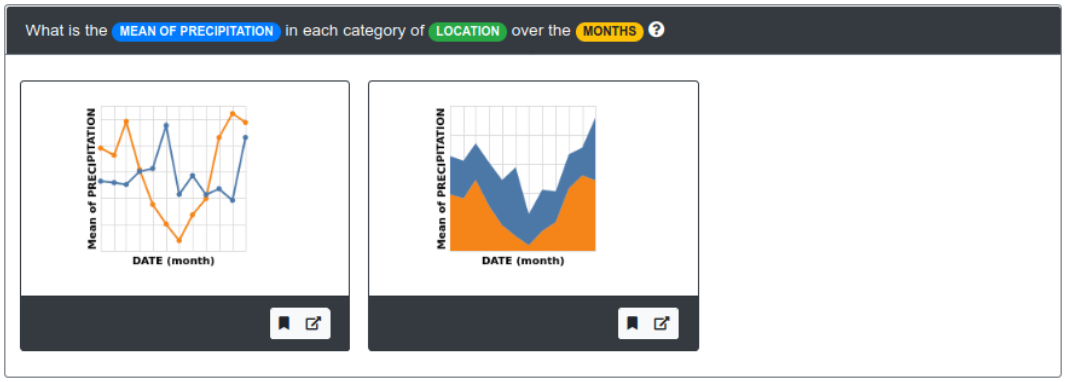

Figure 1.1: A sample recommended visualizations grouped by a question in VisMaker (de Araújo Lima and Barbosa, 2020).

facts? Data facts are textual descriptions of statistical results derived from data (Srinivasan et al., 2019). We then break down our main research question into two more specific research sub-questions:

- *RSQ1: How to visually represent data facts in charts?*
- *RSQ2: What are the positive and negative aspects of visually annotating data facts in charts?*

To answer these questions, we performed the following steps. First, we conducted a systematic literature review to understand the state-of-the-art through exploratory research. Then, we used this body of research from the systematic literature review as input to design a proof-of-concept model of visual annotations of data facts. We then implemented this model as an engine integrated with a visualization system named VisStoryMaker. Finally, we evaluated the VisStoryMaker's perceived value compared to the commercial tool Tableau Public and reported the findings.

Based on our findings, non-expert analysts felt that VisStoryMaker offers a useful and easy-to-use approach to visually annotate data facts in visualization, when compared to Tableau Public. Our findings indicate that visual annotations of data facts aid users in *exploratory analysis*, thus enhancing visual analysis. Moreover we found evidence that visual annotations provide support to *visual data communication*, since annotated visualizations can be incorporated into news articles or presentations to convey reader-friendly graphics to a wider audience. Our contributions include a systematic literature review, and the development and implementation of a conceptual model relating data facts and their visual representations into features that VisStoryMaker uses to automatically generate annotated charts.

The remainder of this document is structured as follows. We introduce some key concepts in chapter 2. In chapter 3, we discuss the literature review.

In chapter 4, we detail our research design, and the system developed. In chapter 5, we present the user study, our findings, their implications, and limitations. Finally, in chapter 6, we outline future works and conclude this document.

2
Fundamentals

In this chapter, we depict the key concepts that ground this research, namely: Visualization Tasks (Section 2.1), Visualization Recommendation (Section 2.2), and Annotations (Section 2.3).

2.1
Visualization Tasks

Visualization tasks are different analytical activities that the analyst can perform during the creation and interpretation of visualizations (Schulz et al., 2013).

In previous work (Rodrigues et al., 2020), we analyzed many visualization tasks taxonomies. In this work, we decided to use the low-level taxonomy proposed by Amar et al. (2005) as a starting point to generate data facts. Amar et al.'s (2005) taxonomy aims to map people's intentions while interacting with visualization. Their low-level tasks are:

- *retrieve value*: given a set of specific instances, find attributes of those instances;
- *filter*: find instances satisfying some condition(s) on attributes values;
- *compute derived value*: compute and aggregate a numeric representation from a set of instances;
- *find extremum*: find instances containing extreme values of an attribute over its range within the data set (*e.g.*, max, min);
- *sort*: rank a set of instances according to some ordinal metric;
- *determine range*: given a set of instances and an attribute, find the span of values within the set;
- *characterize distribution*: given a set of instances and a quantitative attribute, characterize the distribution of that attribute's values over the set;
- *find anomalies*: identify any anomalies within a set of instances;
- *cluster*: find clusters of instances with similar attribute values;

– *correlate*: given a set of instances and two attributes, determine useful relationships between the values of those attributes;

As part of our work, we implemented an engine to generate data facts. We associated each data fact as an instance of one or more task(s) from Amar et al.'s (2005) taxonomy. For each data fact generated, our system also recommends appropriate visualization(s) to analyze it, as described in Section 4.2. In the following section, we present a definition of visualization recommendation and explain how we related it to the data facts generated.

2.2 Visualization Recommendation

Specifying the most effective visualization to convey information is hard, even for experts, because we must consider many variables – data type, visualization task, and data distribution, among other variables (Moritz et al., 2019). Visualization recommendation is a line of research that aims to address this topic by supporting and automating the visualization design (Agrawala et al., 2011).

Several strategies for visualization recommender systems have been proposed: (i) knowledge-based[1] approach (Wongsuphasawat et al., 2017; de Araújo Lima and Barbosa, 2020), (ii) behavior-driven approach (Gotz and Wen, 2009), and (iii) machine learning-based techniques (Luo et al., 2020; Dibia and Demiralp, 2019; Hu et al., 2019).

Knowledge-based recommender systems rely on graphical perception studies (Bertin, 1983; Cleveland and McGill, 1984; Heer and Bostock, 2010; Munzner, 2014; Kim and Heer, 2018; Saket et al., 2019; Rodrigues et al., 2019). In our research, we adopted the knowledge-based approach to recommend the appropriate visualization(s) for each data fact generated. Besides, for each visualization recommended, we provided a set of visual annotations cues that link the information described in the data facts to visualizations.

2.3 Annotations

On a broader formalization, Heer and Shneiderman (2012) present a clear definition and a taxonomy on visual analysis. They define visual analysis as an iterative view creation, exploration, and refinement process. Figure 2.1 presents their taxonomy. Note that there are a variety of possibilities to support

[1] Although some authors refer to this approach as "rule-based" (*e.g.*, Wongsuphasawat et al. (2015)), in our work we adopt the terminology "knowledge-based", as Saket et al. (2018) did.

visual analysis, some of them already covered by the original *VisMaker* – *e.g.*, visualize, filter, sort, and derive. However, *VisMaker* does not provide support either for *View Manipulation* or *Process & Provenance*.

Data & View Specification	**Visualize** data by choosing visual encodings. **Filter** out data to focus on relevant items. **Sort** items to expose patterns. **Derive** values or models from source data.
View Manipulation	**Select** items to highlight, filter, or manipulate them. **Navigate** to examine high-level patterns and low-level detail. **Coordinate** views for linked, multi-dimensional exploration. **Organize** multiple windows and workspaces.
Process & Provenance	**Record** analysis histories for revisitation, review and sharing. **Annotate** patterns to document findings. **Share** views and annotations to enable collaboration. **Guide** users through analysis tasks or stories.

Figure 2.1: Taxonomy of interactive dynamics for visual analysis (Heer and Shneiderman, 2012).

In particular, annotations are useful for describing facts or highlighting something to pay attention to in visualizations (Knaflic, 2019). Annotations refer to adding one or more visual or textual elements to visualizations (Munzner, 2014). In this work, visual annotation of data facts are visual elements added to graphs visually representing the textual description. However, the manual effort employed by professional designers to create annotations can be difficult and time-consuming (Cairo, 2012; Hullman et al., 2013).

In our work, we explore how annotations of data facts in visualizations can support non-experts analysts. We have built a proof-of-concept model associating visualizations, data facts, and annotations. To illustrate, consider the example in Figure 2.2. In the example, an analyst designed a visualization encoding two quantitative attributes (*PRICE* and *HOUSEPOWER*). Based on this information, our data facts generator engine computed as a potential data fact: "There is an apparent strong positive linear correlation between variable *PRICE* and *HOUSEPOWER* with coefficient $r = 0.76$." This sample data fact is derived from the task "correlate" from Amar et al.'s (2005) taxonomy. In this case, the analyst selected the recommended scatter plot to visualize the data. Furthermore, our system provides a set of visual cues – regression line and label – to visually annotate that data fact into visualization.

In the next chapter, we describe the systematic literature review that underlies this research project.

Figure 2.2: Sample data fact (correlation) visually annotated in a visualization designed in VisStoryMaker.

3
Literature Review

Several visualization tools have been developed commercially and within the research community. At one extreme there are high-level tools, such as the *Explore* feature in Microsoft Excel (Viégas et al., 2018), which generate visualizations from spreadsheets, and at the other there are low-level tools, such as D3 (Bostock et al., 2011), which require programming skills. For additional visualization tooling, we refer the reader to the survey conducted by Qin et al. (2020).

In this chapter, we discuss the prior studies that underline our work. Section 3.1 presents the protocol we defined for our systematic literature review. Section 3.2 depicts each step performed, and Section 3.3 discusses our findings.

3.1
Procedure

Systematic literature studies are one form of secondary study that allows us to get an overview of a research agenda and outline open issues worthy of investigation (Petersen et al., 2015). As part of our work, we conducted a systematic literature review (SLR) following the guidelines provided by Kitchenham and Charters (2007), to find ways to support novice analysts through visualization recommender systems.

Our review focuses on *visualization recommender systems (algorithms or models)* rather than visualizations or visualization systems in general. We define our main research question for the SLR: ***What can we learn from the state-of-the-art visualization recommender systems?*** To be more precise, we opted to break down our main research question into subquestions, which are the following:

- SQ1: What visualization recommender systems have been developed, including their design and approaches?
- SQ2: How were these visualization recommender systems evaluated?
- SQ3: What are important open issues and future lines of work concerning visualization recommender systems?

To answer these questions, we performed the steps summarized in Figure 3.1. Note that, after each step, we present the number of resulting papers. Also, the dotted lines represent adjustments made in previous stages of the review.

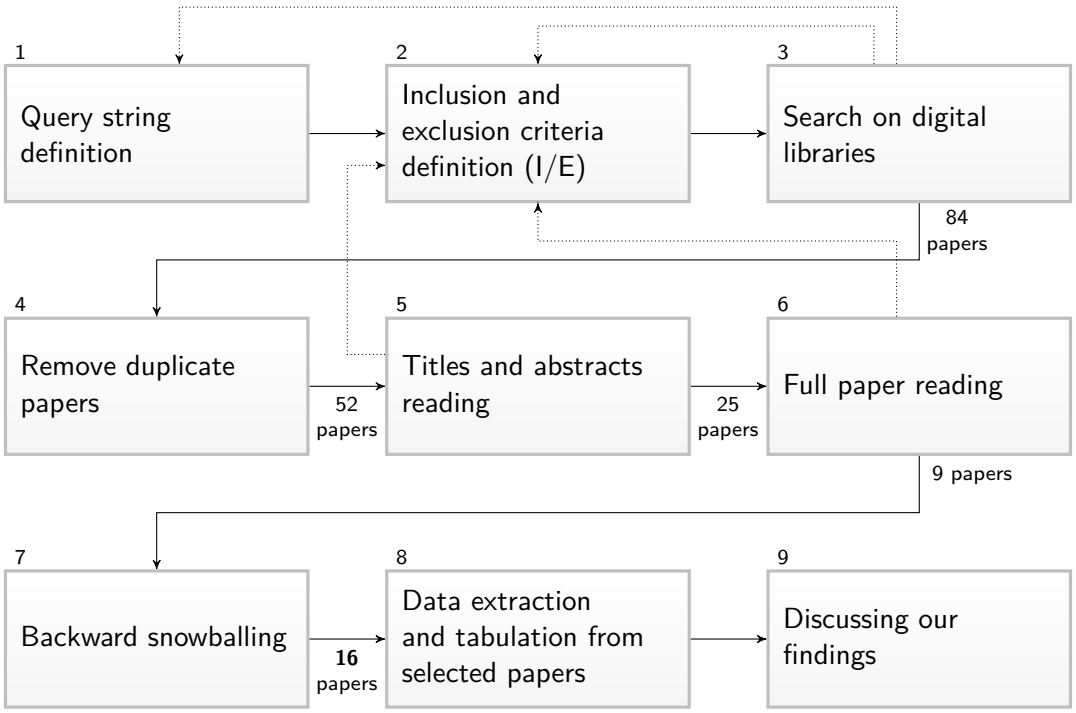

Figure 3.1: Overview of our sistematic literature review.

3.2 Execution

After taking into account our research question and different synonyms for the term *visualization recommendation*, we defined our query strings (step 1) for each database, as shown in Table 3.1. We chose IEEE Xplore[1] and the ACM Digital Library[2] because they both host the premier venues for advances in visualization and visual analytics (*e.g.*, VIS, CHI, EuroVis, TVCG), and Scopus[3] because it claims to be the largest database of titles and abstracts. Thus, we defined the inclusion (I) and exclusion (E) criteria as follows (step 2):

I1: Full papers written in English.

I2: Papers published in peer-reviewed conferences and journals (*e.g.*, CHI, VIS, TVCG, SIGMOD, etc.).

E1: Papers out of our scope (*e.g.*, papers that are not directly related to visualization recommendation).

[1] `https://ieeexplore.ieee.org/Xplore/home.jsp`
[2] `https://dl.acm.org/`
[3] `https://www.scopus.com`

Table 3.1: Search queries per database.

Database	Search query
IEEE	(((“Publication Title”:“Visualization Recommendation System” OR “Visualization Recommendation Tool” OR “Visualization Recommendation”) OR “Abstract”:“Visualization Recommendation System” OR “Visualization Recommendation Tool” OR “Visualization Recommendation”) OR “Index Terms”:“Visualization Recommendation System” OR “Visualization Recommendation Tool” OR “Visualization Recommendation”)
ACM	[Publication Title: “Visualization Recommendation System”] OR [Publication Title: “Visualization Recommendation Tool”] OR [Publication Title: “Visualization Recommendation”] OR [Abstract: “Visualization Recommendation System”] OR [Abstract: “Visualization Recommendation Tool”] OR [Abstract: “Visualization Recommendation”]
Scopus	TITLE-ABS-KEY(“Visualization Recommendation System” OR “Visualization Recommendation Tool” OR “Visualization Recommendation”)

E2: Papers that solely cite the word ‘visualization recommender’, but do not propose one such approach.

E3: Papers solely available as abstracts or posters.

We performed the queries on May 5th, 2020 (step 3), and we obtained as a raw result 84 papers, as described in Table 3.2. We removed the duplicated papers (step 4), leaving 52 papers.

Table 3.2: Amount of resulting documents per database.

Library	Number of papers found
IEEE	16
ACM	23
Scopus	45

We read all 52 titles and abstracts (step 5), looking for candidate papers according to our I/E criteria. It is noteworthy that this step was performed independently by two researchers. Our agreement was calculated using the Fleiss kappa coefficient, obtaining $\kappa = 0.77$. According to Landis and Koch (1977), when $\kappa \geq 0.77$, we can consider that the criteria were substantially well defined and consistently applied so that we could move forward to the next steps. We opted to discuss the conflicts (12 papers) to get a consensus, out of which 5 (five) were removed, and 7 (seven) were included. In a nutshell, the conflicts were caused by misconceptions due to the generality of some

criteria and, to overcome this, we revisited the criteria to make them more specific. By doing this, we obtained 25 papers for the next stage.

We retrieved and read all the full papers (step 6). At the end of this stage, 9 papers remained. However, at this point, we realized that some synonyms were not considered by us for the term *visualization recommendation* in the literature, and for that reason, we conducted a backward snowballing (step 7) considering the guidelines provided by Wohlin (2014). We iterated over the titles and abstracts in the reference list of the included papers, analyzing papers related to automation of visualization design (*e.g.*, , 'Automatic Generation of Visualizations,' 'Automatic Graphical Design,' 'Automated Visualization Design').

Finally, we obtained a total of 16 papers. We then extracted and tabulated the data to answer our research questions (step 8), and discuss our findings (step 9) next.

3.3 Discussion

The following subsections discuss the answers found for each subquestion.

3.3.1 SQ1: What visualization recommender systems have been developed, including their design space, approaches, and visualizations used?

We categorize existing work on visualization recommender engines into *knowledge-based*, *data-driven*, and *hybrid* design tools for visualization. We adopted the terminology used in recommender systems (Aggarwal et al., 2016). Table 3.3 gives an overview of existing visualization recommender systems.

Table 3.3: Overview of visualization recommender systems.

Research	Category	Model	Rank	Design Space	Input	Output	Annotation
APT (Mackinlay, 1986)	Knowledge-based	Perceptual rules	✓	3 types	Quantitative, Ordinal, Nominal	Bar, Scatter, Area chart	-
BOZ (Casner, 1991)	Knowledge-based	Perceptual rules	✗	3 types	User tasks	Line, Pie, Table, Bar	-
SAGE (Roth et al., 1994)	Knowledge-based	Perceptual rules	✗	-	Data type and user task	Charts, table, map, text-outline, networks	-
Show Me (Mackinlay et al., 2007)	Knowledge-based	Perceptual rules	✓	7 types	Categorical, Quantitative, Temporal	Small multiples	-
BDVR (Gotz and Wen, 2009)	Knowledge-based	Behavior-driven	✗	-	Query	Visualizations	-
VizDeck (Key et al., 2012)	Data-driven	Statistics	✗	7 types	Keywords	Dashboard	-
SeeDB (Vartak et al., 2015)	Knowledge-based	Deviation-based metric	✗	3 types	Query	Bar, Line, Scatter	-
Voyager 2 (Wongsuphasawat et al., 2017)	Knowledge-based	Perceptual Rules	✓	6 types	Nominal, Ordinal, Temporal and Quantitative	Scatter, Bar, Histogram, Strip, Line, table	-
DIVE (Hu et al., 2018)	Data-driven	Statistics	✗	4 types	Nominal, Ordinal, Quantitative, Temporal	Visualizations	Title or description
DataSite (Cui et al., 2019)	Data-driven	Statistics, K-Means and DBSCAN Clustering, Regression	✗	3-4 types	Numerical, Categorical	Histogram, Scatter, HeatMap and insights	-
Voder (Srinivasan et al., 2019)	Data-driven	Natural Language Generator	✓	4 types	Number, Category	Histogram, Donut, Strip, Bar	Visual cues
VizML (Hu et al., 2019)	Data-driven	Neural Networks	✓	5 types	Visualization Pairs	Bar, Line, Pie, Scatter	-
Data2Vis (Dibia and Demiralp, 2019)	Data-driven	DNN	✓	Vega-Lite	Quantitative	Vega-Lite Specs	-
Draco (Moritz et al., 2019)	Hybrid	RankSVM	✓	Vega-Lite	Partial specification and task	Vega-Lite specs	-
DeepEye (Luo et al., 2020)	Data-driven	Decision Tree and Learning to rank	✓	4 types	Query	Bar, Line, Pie, Scatter	-

3.3.1.1 Knowledge-based recommender engines

A large body of automated visualization design tools is based on prior knowledge produced by graphical perception studies. Inspired by Bertin's work on Semiology of Graphics (Bertin, 1983) and Cleveland and McGill's work on Graphical Perception (Cleveland and McGill, 1984), Mackinlay's (1986) *APT* is a seminal work on this approach. *APT* presents a composition algebra to automate visualization design. It then uses *expressiveness* and *effectiveness* criteria to recommend and rank visualizations. *BOZ* (Casner, 1991) and *SAGE* (Roth et al., 1994) both extend *APT* by considering user tasks and additional data properties (*e.g.*, cardinality, uniqueness), respectively.

Mackinlay et al. (2007) proposed *Show Me*, which incorporated an interface for visualization recommendation into *Tableau*. *Show Me* can automatically generate multiple small visualizations, and the analyst can interactively choose among alternatives – as presented in Figure 3.2. Gotz and Wen (2009) proposed a behavior-driven visualization recommendation (*BDVR*). Given an analyst's input query, *BDVR* attempts to infer the analyst's task – scanning, flipping, swapping, or drill-down – from behavior and use the information to recommend appropriate visualizations.

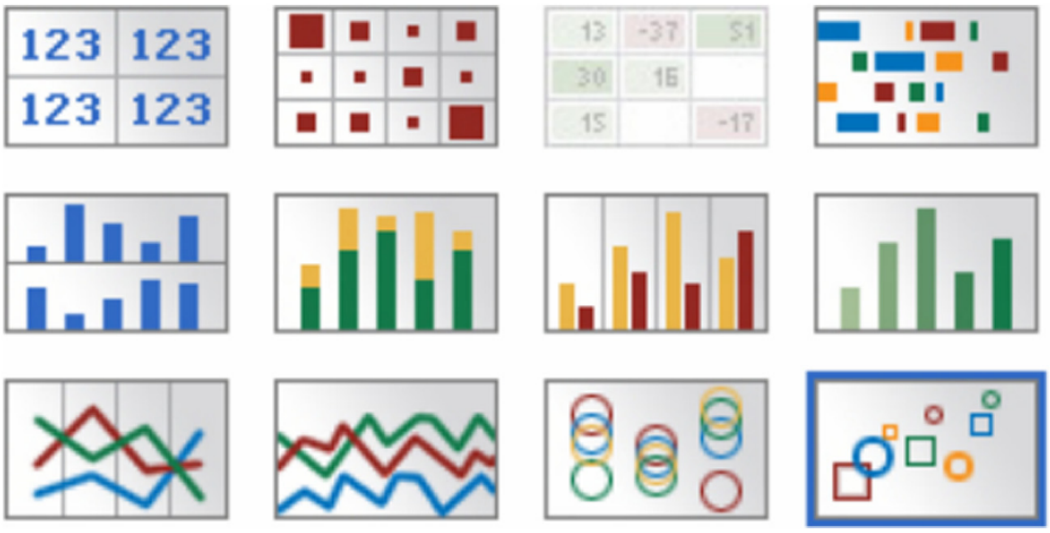

Figure 3.2: The ranking of alternative visualizations of *Show Me* (Mackinlay et al., 2007).

Following this line of work, Vartak et al. (2015) proposed *SeeDB*, which can recommend visualizations after an analyst inputs a query. *Voyager* (Wongsuphasawat et al., 2015) and *Voyager 2* (Wongsuphasawat et al., 2017) are mixed-initiative systems. *Voyager* motivates design principles for interacting with visualization recommendations. *Voyager 2* combines manual and auto-

matic visualization specifications to aid analysts in engaging a broader and focused analysis. The Voyager project is powered by *CompassQL* (Wongsuphasawat et al., 2016). It uses a set of heuristic rules to develop effectiveness and efficiency criteria to evaluate visualization alternatives.

3.3.1.2 Data-driven recommender engines

With advances in machine learning (ML), many visualization researchers have taken initial steps toward developing ML models to recommend visualizations. An ML model tries to predict appropriate visualizations given some inputs (*e.g.*, data types, tasks, etc.).

To the best of our knowledge, *Viz Deck* (Key et al., 2012) was the first attempt to incorporate an automated statistical approach based on the properties of the data. *Viz Deck* is a web-based tool that trains a model to learn correlations among data and properties of visualizations in an attempt to predict the preferred chart from the analyst.

Hu et al. (2018) introduced *DIVE*, which is heavily inspired in *Voyager* and extends its mixed-initiative visualization approach to other parts of the data exploration pipeline – *e.g.*, data ingestion, statistical analysis, and storytelling. Cui et al. (2019) then proposed *DataSite* by focusing on parallel computations from a suite of statistical functions and ML algorithms (*e.g.*, descriptive statistics, clustering, regression, etc.). Srinivasan et al. (2019) introduced *Voder*, which combines visualization recommendations with descriptive statistics and natural language generation.

Dibia and Demiralp (2019) presented *Data2Vis*, which is a neural translation model that produces visualization specifications in Vega-Lite grammar (Satyanarayan et al., 2017). Their proposed end-to-end generation model was based on long short-term memory and trained over thousands of visualizations samples. More recently, Hu et al. (2019) introduced *VizML*, a visualization recommendation model trained over one million dataset-visualization pairs collected from public visualization communities. Their model learns to predict design choices and can be integrated into visualization systems.

3.3.1.3 Hybrid recommender engines

In knowledge-based systems, the system uses the knowledge provided by prior graphical perception studies. In data-driven systems, the system learns the recommendation from data. Hybrid recommender systems are both knowledge-based and data-driven.

Draco (Moritz et al., 2019) is a formal model that represents (i) visualization as logical facts and (ii) design principles as hard and soft constraints. Its default model uses rules derived from empirical studies but formalized by experts. Additionally, *Draco* uses a learning-to-rank algorithm to learn constraint weights over ranked pairs of visualizations from graphical perception studies (Kim and Heer, 2018; Saket et al., 2019).

DeepEye (Luo et al., 2020) is a visualization design and recommender system that relies on (i) two ML models – a decision tree to determine good/bad visualizations – and a learning-to-rank model to rank visualizations; (ii) knowledge from experts who specify partial orders as rules to rank visualizations.

In summary, our goal in addressing SQ1 was to map published strategies for visualization recommendation. Table 3.3 informs us, among other things, that the most consolidated approach is knowledge-based (8 published full papers). Therefore, we developed a knowledge-based visualization recommender engine to suggest appropriate graphics for each data fact generated.

3.3.2 SQ2: How were these visualization recommender systems evaluated?

Different recommendation strategies require different evaluation approaches. Particularities aside (*e.g.*, dataset used, task required to complete, etc.), knowledge-based systems mainly evaluate their approach through controlled user studies – either to assist the system design (Srinivasan et al., 2019) and/or to assess its performance (Wongsuphasawat et al., 2017; Hu et al., 2018). In a nutshell, knowledge-based systems require users to interact with two different systems in data exploration tasks (open-ended and/or focused analysis).

However, when considering data-driven and hybrid recommender systems, we faced a greater diversity of evaluation strategies. Indeed, we have not identified a 'standard' evaluation strategy for these systems, probably due to the novel and unconsolidated aspects of this research agenda.

Similar to knowledge-based systems, a portion of data-driven systems rely on user studies (Cui et al., 2019; Srinivasan et al., 2019; Vartak et al., 2015), and others in statistical benchmarks (Hu et al., 2019; Moritz et al., 2019; Dibia and Demiralp, 2019). For instance, Hu et al. (2019) evaluated the generability and uncertainty of their model by comparing it against a benchmark based on a crowdsourced test set (Heer and Bostock, 2010). Moritz et al. (2019) evaluated their trained model by measuring the percentage of "correctly ranked" visualization-pairs.

As described in Section 5.2, we have evaluated our work by a con-

trolled mixed-methods user study, inspired in the evaluation strategies from de Araújo Lima and Barbosa (2020); Wongsuphasawat et al. (2017); Srinivasan et al. (2019).

3.3.3 SQ3: What are important open issues and future lines of work concerning visualization recommender systems?

General future lines of work include, but are not limited to: (i) providing personalized recommendations based on the analysis of user interactions; (ii) incorporating concepts of data storytelling; (iii) investigating user preferences; (iv) establishing customized measures of visualization effectiveness.

In terms of knowledge-based systems, it is often required from its designers to curate design guidelines derived from previous and current graphical perception studies, which requires a lot of effort and is time-consuming. Concerning data-driven and hybrid approaches, there is a lack of scalable methods for collecting and labeling training data and methods to improve the interpretability and explainability of recommender engines.

Another open issue concerns the investigation of mechanisms that provide more accessible graphics, for instance, through reader-friendly annotations, as motivated by Grammel et al. (2010); Knaflic (2019) and other researchers. Indeed, few visualization recommendation studies explore this topic, which is more demanding (Hu et al., 2018; Srinivasan et al., 2019). Hu et al. (2018) provide support to modify the visualization title and description. Although Srinivasan et al. (2019) explore a more in-depth approach to annotating in visualizations, they use closed-coded natural language generation.

Our approach, as described in chapter 4, resembles (Hu et al., 2018; Srinivasan et al., 2019) in a sense that we investigate providing annotations mechanism to support users. However, we differ from them regarding target users as non-expert analysts, and our system includes a questions-related generator and a story module. Also, our system does not use third parties commercial features as input to generate the data facts. In the next section, we describe the related work that closely relates to VisStoryMaker.

3.4 Related Work

The *visualization recommendation*, *data facts generator*, and *annotations* components of VisStoryMaker are informed by prior work on these fields. Also, the system design and implementation of VisStoryMaker were inspired by lessons learned from these previous studies.

3.4.1 Visualization Recommendation

The context of visualization specification in our work is a *GUI-based interactive* tool, using Qin et al.'s (2020) terminology. One of the most prominent examples of this strategy is *Tableau*[4] (formerly *Polaris* (Stolte et al., 2002)). Figure 3.3 presents the main Tableau interface with some marks. Region "A" presents a panel where the users can drag and drop the attributes already loaded from the dataset, which will be rendered in the corresponding visualization, in panel "B". Panel "C" presents the *Show Me* (Mackinlay et al., 2007) interface, which recommends alternative visualizations given the user's selections. Inspired in *Tableau*, in *VisStoryMaker*, we implemented a GUI-based interactive approach to allow analysts to design visualizations.

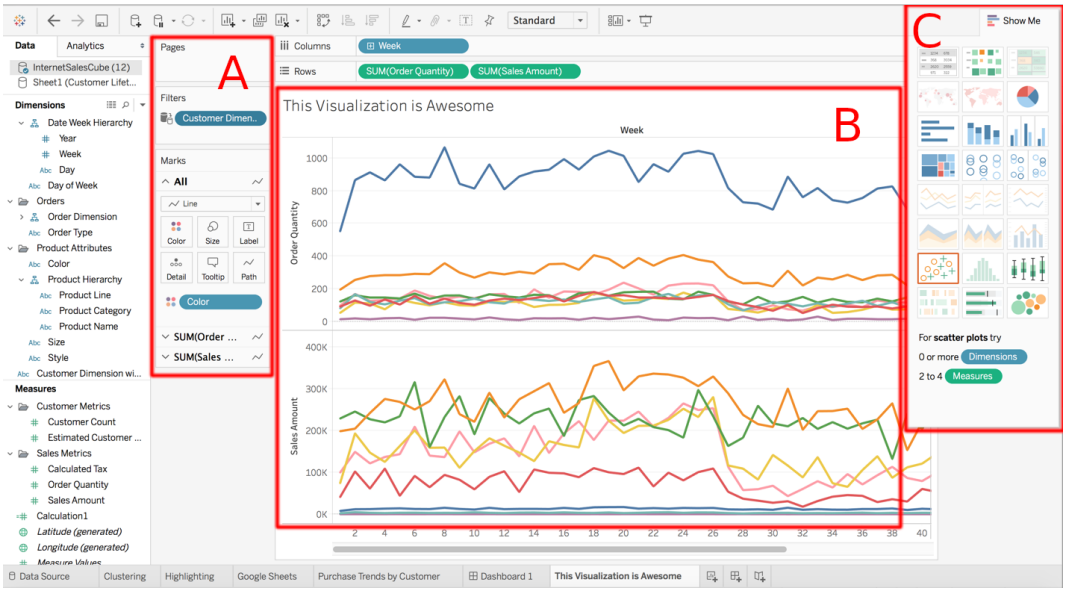

Figure 3.3: Main user interface of Tableau (Mackinlay et al., 2007).

Voyager 2 (Wongsuphasawat et al., 2017) aims to facilitate both open-ended and focused analysis through visualization design and recommendation. The core of its recommendation engine is *CompassQL* (Wongsuphasawat et al., 2016), which suggests appropriate visualizations based on graphical perception studies of Mackinlay (1986) and Cleveland and McGill (1984). Figure 3.4 presents the process followed by the *CompassQL* engine. First, the user selects the variables to construct a visualization (A), then the system combines the selected variables with new others, listing and applying aggregate functions on attributes (B). Next, the system recommends visualizations (C) and presents a clustered list of possible ranked visualizations using perceptual effectiveness metrics (D).

[4] `https://www.tableau.com/`

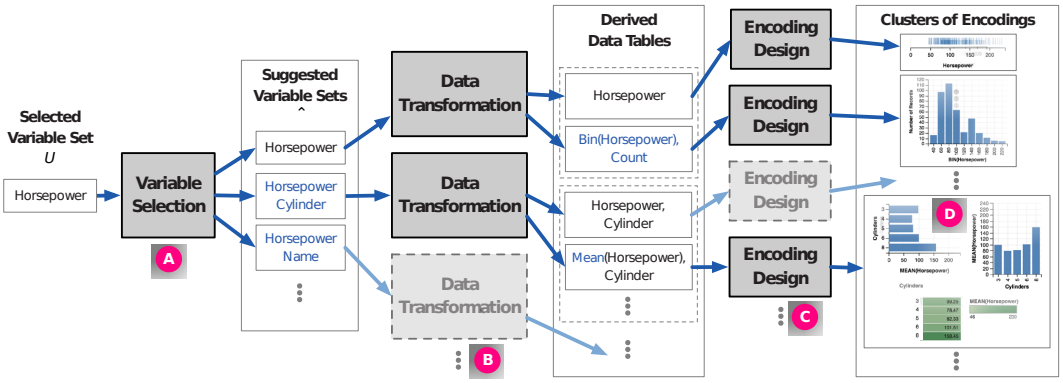

Figure 3.4: The *Compass* visualization recommendation engine (Wongsuphasawat et al., 2016).

Similarly, *VisMaker* (de Araújo Lima and Barbosa, 2020) is a visualization recommender tool, which proposed an engine inspired by *Compass* (Wongsuphasawat et al., 2016). VisMaker's innovation lies in the proposal of a *question-oriented* engine, which combines unselected variables and groups by questions to do the recommendations. They also incorporate the perceptual encoding ranks from Cleveland and McGill (1984) and Munzner (2014) to guide their proposed recommendation engine. *VisMaker*'s main user interface is presented in Figure 3.5. de Araújo Lima and Barbosa's work serves as the basis for our work. To be more precise, in *VisStoryMaker*, we augmented visual analysis possibilities of original VisMaker through visual annotation of data facts to better support novice analysts.

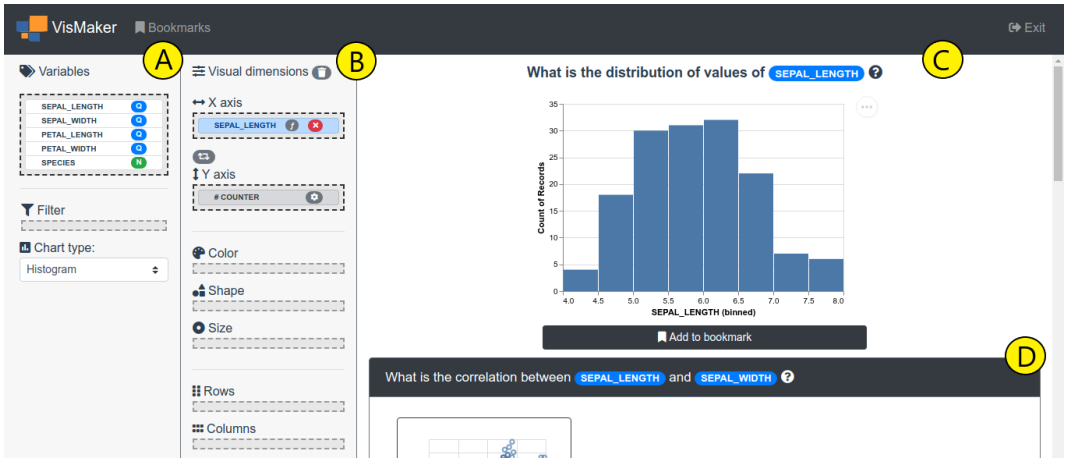

Figure 3.5: VisMaker's main user interface, with its four panels: (A) variables, (B) visual encodings, (C) main chart area, (D) related recommended questions and corresponding visualizations (de Araújo Lima and Barbosa, 2020)

3.4.2 Computing Data Facts

Cui et al. (2019) proposed a visual analytics system, DataSite, which implements a server-side engine that automatically computes insight-based recommendations to help users in the sensemaking process. They presented these computations as notifications in a feed timeline (Cui et al., 2019). They referred to these computations as "insights", but when we analyze some of these computations (Figure 3.6), we see that they are simple textual descriptions of the output of statistical functions applied to the data. Given the various definitions of the term "insight" within the visualization community (North, 2006; Chang et al., 2009; Chen et al., 2009), as mentioned earlier, we call these textual descriptions "data facts". We plan to implement a data facts generator engine in our work. We draw inspiration from Cui et al.'s (2019) computation engine to design our solution.

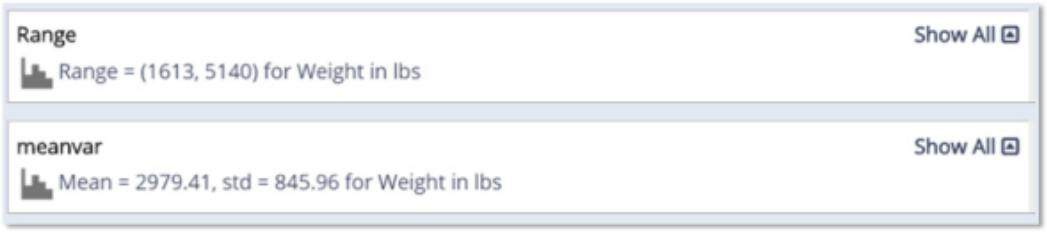

Figure 3.6: Sample feed items for the average weight (in lbs), as well as range (in lbs) (Cui et al., 2019).

Srinivasan et al. (2019) presented a prototype software tool, *Voder* (Figure 3.7), which is a visualization recommender tool that investigates the use of system-generated data facts as interactive widgets to aid human perception. It is noteworthy that their generation engine of data facts is based on the output of the commercial plug-ins *Quill*,[5] and *Microsoft Power BI*'s insights feature,[6] *i.e.*, their approach is a black box. In our work, we adopt the same definition of data facts used by Srinivasan et al. (2019). However, unlike them, we do not use the commercial plug-ins cited above; we will model our own data facts generator engine.

[5]Narrative science. `https://narrativescience.com/`

[6]Types of insights supported by Microsoft Power BI. `https://docs.microsoft.com/en-us/power-bi/service-insight-types`

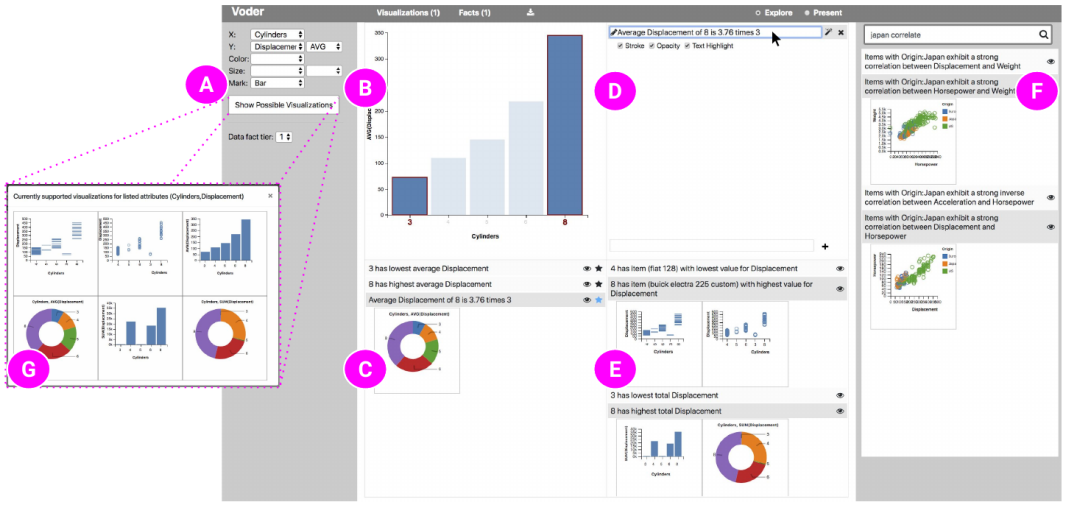

Figure 3.7: *Voder*'s main user interface: (A) Visualization specification and data fact tier selection, (B) Active visualization, (C) System-generated data facts observable in the active visualization, (D) Starred data facts for the active visualization, (E) System-generated data facts related to a different configuration of the active visualization's attributes, (F) Data fact query panel, and (G) Supported visualizations.

3.4.3 Visualization Annotation

Hullman et al. (2013) presented *Contextifier*, a system for producing annotated line graphs for financial time series, see Figure 3.8. Their system automatically creates a line graph and chooses textual annotations based on the content of an input news article. They focus on text annotation in the financial time series domain. In contrast, we chose to focus on the use of visual annotations cues of system-generated data facts in basic visualizations (histogram, bar chart, scatter plot, among others).

Kong and Agrawala (2012) presented a clear definition of graphical overlays and a taxonomy. They define graphical overlays as visual elements added in base visualization to facilitate graph comprehension. Figure 3.9 contains an subset of their taxonomy on visual overlays in some bar charts. We use this taxonomy as a starting point to design our data facts visual representations options.

Similar to them, our system *VisStoryMaker* provides visual annotations of data facts as additional visual annotation layers. In contrast, our system generates visual annotations based on the underlying data values, not on the knowledge of mark and axis properties.

Figure 3.8: An annotated visualization produced by *Contextifier* (Hullman et al., 2013).

3.4.4 Considerations

In our research, we proposed a proof-of-concept model (Section 4.2) to represent data facts in charts visually, by associating visualizations, data facts, and visual annotations. We realized this model in the *VisMaker* tool and called this augmented version VisStoryMaker. Namely, the source code of *VisMaker* is the base for our system. That said, *VisStoryMaker* provides a simple interface to construct visualizations, similar to *Tableau*. From the underlying data used to build the graphics, our system computes common data facts inspired by *DataSite* and *Voder*. For each generated data fact, our system recommends appropriate visualization(s) analogous to *Voyager* and *VisMaker*. Ultimately, for each visualization recommended, our system suggests some visual annotation cues to highlight data facts in visualizations influenced by the work of Hullman et al. (2013) and Kong and Agrawala (2012).

Table 3.4 summarizes the related work. In the final row, we included the features of our system. In the next chapter, we dive into *VisStoryMaker*.

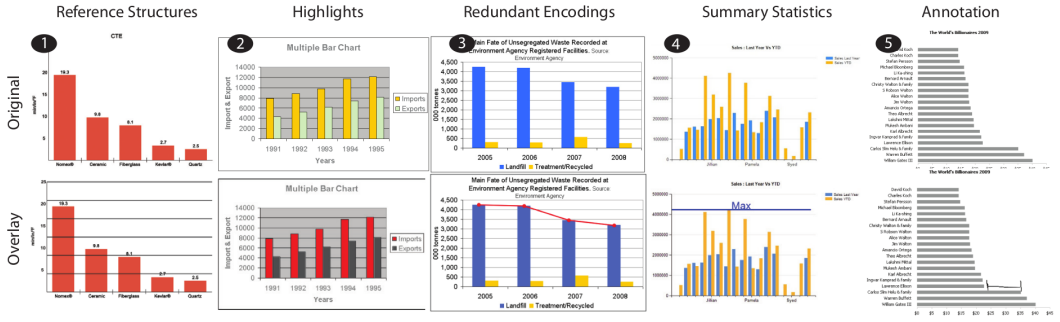

Figure 3.9: Sample annotated charts from taxonomy of overlays (Kong and Agrawala, 2012).

Table 3.4: Main contributions from related work compared to our work.

Paper	Recommendations	Approach based	Source Code
Visualization Recommendation			
Tableau (Mackinlay et al., 2007)	Visualizations	Encoding Effectiveness	closed
Voyager 2 (Wongsuphasawat et al., 2015)	Visualizations	Encoding Effectiveness	open
VisMaker (de Araújo Lima and Barbosa, 2020)	Questions and Visualizations	Encoding Effectiveness	closed
Computing Data Facts			
DataSite (Cui et al., 2019)	"Insights"	Statistics	closed
Voder (Srinivasan et al., 2019)	Data Facts and Visualizations	Quill and Power BI output	closed
Visualization Annotation			
Contextifier (Hullman et al., 2013)	Textual Annotations	-	closed
Taxonomy of Overlays (Kong and Agrawala, 2012)	Visual Annotation Cues	-	open
VisStoryMaker	Visualizations, Data Facts, and Visual Annotation Cues	Encoding Effectiveness	open

4
VisStoryMaker

This Chapter presents the requirements we had in mind while prototyping VisStoryMaker (Section 4.1). We then describe VisStoryMaker's core engine (Section 4.2) and interface (Section 4.3) and provide the complementary implementation details (Section 4.4).

4.1
Requirements

In order to guide the development of *VisStoryMaker*, we have defined both functional (*FR*) and non-functional (*NFR*) requirements. Table 4.1 presents the non-functional requirements, and Table 4.2 depicts the functional requirements of *VisStoryMaker*. In the next section, we present the core model of *VisStoryMaker*.

Table 4.1: *VisStoryMaker*'s non-functional requirements

ID	Name	Description
NFR01	Usefulness	The system should be useful, allowing non-experts analysts to design visualizations and visually represent data facts.
NFR02	Ease of Use	The system should be easy to use, enabling non-experts analysts to easily design visualizations and visually annotate data facts.

Table 4.2: *VisStoryMaker*'s functional requirements

ID	Name	Description	Priority
FR01	Loading dataset	The system must allow the analyst to upload a dataset in *csv* format.	High
FR02	Constructing visualizations	The system must allow the analyst to construct visualizations.	High
FR03	Generating data facts	The system must compute and present to the analyst a list of data facts.	High
FR04	Recommending visualizations	The system must recommend appropriate visualizations for each generated data fact.	High
FR05	Annotating visually data facts	The system must recommend visual annotation cues for each data fact.	High

4.2 Model of Data Facts, Visualizations, and Visual Annotation Cues

Through our SLR, we answered our first research sub-question – *RSQ1: How to visually represent data facts in charts?* Table 4.4 characterizes our proposed proof-of-concept model for visually representing data facts in visualizations. This model underlies the core engine of the *VisStoryMaker* tool, combining visualizations, data facts, and visual annotations cues.

Table 4.3: Tasks and statistical functions currently available in *VisStoryMaker*.

Task	Statistical function
Find Extremum	Minimum Maximum
Derived Value	Average Median
Find anomalies[1]	data point $\leq Q1 - 1.5 \times IQR$ data point $\geq Q3 + 1.5 \times IQR$
Correlation[2]	$r > 0.7$, strong positive correlation $r < -0.7$, strong negative correlation $r > 0.5$, moderate positive correlation $r < -0.5$, moderate negative correlation
Characterize distribution (relative values)[3]	$categoryMaxValue \geq \kappa \times categoryMinValue$ (category pair with largest difference)
Characterize distribution (common range of values)	Half of values are in the range Q1-Q3

[1.] $Q1, Q3, IQR$ stands for *first quartile*, *third quartile* and *interquartile range*, respectively. [2.] r is Pearson's correlation coefficient. [3.] κ is the proportion between $categoryMaxValue, categoryMinValue$.

At first, the model maps user-selected data types (*e.g.*, quantitative, nominal) with possible tasks that could be performed from Amar et al.'s taxonomy – *e.g.*, compute a derived value, find extremum, find anomalies. Due to the similarity between low-level tasks and data facts, we associated one or more task(s) to substantiate data facts. As defined earlier, a data fact is a textual description of the output of statistical functions. Table 4.3 presents the set of heuristics combining *<task, statistical function>* currently available in *VisStoryMaker*. We drew on former systems as inspiration to produce the textual descriptions (Cui et al., 2019; Srinivasan et al., 2019). All data facts come with recommended visualizations grounded on graphical perception studies considering tasks (Saket et al., 2019; Kim and Heer, 2018; Rodrigues et al., 2019; Narechania et al., 2021). Finally, for each recommended graph, the model presents options of visual annotations cues to highlight data

facts in the visualization, based mainly on Kong and Agrawala's taxonomy of overlays and the information visualization literature (Knaflic, 2019; Cairo, 2012; Munzner, 2014). Figure 4.1 illustrates the mechanism described above.

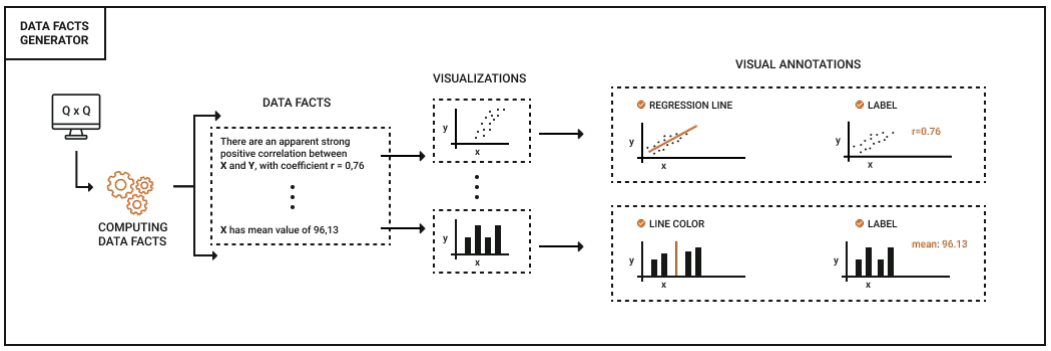

Figure 4.1: Illustration of our model's operation for visually annotating data facts in visualizations

Now that we have explained the mechanism's operation, we will present all options of visual annotations of data facts at the system's core. Table 4.4 relates data types, tasks, visualizations, data facts, and visual annotations which power the VisStoryMaker's visual annotation recommender. We marked with an asterisk (*) the standard visual annotation for each data fact in Table 4.4. Note that we defined 'color' as the standard option for data facts because it is a very common design choice to highlight selected items by changing their color (Munzner, 2014, p.252).

We designed our proof-of-concept model (Table 4.4) to be extensible, *i.e.*, although it is not an exhaustive listing of all possible data facts and visual representations, it can be augmented later on as future work. To operationalize our model, we implemented a mixed-initiative interface, which we detail in the next section.

Table 4.4: Model of data facts, visualizations, and visual annotations cues.

Types	Task	Visual-ization	Example Data Fact	Annotations
Q	Derived Value	Histogram	var0 has mean of val_mean.	*Color line, Label
	Find extremum	Dot	val_max is the highest element for var0.	*Fill color, Stroke
	Characterize distribution	Histogram, Strip	Half of values of var0 are in the range $Q1$ - $Q3$.	*Fill color, Stroke
	Find Anomalies	Box	var0 seems to have amount_outlier outliers.	*Fill color, Stroke
{N,O}	Find Extremum	Bar chart	category0_label has the highest number of occurrences	*Fill color, Stroke, Text Highlight
	Characterize distribution	Bar chart	Number of items in category0_label is X times the number of items in category1_label.	*Fill color, Stroke, Text Highlight
T	Compute Derived Value	Line	The mean number of occurrences of var_0 is mean_occ.	*Point, Line, Label
QxQ	Correlation	Scatter	There are an apparent strong positive correlation between var0 and var1, with coefficient $r = 0.75$.	*Regression line, Label
Qx{N,O}	Characterize Distribution (+Derived Value)	Bar	Average var0 of category0_label is X times category1_label.	*Fill color, Stroke, Text highlight
	Find Extremum (+Derived Value)	Bar	categoryMax_label has highest average value for var0.	*Fill color, Stroke, Text highlight
	Find Extremum	Strip, scatter	var1 has item categoryMin_label with lowest value for var0.	*Fill color, Stroke
QxT	Compute Derived Value	Line, Area	var0 has mean of val_mean in this period.	*Color mean line, point, label
{N,O}x{N,O}	Find Extremum	Stacked Bar, Scatter + Size	The largest group of items in the dataset have var0: category0_label and var1: category1_label.	*Fill color, Stroke, Text Highlight
	Characterize Distribution (+Find Extremum)	Stacked Bar, Scatterplot + Size	category1_label has most number of items. Most items in category1_label belong to category2_label for var1.	*Fill color, Stroke and Text Highlight

4.3 User Interface

To make our proposed model operational, we implemented a mixed-initiative user interface, *i.e.*, we coupled an automated engine to extract data facts and direct manipulation of visual representations through the interface (Horvitz, 1999). Figure 4.2 shows *VisStoryMaker*'s prototype interface. To guide our system's information architecture and interaction design, we considered lessons learned from former visualization recommender systems (from our systematic literature review) and informal expert feedback.

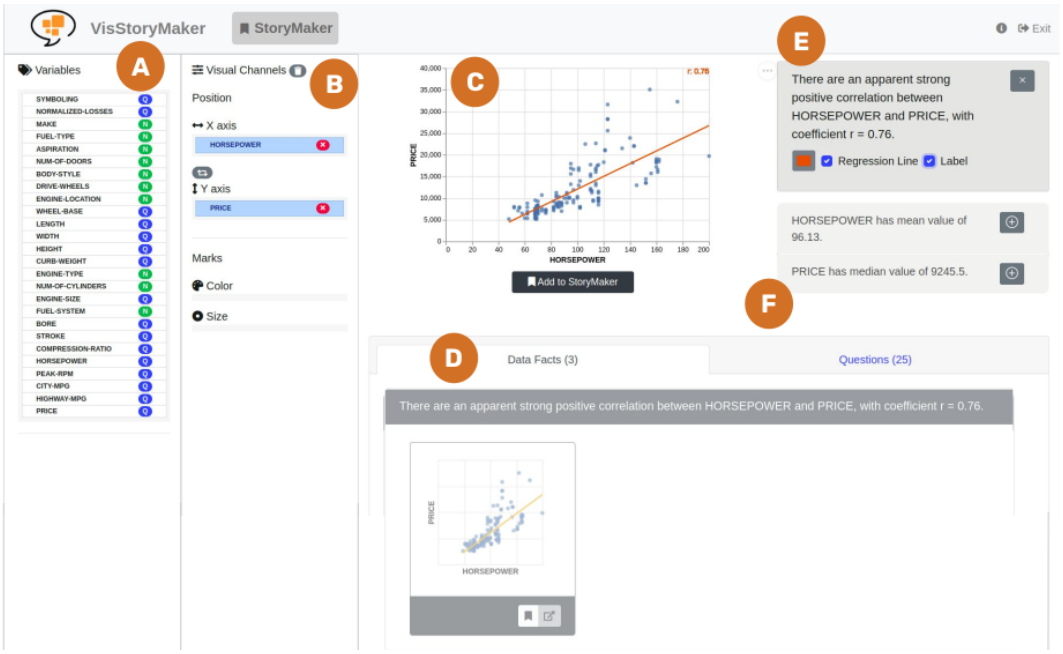

Figure 4.2: *VisStoryMaker*'s prototype interface.

We kept the *Variable Panel* (A) and the *Visual Channels Panel* (B) from the original *VisMaker* to design visualization. *Main Visualization Panel* (C) displays the currently designed visualization. Thus, the system satisfies the functional requirements FR01 and FR02.

We augmented the original interface with components (D, E, and F). The system displays a gallery of data facts in the navigation tab 'Data Facts' (D). Each data fact comes with chart recommendations and a visual annotation preview to facilitate exploration, inspired in the design of the *related views* (Wongsuphasawat et al., 2017). Hence, we meet functional requirements FR03 and FR04.

Last, *VisStoryMaker* exposes the user-chosen data facts (E). The system allows the users to choose and customize the preferred visual representations among a few suggestions, meeting the final requirement, FR05. *VisStoryMaker*

also provides other data facts that can be visually annotated in the chart (F). We describe some implementation details in the next section.

4.4 Implementation Details

VisStoryMaker is a prototype tool where the analyst can design visualizations through manual specification, navigate through system-generated data facts and questions, and construct data stories with the *StoryMaker* module.

In subsection 4.4.1, we describe the technologies used to develop VisStoryMaker, and in subsection 4.4.2, the currently available visualizations in the tool.

4.4.1 Technologies Used

VisStoryMaker is based on a client/server architecture. The client-side is developed with *Vue.js*.[1] The server side is built on *Node.js*,[2] a Javascript-based framework. In addition, we picked up *Vega-Lite* (Satyanarayan et al., 2017) as our visualization API.

We chose *Vega-Lite* (Satyanarayan et al., 2017) because it is an open-source and widely adopted grammar of interactive graphics, which combines the principles of Grammar of Graphics (Wilkinson, 2005) and a novel grammar of interaction. Vega-Lite is interesting because it provides a succinct way to specify visualizations.

For instance, Figure 4.3 presents a dual axis visualization structured in *layers*. One layer – line – presents the values for precipitation, and the other layer – area – presents the minimum and maximum temperature values, both for the city of Seattle. Their y-axes are in different scales. This way of visualization design is interesting for our work, because we might, for instance, model a layer as visualization and additional layers as visual representations of data facts.

4.4.2 Available Visualizations

The visualizations available in *VisStoryMaker* are those illustrated in Figure 4.4 and described below (we adopted the definitions of Few (2009)).

1. **Histogram:** describes the distribution of a single quantitative variable, wherein each bin (range of values) is represented by a bar, and the

[1] `https://vuejs.org/`
[2] `https://nodejs.org/`

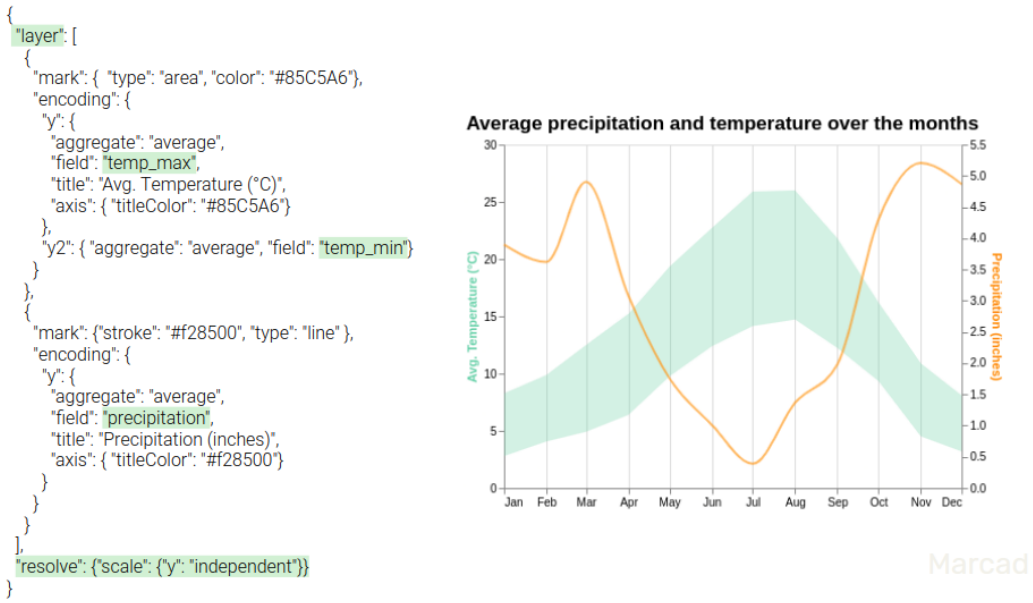

Figure 4.3: A dual-axis chart that layers area for temperature and line for precipitation; each layer uses an independent y-scale.

magnitude of the bar is determined by the number of objects whose values of that variable fall within each bin;

2. **Bar:** represents the relationship between a quantitative variable and a categorical one. In this visualization, each bar represents a different categorical variable, and the magnitude of each bar represents the correspondent quantitative value (or number of objects associated with that category);

3. **Heatmap:** relates two discrete variables across two axes in the same plane, with a color scale that expresses a numeric value related to both variables (*e.g.*, the number of co-occurrences of the values of two nominal variables of a dataset);

4. **Scatter plot:** shows the relationship between two quantitative variables, mapped onto the two axes of the same Cartesian plane;

5. **Boxplot:** presents an abbreviated visualization of the distribution of one or more quantitative variables, representing their minimum, maximum, median, and first and third quartiles;

6. **Strip plot:** makes it possible to visualize the distribution of numeric variables in more detail, showing where each data instance is located in an axis;

7. **Line chart:** displays the evolution of one or more numeric variables over an ordered dimension. It is often used to visualize time series;

8. **Area chart:** is quite similar to a line chart, but the quantitative values are presented by filled regions ("under the lines") (Few, 2009).

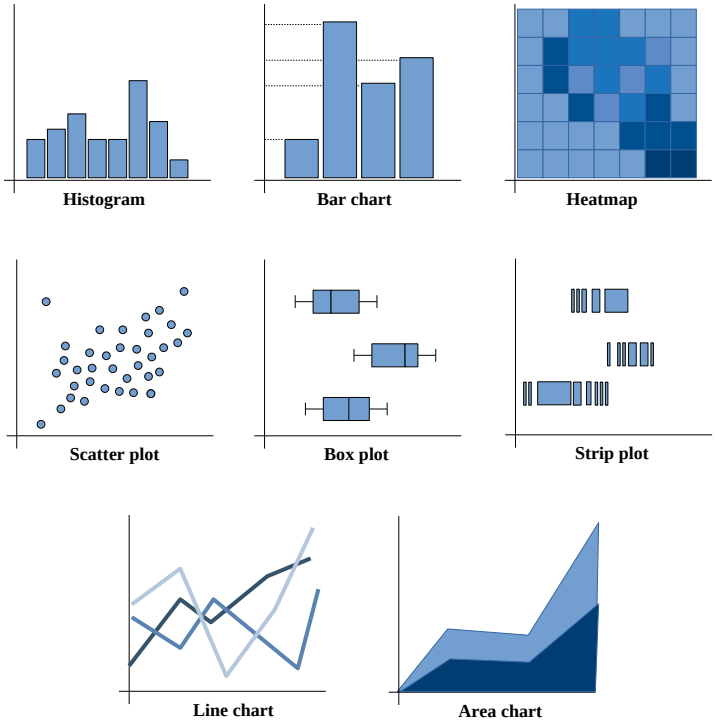

Figure 4.4: Available visualizations (de Araújo Lima and Barbosa, 2020)

4.5 Considerations

Given the developed system (Sections 4.3 and 4.4), we achieved our goal of realizing the proposed model (Section 4.2), and therewith we fulfilled the functional requirements (Section 4.1, Table 4.2).

Now that we have presented our proposed model and how we implemented it in *VisStoryMaker*, we turn to the evaluation of the perceived ease of use and usefulness of *VisStoryMaker*, fulfilling the non-functional requirements (Section 4.1, Table 4.1). In the next chapter, we present the evaluation aimed to answer the *RSQ2: What are the positive and negative aspects of visually annotating data facts in charts?*

5
Evaluation

This chapter depicts how we evaluated the perceived value of *VisStoryMaker*. We conducted a mixed-methods user study to understand *RSQ2: What are the positive and negative aspects of visually annotating data facts in charts?* While planning this study, we had three goals in mind:

1. appraise whether the textual descriptions (data facts or questions) support users to explore the data

2. assess whether visual representations of data facts aid users in communicating with visualizations

3. benchmark users' perceptions about *VisStoryMaker*'s visual annotation approach against *Tableau Public*'s

5.1
Participants and Experiment Design

We recruited 28 participants (11 females) between 18 and 54 years of age. The participants' main job occupation include: journalist (one), teachers (two), data scientists or engineers (five), product or team managers (six), software developers (seven), and graduate students (seven) – from different research fields: architecture, law, human-computer interaction, and optimization.

All participants self-reported as non-experts with visualization tools – *i.e.*, intermediate-level or novice users. Intermediate-level users were enrolled in or had taken a graduate-level data visualization course, or they had some prior experience creating basic charts with visualization tools[1] or performing data analysis with a visualization library.[2] The novice users were composed of eight participants; four of them disclosed they had a brief acquaintance with *Tableau* or *Power BI*, and the other four expressed no prior experience with visualization tools. All participants, intermediate-level and novices, were acquainted with basic descriptive statistics concepts – maximum, minimum, median, average, correlation, and outliers.

[1]Visualization tools stated: *Tableau*, *Power BI*, *Grafana*, *Microstrategy*, *QGIS*, *Google Data Studio*.

[2]Visualization libraries cited: *ggpplot2*, *Matplotlib*, *Seaborn*, *D3.js*, *Plotly*, *Vega-lite*, *Excel*

We assigned participants to four experimentation scenarios (seven in each scenario) by alternating the presentation order of <*dataset*, *tool*>, to avoid ordering effects on the results (Day et al., 2012). Each experimentation scenario can be seen in Table 5.1. We conducted each session synchronously and remotely, via Zoom. Participation in the study was voluntary, and participants were not financially compensated. We sent out recruitment emails to mailing lists. We used a convenience sample (Clark, 2017) due to individual invitations or institutional proximity with individuals.

Table 5.1: Experimentation scenarios according to dataset and tool.

Scenario	Dataset A	Tool A	Dataset B	Tool B
1	vaccination	VisStoryMaker	emp_perf	Tableau Public
2	emp_perf	VisStoryMaker	vaccination	Tableau Public
3	vaccination	Tableau Public	emp_perf	VisStoryMaker
4	emp_perf	Tableau Public	vaccination	VisStoryMaker

5.2 Procedure

Before the study session, we collected their consent to screen capture and audio recording for later review. The informed consent form can be found in Appendix A.1. Once they have their approval, we gathered some background information from participants for our analysis. The user profile form can be consulted on Appendix A.2. We piloted three times to consolidate the study procedure.

Study sessions lasted between 60-90 minutes. We first gave a brief training on the interface and a few features of the first tool ($\sim$ 5 min).[3][4] Training was conducted using a dataset about cars.[5] Next, we gave participants the first dataset according to the experimentation scenario they belong to (Table 5.1). We provided a dataset summary document describing attribute names, corresponding data types, and their translation into Portuguese, available in appendices A.3 and A.4. None of the participants had known the dataset before.

We divided the task into two parts: (i) a guided task with closed-ended questions, and (ii) an unguided task with an open-ended format. In the guided task, we instructed the participants to construct a visualization and explore the tool's key features. Then, we asked them to use the tool to provide answers

[3] *VisStoryMaker*'s tutorial: `https://youtu.be/V3YC55j2-n0`

[4] *Tableau Public*'s tutorial: `https://youtu.be/s0hRpuWtXlE`

[5] The dataset can be viewed or downloaded from `https://drive.google.com/file/d/1313XTAi7l9S0WORlroUdo9R_lAizaKHr/view?usp=share_link`

to closed-ended questions ($\sim$ 10min) – found in appendices A.5 and A.6. We intended to ensure the participants utilized the visual annotation feature at least once for later evaluation. With respect to the unguided part, the task was fairly open-ended: we asked participants to explore the dataset using the tool to present their findings ($\sim$ 10min). At the end of the tasks, participants completed a post-task evaluation form – presented in appendixes A.7 and A.8. Then, we guided the participants to watch the training and perform the tasks using the second tool and dataset ($\sim$ 20min).

An experimenter observed each session and took notes. We encouraged the participants to 'think aloud' while interacting with the tools (Lazar et al., 2017). At the end of each session, we briefly interviewed participants: we asked about their experiences with the tool and feedback on a few specific features of the *VisStoryMaker* ($\sim$ 5min) – shown in appendix A.9.

Figure 5.1 presents an overview of this study; the tools and datasets used in each of the sessions depend on which experimentation scenario the participant belongs to, as expressed in Table 5.1.

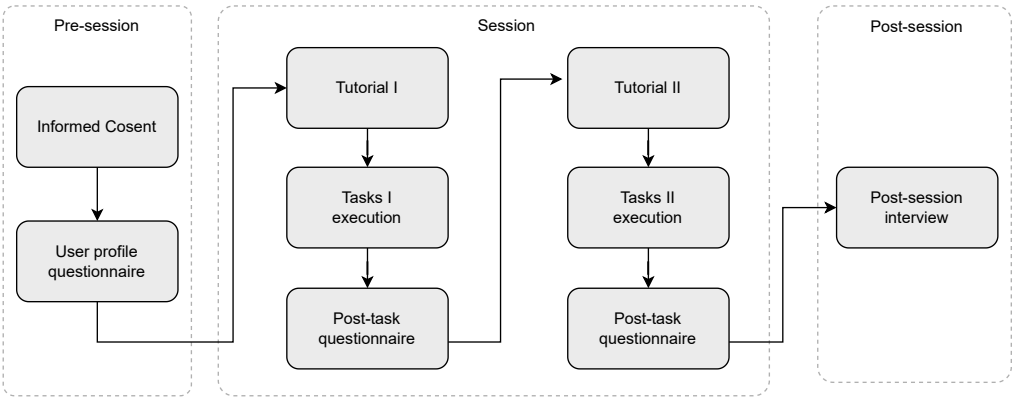

Figure 5.1: Flowchart of study procedure

Now that we explained the study procedure, we can move on and dive into the materials we produced for this study.

5.3 Material

This study relies on some materials to guide and allow participants to perform it. Namely:

1. Informed consent form (Appendix A.1)
2. User profile characterization questionnaire (appendix A.2)
3. Document summarizing the dataset *employee performance* (Appendix A.3)

4. Document summarizing the dataset *covid vacinations* (Appendix A.4)
5. VisStoryMaker's training material: `https://youtu.be/V3YC55j2-n0`
6. Tableau Public's training material: `https://youtu.be/s0hRpuWtXlE`
7. VisStoryMaker's task (Appendix A.5)
8. Tableau Public's task (Appendix A.6)
9. VisStoryMaker's post-task form (Appendix A.7)
10. Tableau's Public's post-task form (Appendix A.8)
11. Interview script (Appendix A.9)

Although we aimed to evaluate a specific part of the system (*i.e.*, the visual annotation feature), we were aware that users form an overall opinion of the system, and that could bias the results. To mitigate these potential biases, we chose to split each task (in steps 7 and 8) into two parts. In the first part, we instructed participants to build a chart and explore the system interface. We then asked them closed-ended questions. For instance: once a participant had constructed a chart, we asked "I - how would you visually highlight the mean in the constructed chart?" To check whether participants completed the first action, we objectively asked them, "II - What is the value of the mean for the constructed chart?" We formulated the last question in this guided part ("III - Could you change or customize the visual representation of the mean value that you had chosen? If so, how?") to encourage them to explore different options of visual representations and customization features (*e.g.*, changing color, adding labels, and so on). Once the participants completed these actions, we instructed them to move on to the second part of the task. The second part was pretty straightforward, we gave them $\sim$ 10min to explore the data and present their findings freely. We encouraged them to use the VisStoryMaker's and Tableau Public's story modules.

At the conclusion of each task, the participants filled out a questionnaire regarding the tool they had used. We designed the questionnaires (steps 9 and 10) to address objective 3 by assessing the perceived ease of use and usefulness grounded on the Technology Acceptance Model (Davis, 1989). To meet objectives 1 and 2, we formulated four questions exclusive to the *VisStoryMaker*'s post-task evaluation form, described below:

– Q01 - The data facts helped me to EXPLORE the data
– Q02 - The questions helped me to EXPLORE the data

- Q03 - The visual annotations of data facts helped me to COMMUNICATE the insights from the data
- Q04 - The questions helped me to COMMUNICATE the insights from the data

We used the questions below as a template to construct each post-task evaluation form presented in Appendices A.7 and A.8. Participants used a 7-point Likert scale to answer each question.

- **Ease of Use**
  - Q05 - Overall, *the tool* is easy to use
  - Q06 - It is simple to use *the tool*
  - Q07 - *The tool* made it easy for me to visually annotate data facts in charts
- **Usefulness**
  - Q08 - *The tool*'s feature of highlighting data facts on charts is useful
  - Q09 - The different options for visually representing data facts on charts in *the tool* are useful
  - Q10 - The personalization options for visual annotations are useful in *the tool*
- **Attitude**
  - Q11 - Using *the tool* to explore data is a good idea
  - Q12 - Using *the tool* to communicate insights from data is a good idea
- **Satisfaction**
  - Q13 - *The tool*'s interface is pleasant
  - Q14 - I enjoyed using *the tool*'s interface
  - Q15 - Using *the tool*'s interface required mental effort
  - Q16 - Interacting with *the tool* was frustrating
  - Q17 - Overall, I am satisfied with *the tool*

'The tool' depends on which experimentation scenario the participant belongs to, according to Table 5.1.

In conclusion, we briefly interviewed the participants following a script presented in Appendix A.9. We asked them general questions about their experience using both tools: "*Overall, what did you think of the tool?*" If the participants answered us shortly, we asked them more specific questions,

such as "*What did you like the most about the tool?*" or "*What bothered you most about the tool?*", and so on. To get feedback on specific features of *VisStoryMaker*, we inquired them "*What data facts would you like to add (or remove) in VisStoryMaker*?" and "*What other ways would you like to visually represent the data facts*?" In both questions, we solicited the participants to keep in mind the data facts and visual annotations they interacted with in *VisStoryMaker*. In conclusion, we asked them whether they had further feedback on any tool or its features.

Now that we have presented the materials and some observations, we will present the results obtained.

5.4 Users' Perceptions Feedback

In this section, we are going to present the users' perceptions on the usage of the systems. Section 5.4.1 depicts the results for objective 1 and 2, Section 5.4.2 presents the benchmark of perceived value for non-experts analysts of VisStoryMaker in contrast with Tableau Public, meeting objective 3. Section 5.4.3 describes some additional feedback. Last, in subsection 5.5, we consolidate the results and answer our *RSQ2: What are the positive and negative aspects of visually annotating data facts in charts?*.

The scripts created to analyze the study data can be consulted as supplementary material at the following link `https://bit.ly/data-analysis-visstorymaker`

5.4.1 Visual Annotations of Data Facts to Aid Exploration and Communication

As stated earlier, we aimed to assess whether the textual descriptions support data exploration (objective 1) and whether visual annotations aid in communicating insights obtained from data (objective 2). For that reason, we elaborated four specific questions for *VisStoryMaker*'s post-task questionnaire. The results summary is shown in figure 5.2.

In the figure, the questions are mapped onto the y-axis. Participants answered each question on a Likert 7-point scale, as color-coded in the color legend ('Score'). The x-axis encodes the normalized distribution of users' feedback, and labels encode the absolute quantity of answers per score.

As can be seen in Figure 5.2, overall, more than 90% of the respondents thought that textual descriptions (data facts and questions) supported them in exploring the data – considering the scores of 6-agree and 7-strongly agree for items Q1 and Q2, thus satisfying objective 1.

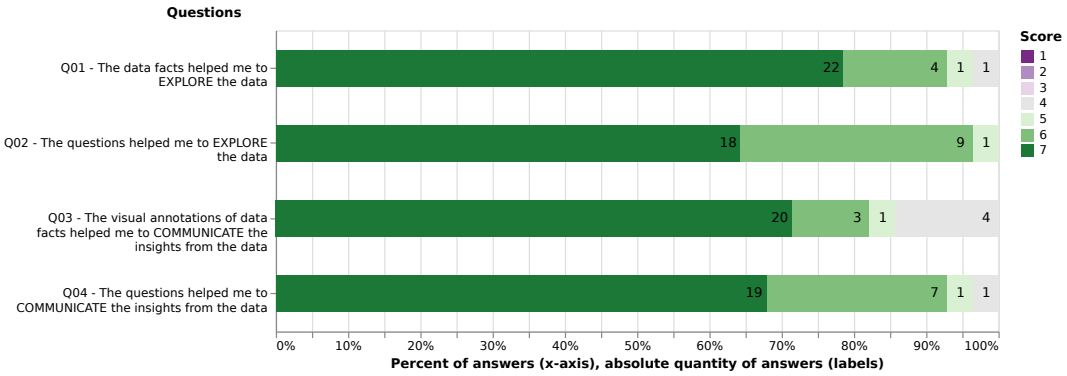

Figure 5.2: Distribution of results per question

In particular, concerning data facts (item Q1), 93% (26) of participants think that data facts aid them in exploring the data. Indeed, several participants (P07, P08, P10, P12, P13, P17, P18, P23, P24, P27) verbally reinforced this subject in the post-test interview. They especially argued that the data facts support them in performing exploration faster, understanding information, hypothesizing about the data, and getting insights about the data. For instance: "*the data facts could help me to hypothesize or get some insights when analyzing the data.*" – P07, "*the tool presented me with several statistics ... this information could lead me to have insights into data.*" – P18, and "*these facts and questions helped me formulate insights*" – P02.

Relating to the questions' feature to support data exploration (item Q2), we reinforced the already expected results obtained in the study of the system's previous version (de Araújo Lima and Barbosa, 2020). By contrast, participants also scored their perceptions about questions and visual annotations of data facts according to their suitability to communicate insights about data – items Q3, Q4, thus fulfilling objective 2.

Regarding visual annotations of data facts, 82% (23) of participants consider that this feature does support them in communicating with data. Participants described some usage scenarios we had not thought of. For instance, a journalist could incorporate the generated facts into news reporting: "*If I needed to write a journalistic article about a topic, with VisStoryMaker, I could have several ideas on how to organize them in a journalistic article...*" – P26; Another participant, a tax auditor, also suggested using facts in creating reports to corroborate ideas: "*as part of my job, I tend to look for outliers. (..) These facts are big deal for people who perform statistical and critical analysis. When you get statistical data, you can compare them with each other and come to a conclusion.*" – P28. Therefore, participants not only recognized the benefits of visual annotations of data facts to communicating with data but also suggested other scenarios in which facts could be useful in their daily activities.

In the next subsection, we will present the results concerning the users' perceptions.

5.4.2 Benchmark of Perceived Usefulness and Ease of Use

It is important to mention that we set goal 3 not for the purpose of 'beating' Tableau but rather to use Tableau Public's perceptions of usefulness as a baseline to achieve. This benchmark also serves to demonstrate the technical feasibility of implementing our proof-of-concept model into a visualization tool. Also, we report the perceived ease of use of VisStoryMaker's interface and the perceived usefulness of visually annotating data facts in graphs.

To begin analyzing the data, we visualized the distribution of the variables to get a first impression of them. We produced 2 (two) normalized stacked bar charts, one for *VisStoryMaker*'s results (Figure 5.3) and the other for *Tableau Public*'s results (Figure 5.4). We placed each question on the y-axis, the percentage distribution of scores on the x-axis, the absolute score values as labels, and color coded the Likert scale on the color legend.

We calculated the median scores for each issue and tool (Table 5.2) as a measure of central tendency, *i.e.*, to somehow analyze the 'most typical' response of each question. We also calculated the difference between the medians (VisSoryMaker's median - Tableau Public's median) to analyze the magnitude of the score difference.

To test whether these results are statistically significant, we started defining the following Hypotheses H_0 and H_1:

Hypothesis H_0 (Null hypothesis)**:** There is no significant difference between the perceived usefulness and ease of use from non-expert analysts of VisStoryMaker's visual annotation approach to the Tableau Public's.

Hypothesis H_1 (Alternative hypothesis)**:** The perceived usefulness and ease of use from non-expert analysts of VisStoryMaker's visual annotation approach are greater or equal (>=) to Tableau Public's.

We computed the non-parametric Wilcoxon matched-pairs test to decide whether the null hypothesis can be rejected (Wilcoxon, 1992). The results for each question are presented in Table 5.2. We highlighted the statistically significant results that were less than or equal to the following α values: .05 (*), .01 (**), and .001 (***).

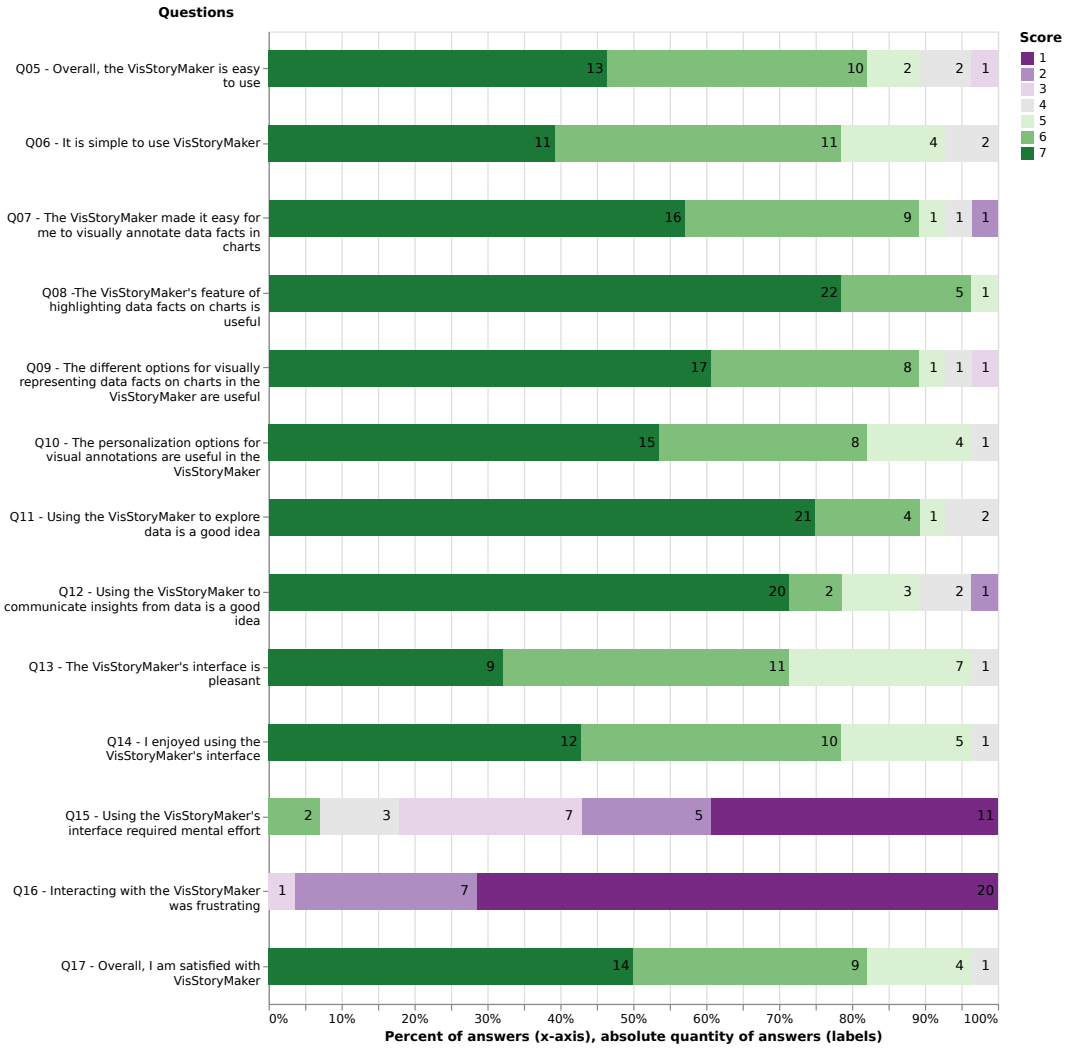

Figure 5.3: Distribution of VisStoryMaker's results per question

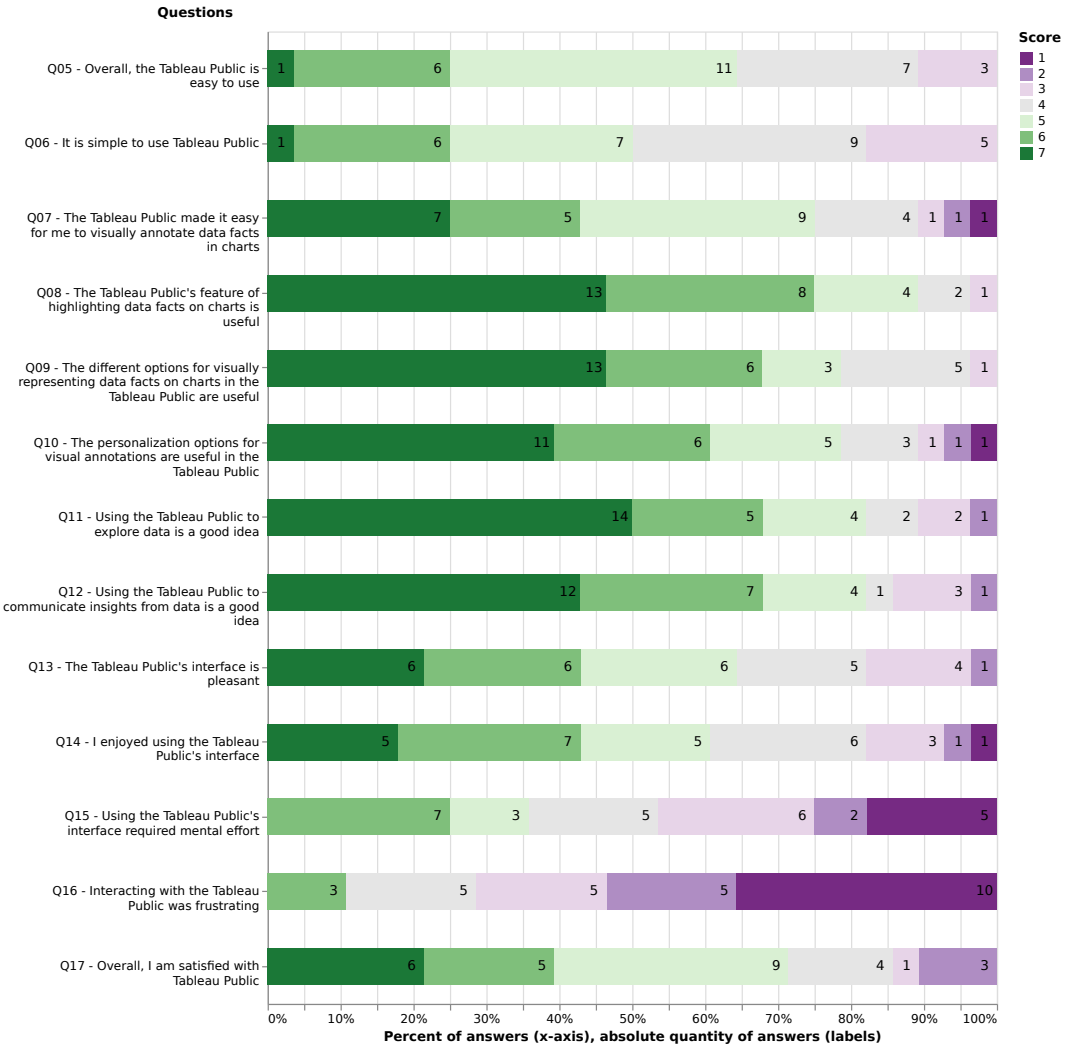

Figure 5.4: Distribution of Tableau Public's results per question

Table 5.2: Results of Wilcoxon matched-pairs test

Question	VSM median	TP median	VSM median - TP median	p-value	significant?	statistic	effect size (rank biserial correlation coefficient)	effect size assessment
Q05 - Overall, the tool is easy to use	6.0	5.0	1.0	**0.000060**	***	16.5	0.9	very strong
Q06 - It is simple to use tool	6.0	4.5	1.5	**0.000042**	***	9.0	0.94	very strong
Q07 - The tool made it easy for me to visually annotate data facts in charts	7.0	5.0	2.0	**0.003350**	**	27.5	0.74	strong
Q08 -The tool's feature of highlighting data facts on charts is useful	7.0	6.0	1.0	**0.003939**	**	11.0	0.82	very strong
Q09 - The different options for visually representing data facts on charts in the tool are useful	7.0	6.0	1.0	0.061773		50.0	-	-
Q10 - The personalization options for visual annotations are useful in the tool	7.0	6.0	1.0	0.055761		42.0	-	-
Q11 - Using the tool to explore data is a good idea	7.0	6.5	0.5	**0.019021**	*	19.5	0.68	strong
Q12 - Using the tool to communicate insights from data is a good idea	7.0	6.0	1.0	0.089088		47.0	-	-
Q13 - The tool's interface is pleasant	6.0	5.0	1.0	**0.007202**	**	58.0	0.61	strong
Q14 - I enjoyed using the tool's interface	6.0	5.0	1.0	**0.001700**	**	31.0	0.75	strong
Q15 - Using the tool's interface required mental effort	2.0	4.0	-2.0	**0.000328**	***	10.0	0.9	very strong
Q16 - Interacting with the tool was frustrating	1.0	2.0	-1.0	**0.000907**	***	7.0	0.91	very strong
Q17 - Overall, I am satisfied with tool	6.5	5.0	1.5	**0.000777**	***	16.0	0.85	very strong

VSM = VisStoryMaker, TP = Tableau Public. $N = 28$, * $p < .05$, **$p < .01$, ***$p < .001$, two-tailed)

According to the two-tailed Wilcoxon matched-pairs test, the perceived usefulness and ease of use by non-expert analysts of *VisStoryMaker*'s visual annotation approach scored significantly greater than *Tableau Public*'s on the highlighted issues above, after performing the task of visually annotating data facts in graphs. Thus, the null hypothesis can be rejected (Sani and Todman, 2008). We failed to reject the null hypothesis for issues Q09, Q10, and Q12; therefore, we can assume there is no significant difference between the two systems concerning these issues.

Continuing the analysis, we investigated whether there was practical significant difference for each statistically significant result. We quantified the effect size by matched pairs rank-biserial correlation (Cureton, 1956). According to (Bartz, 1999, p. 184), the results that we obtained for effect size suggest strong practical significance, as shown in the final column of Table 5.2.

Now that we have obtained the statistically and practically significant results, we are going to analyze the interview answers to look for possible explanations for the results. We started considering the magnitude order of the differences between the medians (VisStoryMaker's median − Tableau Public's median). Therefore, whenever the difference between medians is positive, it means that VisStoryMaker's perceptions of use scored higher. Conversely, whenever the difference was negative means that Tableau Public's scored higher.

The issues with the greatest difference between medians were: *Q07 - The tool made it easy for me to visually annotate data facts in charts* (scored 2.0 of discrepancy); and *Q15 - Using the tool's interface required mental effort* (differed −2.0). Regarding item Q07, participants P04, P19, P15, and P22 pointed out that our tool makes it easy and intuitive to highlight facts visually. An intermediate-level participant said "*In general, I found VisStoryMaker much easier to use than Tableau. Especially when it comes to adding visual annotations to the data*" – P22. To complement this, a novice participant cited what may have led to this point of view: "*VisStoryMaker gave me a lot of options, it already anticipates things that I might want to use, so it makes it easier to use because of that.*" – P19. Concerning item Q15, a participant summarizes the common opinion regarding this issue: "*Although Tableau provides more options for you to insert these visual annotations than VisStoryMaker, but Tableau provides a more complicated way of annotating and customizing.*" – P22.

Following this reasoning of difference between medians, the next items showed the second largest discrepancy, of 1.5 points: *Q06 - It is simple to use tool* and *Q17 - Overall, I am satisfied with tool*. Indeed, all novice participants

(8) perceived themselves as satisfied and thought it was simpler to use our system to complete the tasks compared to Tableau Public. This might suggest that, for a user with minimal or no experience in producing annotated charts, VisStoryMaker offers a simple way to accomplish it. To illustrate that, a novice participant said: "*I thought that the way of highlighting specific information (like the mean), VisStoryMaker helps highlight more easily for a person like me, who has no experience with this type of task.*" – P15. Of the intermediate-level participants, most of them (19) rated their perceptions of VisStoryMaker's ease of use as somewhat superior or equal to Tableau Public's. One participant felt frustrated when using VisStoryMaker: "*I thought the tool was harder to learn how to use. For example, I felt confused and frustrated when highlighting the average because I was trying to do it, but I could not.*" – P19. In addition, further study is needed to better understand this specific perception before drawing conclusions.

The remaining issues (with both statistical and practical significance) with the lowest difference between median difference values are presented below:

- *Q05 Overall, the tool is easy to use*: (1.0)
- *Q13 The tool's interface is pleasant*: (1.0)
- *Q14 I enjoyed using the tool's interface*: (1.0)
- *Q08 The tool's feature of highlighting data facts on charts is useful*: (1.0)
- *Q16 Interacting with the tool was frustrating*: (-1.0)
- *Q11 Using the tool to explore data is a good idea*: (0.5)

Participants perceived our system as simple and easy to use (items Q05, Q13, Q14, and Q16). Novices and intermediate-level users felt that the visual annotations and data facts were useful and supported them in creating hypotheses, understanding data, leading to insights, creating reports or presentations, and exploring the data (item Q08, Q11). In subsection 5.4.1, we outlined the main participants' feedback that described these positive points of visual annotations and data facts in regard to exploration and communication insights from data.

Particularly about Tableau Public, twelve users (P01, P04, P05, P06, P07, P08, P10, P13, P16, P20, P21, P25) said it was more complicated to use in comparison to VisStoryMaker. They broadly argued that many features had first intimidated them because so many options demand a long time to choose what to do. In contrast, some participants preferred Tableau Public. For instance: "*about visual annotations, I thought Tableau was way superior to*

VisStoryMaker because ... Tableau allowed me so many options for formatting the visualization, and that gave me more freedom." – P09. In addition, two users said that they would use a combination of two tools: "*I would use VisStoryMaker to explore, and if there were a visualization that I did not like, I would use Tableau.*" – P12, and "*I think the best of both worlds would be to do a preliminary analysis using VisStoryMaker, and then I would use Tableau to generate graphs to communicate to other people.*" – P17. These results reinforce data facts and questions as a way to support data exploration.

5.4.3 Additional Feedback Regarding Visual Annotations of Data Facts

We further inquired participants about their opinions of the catalog of data facts and visual annotations. Users said that the facts were similar to the ones they would typically look for when starting to analyze data. They felt satisfied with the available facts and would not remove any because they considered it useful to have options for saving time, even the simplest ones (maximum, minimum). For instance: "*I think the tool gives a very good catalog for the user to see and to choose which ones to use. In my opinion, there is no need to remove any.*" – P17. These observations might suggest that non-expert analysts felt supported by system-generated data facts and that they typically look for descriptive statistics in visualizations to understand data better.

Some intermediate-level users were excited about the possibilities for data facts and suggested including many additional facts in the tool, such as time series analytics, analysis of tendency, seasonality, information about quartiles, standard deviation, and so on. Indeed, they would like to customize the facts they wanted the tool to calculate (or not). They also missed a way to highlight non-pre-calculated facts, for instance, by linking a widget to a textual description, similar to Tableau Public's feature. In the next section, we discuss the consolidated results.

5.5 Discussion

In this section, we consolidate the results and answer our *RSQ2: What are the positive and negative aspects of visually annotating data facts in charts?* (subsection 5.5.1), and present the threats to validity for this study (subsection 5.5.2).

5.5.1 *RSQ2: What are the positive and negative aspects of visually annotating data facts in charts?*

A negative point identified through our study about the visual annotations was that including multiple visual data facts in the chart could cause visual clutter and could distract readers from the data, in line with a previous study by Bateman et al. (2010). This opens up space for further studies to recommend more subtle visual annotations options, as suggested by this participant: "*It would be interesting to give the option to highlight the mean value on the graph's axis to avoid cluttering the visualization. Sometimes, we include so much information in graphs that it ends up visually cluttering.*" – P18. In addition, other participants reinforced the same argument: "*Maybe you could mark the average with a dot, maybe it could be more visually unobtrusive*" – P27 and "*I think maybe a little more simplified representation*" – P26.

Collectively among participants, what stands out most is the role of data facts in *supporting exploratory analysis*. The non-expert analysts reported that the available facts were common information they typically look for when visualizing data. They perceived data facts as helpful for *hypothesizing* and could lead to *insights* from data, thus *enhancing data analysis*. Users perceived the recommended visualizations as helpful in suggesting visual representations to communicate numbers to a broader audience (as emphasized by a journalist participant). As for *visual data communication*, participants think visual annotations of data facts could support them in *generating ideas* on how to organize the information and incorporate them in journalistic articles, reports, presentations, or scientific papers.

There are two modules inherited from previous versions of this system, namely *Questions* and *StoryMaker* (de Araújo Lima and Barbosa, 2020; Silva and Barbosa, 2022). We organized in Table 5.3 the positive and negative aspects collected from our study, categorized by VisStoryMaker's modules.

Table 5.3: Positive and negative aspects of VisStoryMaker's modules.

<table>
<tr><th colspan="3">Negative Points</th><th colspan="3">Positive Points</th></tr>
<tr><th>Questions</th><th>Data Facts</th><th>StoryMaker</th><th>Questions</th><th>Data Facts</th><th>StoryMaker</th></tr>
<tr><td>- do not customize the charts</td><td>- several visual data facts could cause visual clutter</td><td>- does not visual highlight statitics into charts
- limited export choice (pdf only)</td><td colspan="2">- supports exploratory analysis
- helps hypothesize about data
- visualization recommendation</td><td rowspan="2"></td></tr>
<tr><td colspan="3">- does not provide interactivity features with the charts (zoom, highlight non pre-calculated facts)</td><td></td><td>- could lead to insights
- support visual data communication</td><td>- prefered magazine genre to create story</td></tr>
</table>

Our results showed that our approach to visual annotating data facts is perceived as useful and easy to use by non-expert analysts. We chose to contrast VisStoryMaker's perceived value in relation to Tableau Public's visual annotation approach as a baseline to be achieved. However, there are a few

issues we should discuss to better frame our results, which we do in the next subsection.

5.5.2 Limitations

We acknowledge potential threats to validity that could have biased our results. There is no guarantee that these results may be applicable to the whole target audience of Tableau Public and/or VisStoryMaker. The potential limitations concern:

- *Evaluation.* Although we aimed to evaluate the specific feature of visual annotation from VisStoryMaker, the users tend to form an overall opinion of the system. In Section 5.3, we explained what we did to mitigate the effects of this potential bias;
- *Sample participants.* We sent invites to mailing lists, but the adherence to voluntary participation through this media was weak. To work around that, we recruited a convenience sample due to the institutional proximity and participants' acquaintances, in a snowballing approach;
- *System functionalities.* We chose a reduced set of system features. Indeed, the tasks were limited to the intersection of VisStoryMaker's and Tableau Public's functionalities.
- *Study execution.* We allowed the participants to watch the training video more than once.

Despite these limitations, our findings still present interesting insights and instigate future lines of research, some of which will be described in the following chapter.

6
Conclusions

This chapter presents this research's main contributions (Section 6.1) and outlines future work directions (Section 6.2).

6.1
Contributions

We conducted a systematic literature review (chapter 3) to understand the state of existing knowledge about visualization recommender systems and to guide the development of our model and system. This secondary research contributes to future work since it structures the existing body of research and outlines future lines of research regarding visualization recommender systems.

We used the review's results as input to design a proof-of-concept model of visual annotations of data facts (Section 4.2), which is the main contribution of our work. We implemented this model and integrated it into the VisStoryMaker system to generate data facts and recommend visual annotation cues (Section 4.3).

To gather evidence that the model does contribute to the state-of-the-art, we evaluated VisStoryMaker through a mixed-methods user study. We reported its perceived usefulness and ease of use in contrast to the commercial system Tableau Public as a baseline (chapter 5).

6.2
Future Work

As short-term future work, we aim to perform an in-depth analysis of the qualitative interview data and triangulate it with the screen-recorded interactions. Understanding those interactions and assessing their impact on the quantitative results is an important next step.

Moreover, there are various suggestions for tool enhancement proposed by users throughout the study, such as: enhancing interaction options with visualizations, allowing users to include particular observations as textual descriptions in something akin to balloon widgets, providing further customization options for the working visualization, and so on. These suggestions may also serve as short-term future works.

For the medium-term, interesting future works would be time series analysis: to verify indications of seasonality and/or trends in temporal data, auto-correlation, and more advanced statistical methods.

Some users felt frustrated they could not recover from errors. Therefore, we refer to conducting a heuristic evaluation of VisStoryMaker's interface, revisiting Nielsen's usability heuristics (Nielsen, 1994). Another possible medium-term work may include investigating the effects of onboarding instructions to lower the initial barriers for people to use the tool.

As for long-term work, we propose to explore generating narratives or to support interactive storytelling. The notion of visual data facts annotations could be used as a first step toward data-driven storytelling (Ren et al., 2017). How do we expand the notion of data facts to texts or sentences, and how could they be used to support data storytelling? Could natural language generation models generate data facts? Could data facts generation meet ChatGPT? Several new research opportunities could arise and be explored on this topic.

Still in the line of storytelling research, further studies could be conducted to investigate whether aspects of visual data facts annotations could be incorporated into interactive storytelling. According to Crawford (2004), interactive storytelling is the art of telling stories enhanced with interactive features to offer content – either these features are technological, social or collaborative (Willett et al., 2011). More research is necessary to understand the relationship between these concepts, and how they could be explored in future work.

More research is necessary to investigate integrating machine learning algorithms to augment interface capacities. For instance, can a natural language generator model be used to automatically generate other data facts? If so, how could we integrate this generated information to enrich visual analysis?

Future studies must explore the possible implications of providing end-user development resources. Could we provide mechanisms for users without programming skills to define the data facts they want to be calculated? and what about visual annotations? Furthermore, could a framework or model be developed to calculate data facts for other data types (such as time series and so on)? What would be the procedure to accomplish that?

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A
Study Material

In this appendix, we present the study materials. All the materials are in Portuguese – which is the language the study was conducted. The list of materials is as follows:

1. Free and Informed Consent (section A.1)
2. Participant Profile Characterization Questionnaire (section A.2)
3. Document summarizing the dataset *employee performance* (section A.3)
4. Document summarizing the dataset *covid vacinations* (section A.4)
5. VisStoryMaker's Task (section A.5)
6. Tableau Public's Task (section A.6)
7. Post Task Evaluation VisStorymaker (section A.7)
8. Post Task Evaluation Tableau Public (section A.8)
9. Interview Script (section A.9)

A.1
Free and Informed Consent

Termo de Consentimento Livre e Esclarecido

1. Objetivo

Você está sendo convidado(a) para participar de uma pesquisa que visa comparar duas ferramentas de apoio à exploração e análise visual e numérica de dados. Esta pesquisa está sendo conduzida pelo aluno de mestrado Dieinison Jack Freire Braga sob orientação da professora Simone Diniz Junqueira Barbosa, ambos afiliados ao Departamento de Informática da Pontifícia Universidade Católica do Rio de Janeiro.

Tanto as ferramentas quanto as descrições das tarefas utilizarão a língua inglesa por padrão. Durante a realização do experimento, serão gravados a voz do participante, bem como a sua interação com as ferramentas através de captura de tela.

2. Riscos e desconfortos

A participação nesta pesquisa não traz riscos ou desconfortos aos participantes.

3. Benefícios Potenciais

Esta pesquisa não foi pensada para lhe beneficiar diretamente. Através deste estudo, esperamos confirmar (ou refutar) o apoio de fatos sobre dados e anotações à usuários não especialistas em visualizações. Os principais benefícios incluem insumos e direcionamento para pesquisas futuras, diretrizes de design para ferramentas de visualização, refinamento de sistemas de recomendação de visualização, dentre outros.

4. Garantia de anonimato e privacidade

Todos os dados coletados nesta pesquisa destinam-se exclusivamente a atividades de pesquisa, e somente serão acessados pelos pesquisadores envolvidos nesta pesquisa. Ao divulgarmos os resultados da pesquisa, nos comprometemos em preservar seu anonimato e privacidade, ocultando ou disfarçando toda informação que possa revelar sua identidade.

5. Liberdade de recusa e retirada de consentimento

Sua participação nesta pesquisa é voluntária. Sua recusa não trará nenhum prejuízo.

6. Considerações Éticas

Esta pesquisa tem a aprovação da Câmara de Ética em Pesquisa da Pontifícia Universidade Católica do Rio de Janeiro para pesquisas envolvendo pessoas.

Após completar o estudo, você poderá contactar os pesquisadores (via e-mail para dbraga@inf.puc-rio.br) para saber mais sobre os resultados gerais.

7. Declaração de consentimento

Ao afirmar o seu consentimento abaixo, você declara que:

1 - Recebi informações sobre o objetivo da pesquisa descrita neste documento;
2 - Estou ciente de que as atividades previstas na pesquisa não representam nenhum risco para mim ou para qualquer outro participante;
3 - Concordo voluntariamente em participar deste estudo.

Por gentileza, salve uma cópia deste formulário.

1. Você afirma seu consentimento de acordo com os termos descritos acima? *

- [ ] Autorizo o uso das informações coletadas descritas neste documento.
- [ ] Não autorizo o uso das informações coletadas descritas neste documento.

2. Por favor, informe seu nome:

_____

A.2
Participant Profile Characterization Questionnaire

Perfil do Participante

Antes de começar o estudo, preencha esse formulário com algumas informações sobre seu perfil.

1. Informe o seu nome

_____

2. Qual a sua faixa etária?

- ◯ 18 - 24
- ◯ 25 - 34
- ◯ 35 - 44
- ◯ 45 - 54
- ◯ 55 - 64
- ◯ 65+

3. Qual identidade de gênero você se identifica?

   À medida que você se sinta confortável para responder: (Selecione uma opção)

- ◯ Masculino
- ◯ Feminino
- ◯ Não-binário
- ◯ Agênero
- ◯ Eu prefiro não revelar
- ◯ Outro: _____

4. Qual o seu nível educacional no momento?

- ◯ Ensino médio (completo)
- ◯ Ensino superior (completo)
- ◯ Especialização (completa)
- ◯ Pós-graduação (Mestrado ou Doutorado, completo)

5. Em qual área de estudo ou curso você concluiu (ou está cursando)?
Se possui mais de uma, escolha a mais relevante.

- ◯ Ciência da Computação (Graduação)
- ◯ Engenharia de Computação (Graduação)
- ◯ Sistemas de Informação (Graduação)
- ◯ Bancos de Dados (Pós-graduação)
- ◯ Ciência de Dados (Pós-graduação)
- ◯ Computação Gráfica (Pós-graduação)
- ◯ Engenharia de Software (Pós-graduação)
- ◯ Hipertexto e Multimídia (Pós-graduação)
- ◯ Interação Humano-Computador (Pós-graduação)
- ◯ Linguagens de Programação (Pós-graduação)
- ◯ Otimização e Raciocínio Automático (Pós-graduação)
- ◯ Redes de Computadores e Sistemas Distribuídos (Pós-graduação)
- ◯ Teoria da Computação (Pós-graduação)
- ◯ Outro: _____

6. Qual sua profissão? E quais as principais atividades você costuma exercer na sua área de atuação/pesquisa/curso?

   Se possui mais de uma, descreva a mais relevante. (ex.: engenheiro de software/desenvolvo sites web, analista de P&D/construo visualizações de dados ou dashboards, estudante de mestrado/pesquiso sobre visualizações, etc)

7. Quais ferramentas ou bibliotecas de visualização você utilizou (se alguma)?

   (ex: Power BI, Tableau, R, Matplotlib, Seaborn, Flourish, Vega, etc)

8. Você já utilizou alguma ferramenta de visualização de dados que permite adicionar algum tipo de anotação? Se sim, qual(is) ferramenta(s) e quais tipo de anotações?

   Ex: Tableau/colorir uma barra de outra cor em um gráfico de barras. Flourish/adicionar anotações manuais em formato de caixa de texto.

9. Indique com que frequência realiza cada um dos itens abaixo.

Considerando visualizações básicas: gráficos de barra, linhas, barras agrupadas, boxplot.

	1 - nunca	2	3	4 - médio	5	6	7 - muita frequência
CONSTRUIR visualizações de dados	◯	◯	◯	◯	◯	◯	◯
LER visualizações de dados	◯	◯	◯	◯	◯	◯	◯

10. Como você considera seu grau de conhecimento em visualizações de dados?

◯ INICIANTE – Não tenho experiência com ferramentas de visualização;

◯ INTERMEDIÁRIO – estou matriculado ou já tive aulas de visualização da informação e/ou me sinto confortável em criar visualizações básicas utilizando ferramentas ou bibliotecas de visualização;

◯ EXPERT – Sou bem familiarizado com visualizações e ferramentas ou bibliotecas de visualizações e/ou uso com frequência como parte do meu trabalho/estudo para explorar dados e/ou compartilhar descobertas;

◯ Outro: _____

11. Indique seu grau de conhecimento sobre cada conceito de estatística abaixo.

	1 - nenhum	2	3	4 - médio	5	6	7 - especialista
Máximo e Mínimo	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Média	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Mediana	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Outlier (ponto fora da curva)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Correlação entre variáveis	⬭	⬭	⬭	⬭	⬭	⬭	⬭

A.3
Document summarizing the dataset *employee performance*

Summary Document
Dataset: **employee_performance.csv (16 columns x 1470 rows)**
Descrição: Este é um conjunto de dados pré-processado e fictício criado por cientistas de dados da IBM.

Dataset original:
https://www.kaggle.com/datasets/pavansubhasht/ibm-hr-analytics-attrition-dataset
Dataset pré-processado e utilizado no estudo:
https://drive.google.com/file/d/1NUYYl0Vg7AOGyO-FxQokoblrZDNMUfvB/view?usp=sharing

Attributes, data types, and translation to Portuguese:

Age: quantitative (Idade)
BusinessTravel: nominal (Viagens à negócios)
Department: nominal (Departamento)
DistanceFromHome: quantitative (Distância de casa)
Education: nominal (Nível educacional)
EducationField: nominal (Campo educacional)
Gender: nominal (Gênero)
JobRole: nominal (Cargo)
JobSatisfaction: nominal (Satisfação no trabalho)
MaritalStatus: nominal (Estado civil)
MonthlyIncome: quantitative (Renda mensal)
PerformanceRating: nominal (Classificação de desempenho)
WorkLifeBalance: nominal (Balanço de vida e profissão)
YearsAtCompany: quantitative (Anos na empresa)
YearsInCurrentRole: quantitative (Anos no cargo atual)
YearsSinceLastPromotion: quantitative (Anos desde a última promoção)

A.4
Document summarizing the dataset *covid vacination*

Summary Document
Dataset: **employee_performance.csv (16 columns x 1470 rows)**
Descrição: Este é um conjunto de dados pré-processado e fictício criado por cientistas de dados da IBM.

Dataset original:
https://www.kaggle.com/datasets/pavansubhasht/ibm-hr-analytics-attrition-dataset
Dataset pré-processado e utilizado no estudo:
https://drive.google.com/file/d/1NUYYl0Vg7AOGyO-FxQokoblrZDNMUfvB/view?usp=sharing

Attributes, data types, and translation to Portuguese:

Age: quantitative (Idade)
BusinessTravel: nominal (Viagens à negócios)
Department: nominal (Departamento)
DistanceFromHome: quantitative (Distância de casa)
Education: nominal (Nível educacional)
EducationField: nominal (Campo educacional)
Gender: nominal (Gênero)
JobRole: nominal (Cargo)
JobSatisfaction: nominal (Satisfação no trabalho)
MaritalStatus: nominal (Estado civil)
MonthlyIncome: quantitative (Renda mensal)
PerformanceRating: nominal (Classificação de desempenho)
WorkLifeBalance: nominal (Balanço de vida e profissão)
YearsAtCompany: quantitative (Anos na empresa)
YearsInCurrentRole: quantitative (Anos no cargo atual)
YearsSinceLastPromotion: quantitative (Anos desde a última promoção)

A.5
VisStoryMaker's Task

Tasks VisStoryMaker

1. Qual o seu nome?

_____

2. Qual conjunto de dados você utilizou com o VisStoryMaker?

- ◯ employee_performance
- ◯ covid_vacination

PART I

Siga as instruções abaixo, e depois forneça respostas às perguntas a seguir.

Instruções

1. Carregue o conjunto de dados disponível na ferramenta;
2. Arraste e solte uma variável **quantitativa (Q)** para o eixo X;
3. Use até 1 (um) minuto para navegar e examinar as perguntas e os fatos sobre dados gerados;
4. Arraste e solte uma variável **nominal (N)** para o eixo Y;
5. Use até 1 (um) minuto para navegar e examinar as perguntas e os fatos sobre dados gerados;
6. Escolha pelo menos 1 (uma) visualização para salvar no módulo StoryMaker.
7. Abra o StoryMaker, use até 1 (um) minuto para explorar o módulo StoryMaker.
8. Feche o StoryMaker.

Agora, forneça respostas às seguintes perguntas.

3. Como você destacaria a média na visualização que você construiu?

_____

4. Qual é o valor da média para a visualização que você construiu?

_____

5. Você consegue personalizar/alterar a representação visual da média que você fez? Se sim, qual?

PART II

Instruções:

1. Utilize o conjunto de dados disponível na ferramenta;
2. Dedique até 10 (dez) minutos para explorar os dados livremente e apresentar o que você achou interessante (incentivamos você a usar o StoryMaker para salvar as visualizações que você considerou
   interessantes e adicionar algumas observações, se necessário)..

A.6
Tableau Public's Task

Tableau Public's Task

1. Qual o seu nome?

_____

2. Qual conjunto de dados você utilizou com o Tableau Public?

- ◯ employee_performance
- ◯ covid_vacination

PART I

Siga as instruções abaixo, e depois forneça respostas às perguntas a seguir.

Instruções

1. Carregue o conjunto de dados disponível na ferramenta;
2. Navegue para a aba "Sheet 1";
3. Arraste e solte uma **variável nominal (símbolo: 'Abc' or 'Country')** para o eixo Linhas/Rows;
4. Use até 1 (um) minuto para explorar a interface do Tableau Public;
5. Arraste e solte uma **variável quantitativa (símbolo: '#')** para o eixo Colunas/Columns;
6. Use até 1 (um) minuto para explorar a interface do Tableau Public;
7. Navegue para a aba Nova história/New Story;
8. Clique duas vezes no link "Sheet 1";
9. Use até 1 (um) minuto para explorar este módulo;
10. Volte para a aba "Sheet 1".

Agora, forneça respostas às seguintes perguntas.

3. Como você destacaria a média na visualização que você construiu?

_____

4. Qual é o valor da média para a visualização que você construiu?

5. Você consegue personalizar/alterar a representação visual da média que você escolheu? Se sim, qual?

PART II

Instructions:

1. Utilize o conjunto de dados disponível na ferramenta;
2. Dedique até 10 (dez) minutos para explorar os dados livremente e apresentar o que você achou interessante (incentivamos você a usar o módulo "História" para salvar as visualizações que você considerou interessantes e adicionar algumas observações, se necessário).

A.7
Post Task Evaluation VisStorymaker

Questionário de Avaliação - VisStoryMaker

Forneça respostas sobre suas percepções ao usar o VisStoryMaker.

1. Informe o seu nome

_____

2. Qual conjunto de dados você utilizou?

- [ ] employee_performance
- [ ] covid_vacination

3. Facilidade de Uso

	1 - Discordo totalmente	2	3	4	5	6	7 - Concordo totalmente
No geral, eu achei o VisStoryMaker fácil usar	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Eu achei simples usar o VisStoryMaker	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Eu achei que o VisStoryMaker facilita a adição de anotações visuais de fatos sobre dados nas visualizações	⬭	⬭	⬭	⬭	⬭	⬭	⬭

4. Utilidade

	1 - Discordo totalmente	2	3	4	5	6	7 - Concordo totalmente
Eu achei útil a possibilidade de adicionar anotações visuais de fatos sobre dados no VisStoryMaker	◯	◯	◯	◯	◯	◯	◯
Eu achei úteis as diferentes opções de anotar visualmente fatos sobre dados do VisStoryMaker	◯	◯	◯	◯	◯	◯	◯
Eu achei útil as formas de personalizar as anotações visuais do VisStoryMaker	◯	◯	◯	◯	◯	◯	◯
No VisStoryMaker, as anotações visuais de fatos sobre dados me ajudaram à EXPLORAR os dados	◯	◯	◯	◯	◯	◯	◯
No VisStoryMaker, as anotações visuais de fatos sobre dados me ajudaram à COMUNICAR (apresentar)	◯	◯	◯	◯	◯	◯	◯

as informações obtidas com os dados							
As perguntas me ajudaram à EXPLORAR os dados	⬭	⬭	⬭	⬭	⬭	⬭	⬭
As perguntas me ajudaram à COMUNICAR (apresentar) as informações obtidas com os dados	⬭	⬭	⬭	⬭	⬭	⬭	⬭
As anotações visuais me ajudaram a entender as descrições textuais de fatos sobre dados	⬭	⬭	⬭	⬭	⬭	⬭	⬭

5. Atitude

	1 - Discordo totalmente	2	3	4	5	6	7 - Concordo totalmente
Utilizar o VisStoryMaker para explorar dados é uma boa ideia	◯	◯	◯	◯	◯	◯	◯
Utilizar o VisStoryMaker para comunicar informações obtidas com os dados é uma boa ideia	◯	◯	◯	◯	◯	◯	◯

6. Auto-eficácia

	1 - Discordo totalmente	2	3	4	5	6	7 - Concordo totalmente
A interface do VisStoryMaker é agradável	◯	◯	◯	◯	◯	◯	◯
Eu gostei de usar a interface do VisStoryMaker	◯	◯	◯	◯	◯	◯	◯
Utilizar a interface do VisStoryMaker me exigiu muito esforço mental	◯	◯	◯	◯	◯	◯	◯
Interagir com o VisStoryMaker foi frustante	◯	◯	◯	◯	◯	◯	◯
No geral, eu estou satisfeito com o VisStoryMaker	◯	◯	◯	◯	◯	◯	◯

A.8
Post Task Evaluation Tableau Public

Questionário de Avaliação - Tableau Public

Forneça respostas sobre suas percepções ao usar o Tableau Public.

1. Informe o seu nome

_____

2. Qual conjunto de dados você utilizou?

- [ ] employee_performance
- [ ] covid_vacination

3. Facilidade de Uso

	1 - Discordo totalmente	2	3	4	5	6	7 - Concordo totalmente
No geral, eu achei o Tableau Public fácil de usar	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Eu achei simples usar o Tableau Public	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Eu achei que o Tableau Public facilita a adição de anotações visuais de fatos sobre dados nas visualizações	⬭	⬭	⬭	⬭	⬭	⬭	⬭

4. Utilidade

	1 - Discordo totalmente	2	3	4	5	6	7 - Concordo totalmente
Eu achei útil a possibilidade de adicionar anotações visuais de fatos sobre dados no Tableau Public	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Eu achei úteis as diferentes opções de anotar visualmente fatos sobre dados do Tableau Public	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Eu achei útil as formas de personalizar as anotações visuais do Tableau Public	⬭	⬭	⬭	⬭	⬭	⬭	⬭
No Tableau Public, as anotações visuais de fatos sobre dados me ajudaram à EXPLORAR os dados	⬭	⬭	⬭	⬭	⬭	⬭	⬭
No Tableau Public, as anotações	⬭	⬭	⬭	⬭	⬭	⬭	⬭

visuais de fatos sobre dados me ajudaram à COMUNICAR (apresentar) as informações obtidas com os dados	

5. Atitude

	1 - Discordo totalmente	2	3	4	5	6	7 - Concordo totalmente
Utilizar o Tableau Public para explorar dados é uma boa ideia	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Utilizar o Tableau Public para comunicar informações obtidas com os dados é uma boa ideia	⬭	⬭	⬭	⬭	⬭	⬭	⬭

6. Auto-eficácia

	1 - Discordo totalmente	2	3	4	5	6	7 - Concordo totalmente
A interface do Tableau Public é agradável	◯	◯	◯	◯	◯	◯	◯
Eu gostei de usar a interface do Tableau Public	◯	◯	◯	◯	◯	◯	◯
Utilizar a interface do Tableau Public me exigiu muito esforço mental	◯	◯	◯	◯	◯	◯	◯
Interagir com o Tableau Public foi frustante	◯	◯	◯	◯	◯	◯	◯
No geral, eu estou satisfeito com o Tableau Public	◯	◯	◯	◯	◯	◯	◯

A.9
Interview Script

Entrevista pós teste:

1. De maneira geral, o que você achou do VisStoryMaker?

2. De maneira geral, o que você achou do Tableau Public?

3. Considerando os fatos sobre dados disponíveis na ferramenta VisStoryMaker, quais outros fatos sobre dados você gostaria de adicionar (ou remover) no VisStoryMaker?

4. Tendo em mente as visualizações anotadas que você construiu no VisStoryMaker, de quais outras formas você gostaria de anotar graficamente os fatos de dados?

5. Você gostaria de acrescentar algum comentário?

B
Interview Responses

In this appendix, we are going to present a summary of each participant's answers.

1. **Overall, what did you think about VisStoryMaker?**

   – "*I liked VisStoryMaker (...) because it generates some informations that I can use, for instance the questions and facts. I did not needed to calculate them, they were already made. I did not have to think about them, like in Tableau. On the other hand, I do not remember if I could add an observation field on VisStoryMaker, similar to what I did in Tableau. (...) I would say that VisStoryMaker better supported me in completing the tasks because it generated things like the average I used to complete the tasks. (...).*" – P01

   – "*Aesthetically, the interface is simpler, and it has fewer options than Tableau. I like that it (VisStoryMaker) suggests some possible questions and facts. For me, who does not have experience creating graphics, it is nice to look at the tool and think: 'look, there is this information here.' I would not know how to calculate these informations. These facts and questions helped me formulate insights. I found it easier to use VisStoryMaker than Tableau (...)*" – P02

   – "*I found VisStoryMaker very interesting, (...) I could construct the visualizations and export them to a website or something else that I need. I found it easy to use and intuitive, for things like adding notes, constructing graphic, and generating related questions and facts. I believe that VisStoryMaker better supported me in completing the tasks, because I found it more intuitive. For instance, to create a story in Tableau I first needed to click on a button down there hidden. In VisStoryMaker you already have the option to add the visualization you are working into the story module (...)*" – P03

   – "*It was good, I mean, I liked it (...) I found it hard to find the annotations options, but I thought they were cool. Maybe the interface could make the annotations options more visible. About the story construction part, I found the icon 'add to StoryMaker' confusing*

(...) In the StoryMaker module, it would be interesting to make it more apparent when I am in the editing or visualizing mode, I found it confusing. But overall, it was a nice tool. To complete the task of adding visual annotation, I had difficulty finding how to do that in both tools. However, I found it easier to customize the visual annotations in VisStoryMaker." – P04

- "*I thought it was very simple and easy to use, especially after I interacted with Tableau Public. The questions helped me a lot, they correlated with some other variables. The recommended visualizations helped me a lot to see things. visualizações já ajuda bastante a vc enxergar as coisas.*" – P05
- "*I thought it was simple and easy to use (...) I would say to complete the tasks, VisStoryMaker better supported me due to its ease of use.*" – P06
- "*I thought it was very interesting that I just uploaded the data, and the tool suggested me facts and visualizations. The data facts and questions that the tool generates are common information that I use while analyzing data. The data facts that the tool suggests to me (...) are a very good differential for me. The data facts could help me to hypothesize or get some insights when analyzing the data. The facts and the questions helped me to explore the data.*" – P07
- "*I wanted to use this tool right now to do my work. I thought that it was very well constructed, the interface was very nice to use, and it was fast. You get to the information quickly. I did not have to think too much, it was more intuitive. For instance, compared to another tool that I had used called Microstrategy, I could get to the information faster. I think that a very important part is the questions because it guides a lot of the analysis. (...) The cool part is that it recommends visualizations. That is why I want to use the tool because I want to upload my dataset and see the data facts that may help me get other insights. I did not see that functionality on Tableau (...) Obviously, Tableau has a lot of resources for exploration and communication. However, the VisStoryMaker approach is to start with the questions and, from there, recommend different visualizations. The tasks were very good, and I think the tool can bring great contributions. In some moments, I felt a miss of interaction possibilities, for instance: passing the mouse and seeing the value of the bar. Thus, I do not see it as something negative but as an opportunity for improvement.*" – P08

- "*I thought that VisStoryMaker makes it so easy to visualize the data because the tool recommends combinations of data that I was not aware of. This is something that I missed in Tableau. However, Tableau's interface is easier to use*" – P09
- "*I liked VisStoryMaker, I found it useful. I prefer the VisStoryMaker because it generates those questions. Sometimes, while starting to explore the data, I do not necessarily know what I want with the data, and the questions supported me (...) I would say that the VisStoryMaker tool supported me better to complete the tasks because it is easier to use.*" – P10
- "*I thought the tool very didactic and so easy to use. I am not an expert in creating visualizations; I tend to have a hard time constructing visualizations, although I do enjoy consuming well-designed data visualizations. I confess that I have a certain difficulty in constructing visualization and even combining these types of data: quantitative and nominal. But I thought the VisStoryMaker's interface was very easy to use. One thing that surprised me a lot was the semi-automatic construction of the visualizations and story features combining facts and questions. I found it to be very automated. I even saw that the tool makes combinations with data that I did not use in the visualization, correct? The tool recommends other variables that I did not map. I thought this was fantastic, this is a huge differential in relation to other tools. This functionality adds value to the tool.*" – P11
- "*Eu gostei do VisStoryMaker para exploração porque eu consigo visualizar vários cruzamentos de informações que ele produz, as perguntas são bem interessantes. Então para explorar, a ferramenta é excelente. Você não precisa ficar construindo as visualizações para depois ver o resultado, você consegue ver isso rápido. Eu penso que nem sempre as visualizações são as melhores possíveis, e eu não sei como eu editaria isso (isto é, mudar a visualização). Em relação aos fatos de dados, eu acredito que ajuda na exploração, mas algumas visualizações recomendadas eu não utilizaria.*" – P12
- "*I liked the tool very much. I believe that to explore data, it already suggests enough information for us to see. I thought it was a great idea to combine it with other data. It gives us a better notion of what data is being combined there. For data exploration, it was very good. The interface was good, and had nice functionalities. (...) To perform the task of visually annotating data facts in the visualization, I thought it was easier to do in VisStoryMaker.*" – P13

- "*I thought the concept of the questions and the facts was really nice. In 10 min, I was able to extract information from a dataset that I didn't know, and even construct a possible presentation to show it to someone. I found the customization part interesting, and I think it can go beyond that. What I liked the most was the idea of the questions and facts. I found it very interesting. Sometimes when we explore a dataset, it takes a while to figure out what information we could extract. These suggestions were already so good.*" – P14
- "*I thought the proposal was very similar to Tableau. I found that in the way of highlighting specific information (like the mean), VisStoryMaker helps highlight more easily for a person like me who has no experience with this type of task. I found that highlighting in VisStoryMaker was easier. I found it very intuitive to change the color and export to images. I found the interface pleasant (...)*" – P15
- "*(...) I thought it was easier to do the tasks using VisStoryMaker. I thought the interface was easier, it was much more intuitive. Mainly because it gives me built-in visualizations that I can choose from (...) But I think VisStoryMaker ends up taking away some of your creative freedom by not giving you as many customization options as Tableau does. But the facts helped me to get ideas about the data.*" – P16
- "*I thought it was very simple and straightforward. I think VisStoryMaker is very useful for exploring data before you even present something to someone. Positive points: the tool is very clean and simple. Negatives: I couldn't save what I was doing, I also didn't like the pdf document that was exported, I found it to be of very poor quality, I don't think it would work well to put in an article, for example. I liked the functionality of the facts and the questions. I believe VisStoryMaker helped me the most in completing the tasks.*" – P17
- "*I liked that the tool presented several statistics that I can use to perform exploratory analysis. This information can help lead me to have insights about data. VisStoryMaker is much better for those who are just starting to explore data.*" – P18
- "*I found the tool a little more difficult to learn how to use it. For example, I felt confused and frustrated to highlight the average, because I was trying to do it, but I couldn't. It gives you a lot of options, it already gives you a lot of options. VisStoryMaker gave me a lot of options, it already anticipates things that I might want*

to use, so it makes it easier to use because of that. The facts and the questions helped me form ideas about the data. I think that this information would help me to prepare a presentation." – P19

– "*I liked VisStoryMaker, it seems simpler to use. I like that it generates those data facts. It is interesting to know some things right away. I found it simpler, maybe it doesn't have all the functions of Tableau, but it was useful for me to complete the tasks. The facts make it easier for you to understand some information, you don't need to think about some things because the system calculates them. They generate some questions that can be interesting.*" – P20

– "*I thought VisStoryMaker was easier to use than Tableau. I thought it was great to have the data facts and the questions for you to draw conclusions on top of the data (...) Sometimes I don't have a well-defined analysis in the beginning, and the possibility of a tool like this helps to stimulate and raise questions about my analyses. For a decision-maker, I think the more inputs you have, the better. VisStoryMaker stands out from Tableau in this sense.*" – P21

– "*In general, I found VisStoryMaker much easier to use than Tableau. Especially when it comes to adding visual annotations to the data. Although Tableau provides more options for you to insert these visual annotations than VisStoryMaker, but Tableau provides a more complicated way of annotating and customizing. VisStoryMaker has fewer options, but I understood how to customize them faster (...) But overall, I found VisStoryMaker to be simpler to use and to include visual annotations. Regarding the story module, I found the VisStoryMaker module much better, because I didn't like Tableau's slide carousel presentation. It was not intuitive to me at first after I understood it. To me it makes more sense to tell a story with data in a more vertical order as if it were a flowing text. VisStoryMaker is much better at this. I thought was more intuitive to customize each visualization in VisStoryMaker.*" – P22

– "*I think VisStoryMaker is really good not only for constructing visualizations but also for understanding the data. I found that the questions and facts helped me understand some things, and that's a start for data exploration. I think it is a powerful tool in that respect. Tableau is better for communication and aesthetics. I would start by using VisStoryMaker to take all the information that it generates to understand the data. Then I would generate these visualizations into a final report in Tableau.*" – P23

– "*I found VisStoryMaker to be very good, especially the automatic facts and questions feature, I think these two features can save time in data exploration labor. I would like to be able to retrieve graphs that I have previously built, or else similar to Tableau that separates visualizations into worksheets. VisStoryMaker supported me better in completing the tasks of annotating graphs because it gave me calculated facts.*" – P24

– "*I liked VisStoryMaker better because it is simpler and more objective. This tool does what it sets out to do: display graphs and facts. It could provide more instructions about the buttons, the symbols were not so clear for me as I am starting to use the tool. I find VisStoryMaker much more practical. However, it limits me in several options compared to Tableau. However, to begin with, I prefer VisStoryMaker because it doesn't require much mental effort from me. I believe that VisStoryMaker was more supportive in completing the tasks, I found it much faster.*" – P25

– "*I found VisStoryMaker to be a little more intuitive than Tableau, because it has fewer features visually, so I thought it was faster to complete the tasks. I found the part of facts and questions that it generates excellent, I think it greatly enriches data analysis. It generates some possibilities, and based on this information, you can have other ideas on how to present that data. If I needed to write a journalistic article about a topic, with VistoryMaker I could have several ideas on how to organize them in a journalistic article, even how to present them visually so that other people can see those graphs and better understand the numbers. I think it is really useful. VisStoryMaker is more intuitive for a beginner like me.*" – P26

– "*I thought it was perfect, very good for people who are in a hurry, who are not specialists, who are learning visualizations for data analysis. For a novice user, it's perfect, it has good suggestions for facts and questions. For a more advanced user too, because it suggests some basic statistics that I think are essential for an exploratory analysis. So I think it serves both audiences well: more experienced and not so experienced. The tool will suggest things that might be useful. The facts and questions helped me hypothesize about the data. The questions in particular, make some combinations that maybe we wouldn't think of. I got confused when downloading the story in VisStoryMaker. But, I prefer VisStoryMaker's way of presenting a story, which presents a box with visualization and text below each other.*" – P27

– "*As a tax auditor, I think that in VisStoryMaker those facts and questions are excellent! Because they are based a lot on statistical correlation methods, visualization of outliers, median, and concentration of occurrences within a range. So, for an auditor like me who uses a lot of statistics to perform procedures, I think the tool generates answers much faster and easier. As part of my job, I tend to look for outliers. (..) These fact features are a handful for people who perform statistical and critical analysis. When you get statistical data, you can compare them with each other and come to a conclusion. If I had those facts available, I might take those facts as a contradictory point of evidence and try to explore the ranges between the averages a little bit and things like that, to corroborate ideas. For me, from an audit point of view, data analysis is used a lot as a comparison of evidence for future business.*" – P28

2. **Overall, what did you think about Tableau Public?**

– "*I found Tableau a little more complex, and it does not generate this information (facts and questions), the user has to go on building and testing the average, and so on. It doesn't show you the biggest element, you have to measure it. I did not like it when I wanted to redo a visualization and I could not. (...) I liked interacting with the graph.*" – P01
– "*(...) I found it a little intuitive, but I could see that it had many options. I imagine that if I studied how to use Tableau, I would be able to explore data a little more. (...) I took a while to understand the interface, but I think that with time using the tool, I would be able to use it well. (...) I did not think the interface was very fluid. For instance, the interface showed me a button with an icon, and I did not know the action that the system would do, I had to hover the mouse over it to see a tooltip. That is, not everything was visually obvious to me, I had to keep exploring and clicking. But I felt that I had more options to explore the data in Tableau.*" – P02
– "*I had previously interacted with Tableau. When I started the test, I couldn't connect with the data. Because it is older, it has a lot more options. I think it is a very good tool.*" – P03
– "*I thought it was an interesting tool, but I had difficulties building the visualizations. (...) I liked the way of organizing the story (like slides). I thought Tableau has a lot of features. I thought VisStoryMaker was more focused, and Tableau's interface is more information-dense.*" – P04

- "*I found Tableau to be very useful, it has many features, but I found it more complicated than VisStoryMaker. (...) Tableau seems to be more complex and not so easy to use. I spent a lot of time in Tableau because I needed more time to think about what I wanted to map, but not in VisStoryMaker.*" – P05
- "*I found Tableau complicated to use, with a lot of information that sometimes seemed confusing. For those who have a good grasp of its interface, it is really powerful.*" – P06
- "*Tableau is a useful tool, but it is very manual. For me to do exploration, I have to create the visualizations knowing what I want, unlike VisStoryMaker, which gives me different options that I can choose from. So, it is a useful tool, but it is complex to use.*" – P07
- "*At the beginning, I was confused by the large amount of information. And I found that it was complicated to make the visual annotations. My first impression was that the interface was confusing.*" – P08
- "*About visual annotations, I thought Tableau was way superior to VisStoryMaker because I really like visual formatting. So, Tableau allowed me a lot more options for formatting the visualization and gave me more freedom. VisStoryMaker ends up limiting me more because it has pre-definitions.*" – P09
- "*I thought Tableau's interface is nicer, but on the other hand, it is harder to use. And it does not suggest what you can do, unlike VisStoryMaker. I think it is more difficult to find things.*" – P10
- "*I had a little difficulty navigating the Tableau interface, interpreting the features, exploring the content better, because I had no experience with this tool. I think that it is a tool that should deliver good content, but I didn't find it so didactic, so simple to use. The part about annotating the graphics, I had more difficulty. I don't know if it has it or not. I was lost. I had a little difficulty with the customization part.*" – P11
- "*I liked it, I thought that the tool is more editable. But at the same time I needed to generate all the information that I wanted to visualize. I had to explore the data manually. I didn't have any help from the tool. So it is complicated about that. I would maybe use a combination of the two tools, I would use VisStoryMaker to explore and if there is a visualization that I didn't like, I would use Tableau.*" – P12
- "*I found Tableau more complicated, it required more mental effort from me. What I liked most about Tableau was the story function-*

ality, because it allows me to change the visualizations in the story module. This is because sometimes I add a visualization, and only later would I want to change it to highlight something that I hadn't thought of before (...)" – P13

- "*I thought it was an interesting tool. The learning curve was not that complicated. Watching the tutorial, I was already able to do some things. I liked the aggregation functions: sum, average, the visual representations I found nice (...) I found the visual annotations part easy to use.*" – P14
- "*I found it a very interesting tool for visual representation of data. In my opinion, it is easier to use than other visualization tools, for example, than Power BI. I found it to be a very easy tool to use. I did find it difficult in some ways to differentiate between nominal and quantitative data. I think the way you build visualizations (drag and drop) is a much nicer feature than programming.*" – P15
- "*(...) compared to VisStoryMaker, I found VisStoryMaker easier to use. I had difficulty in Tableau in moving the averaging bar, the interactivity was very fast.*" – P16
- "*Positive points: I have more freedom to do what I want. Negatives: I think I would need to have knowledge about the data set. I think it is not an appropriate tool to do an initial exploratory analysis, I think it is very boring to have to do all the exploration in it. I think the best thing would be to do this analysis using another tool or framework, and then I would use Tableau to generate graphs to communicate to other people. For me, as a data scientist, I don't like using tools like Tableau.*" – P17
- "*Tableau is a great tool, but I think it is more suitable for more advanced users.*" – P18
- "*I liked it, I found it easy to use and intuitive. That's it, I would use it. I didn't like the customization part, I thought it was customizing one thing, but it was something else.*" – P19
- "*Tableau seems to be a complete tool, it has many functionalities. I found it interesting. I think that mainly because it has many options, it is very difficult to learn how to use. It has many resources and for those who are starting it can be scary.*" – P20
- "*I found Tableau Public to be a tool for more advanced users in data analysis, who know the terms and have explored the tool before. Overall, I found Tableau to be more difficult to use, compared to VisStoryMaker.*" – P21

- "*I found Tableau's interface to be very simple, and an aesthetic that reminded me of something more modern and professional. (...) I liked Tableau's filter options and aggregation functions. I liked the options it gave me in the analysis tab. I was under the impression that I wanted to do things, but I didn't know if the tool would support me in that or not.*" – P22
- "*I liked Tableau's interface better, I like how it looks and I like the visualizations that it generates. I found them to be more interactive. It is easy to use and has a nice interface. I think it has a lot of features, but I found the features that I interacted with in the tool interesting.*" – P23
- "*It seems to be a good tool, it seems to have a lot of things that I didn't explore. But it is a good and complete tool. I liked the way of customizing the title of the graphs, I was able to explore a piece of extra information (average) in a simple way. I found good the possibility to drag two variables to an axis and be able to visualize.*" – P24
- "*I think that, in general, Tableau is a good tool, but I think that for people who are not so experienced in tabulating data, it seems more complicated than VisStoryMaker. I think this is because it has more buttons and functionality. It is much more complex, but I would need more experience to interact with Tableau. It has a lot of things that I can do, and I probably need time to learn and time to explore some tasks that I need to do.*" – P25
- "*I thought it was very useful. I thought there were a lot of features for me to refer to in the interface. When using it the first time, I needed some time to understand the features. But I found it intuitive, and as I was exploring I was discovering the resources. (...) I think that for building and organizing data is excellent. So I liked it very much, it makes life much easier for those who need to make these graphics, you don't need a designer, for example. As a journalist, I work with designers on a daily basis, so a tool like this would give me the autonomy to build visualizations to explore the data. Usually I get the data and talk to the designers about the way I want to communicate, the way we are going to present it. Sometimes I give suggestions to generate bar graphs, sometimes the designers give suggestions on how it would be better to visualize. (...) A tool like this would be very useful for journalists, and for those who produce content more autonomously.*" – P26

- "*I liked Tableau, it allowed me to do some very nice visualizations. I found Tableau, in comparison with VisStoryMaker, more complete, it allows you to do more things. So, I think it gives you more power to do more things (...) With Tableau, you have more control over what you want it to present. So I think it gives you more autonomy. I liked it. I would need more time to learn more features (...) For a person who is not an expert, it is overwhelmed by the number of features.*" – P27
- "*I preferred Tableau over VisStoryMaker. I like the use of Tableau. I didn't have any criticisms, I found it user-friendly. Tableau doesn't have facts and questions, but it brings visualizations that you can use on a daily basis.*" – P28

3. **Considering the data facts available in VisStoryMaker, which other data facts would you like to add (or remove) in VisStoryMaker?**

- "*I don't think so. I think the basic ones are the same, I can't think of another one.*" – P01
- "*I do not think so. I think it would be interesting if I had the option to add some fact that is not pre-calculated. I can't think of another one right now, but what if I wanted to, how would I add another fact? I would like to be able to customize that.*" – P02
- "*No, for what I needed to do, I could do it with both tools.*" – P03
- "*I didn't miss another data fact.*" – P04
- "*For the data that was available and the time I had, I didn't miss other data suits.*" – P05
- "*I don't know.*" – P06
- "*I think the ones that were available in VisStoryMaker, are the ones I generally use when I have quantitative data. At the moment, I can't think of any different ones. For a user who is not an expert, VisStoryMaker already has the basics. I think it depends on the context of the data you are analyzing.*" – P07
- "*As I am working with time series, I think it would be interesting to have facts about trend analysis, seasonality, correlation, and autocorrelation. This kind of information is very cool and very common.*" – P08
- "*I can't think of another one at the moment. I think all the data facts that were presented are important. From a perspective of a person who has no programming skills, when using visualization tools, I sometimes want a simpler visualization. So I think it is important to have all the data facts available (...)*" – P09

- "*I don't think so.*" – P10
- "*I think that all that were available have relevant content. I can't name any others at the moment.*" – P11
- "*No.*" – P12
- "*Suddenly having suggestions for visualizations and facts about time series. I thought that all the facts that the tool generates are necessary.*" – P13
- "*I don't know. It was a short time of exploration for me to miss some others.*" – P14
- "*I think the tool gives a very good catalog for the user to see and choose which ones to use. In my opinion, there is no need to remove any.*" – P15
- "*I ended up not missing any. I think for users who don't have much knowledge of statistics, I think it's all right.*" – P16
- "*I think that the facts helped to better understand the data, because you don't need to calculate each fact to identify what is in the data. VisStoryMaker generates a summary of what is in the data. The only bad things were that I couldn't add any information that I wanted to the graphs, and I couldn't interact with the graph.*" – P17
- "*I would like to be able to visually annotate information from the StoryMaker statistics tabs (standard deviation, etc).*" – P18
- "*I didn't miss anything else. I think it has a good amount. Maybe using it for a longer time, I could have more suggestions. I wouldn't remove any, I think they can all help when you don't have a clear vision of what you want to visualize.*" – P19
- "*I didn't miss any other facts, I thought the ones you have were sufficient.*" – P20
- "*I thought it would be interesting if I grouped the quantitative data with some aggregation functions. When I select the functions, it would automatically change the data facts and questions. Maybe calculate the data facts considering the aggregation function that I selected. I saw something similar to this in Tableau, and missed this option in VisStoryMaker. (...)*" – P21
- "*I would not remove the facts, I found them all useful. Could have some quartile information.*" – P22
- "*I think it gives me a good amount of facts. I would not remove any facts that are available.*" – P23
- "*I think it would be interesting to separate the facts into categories.*" – P24
- "*I don't think so.*" – P25

- "*I think it is very complete. I don't think I would remove any facts, the more facts available, the better.*" – P26
- "*It would be interesting to have other options of visualizations. I wouldn't remove any facts available, because I think the idea is to suggest things that you wouldn't be thinking about, and you add only what you want.*" – P27
- "*I didn't miss anything. I usually use a lot of mean and median (...) the system generated more information than I expected.*" – P28

4. **Keeping in mind the annotated visualizations you have built in VisStoryMaker, what other ways would you like to visually annotate the data facts?**

- "*I can't imagine any other way, but maybe put a stronger dotted line to make it stand out more. Maybe allow to put the number, put the line and the number to know, for example, what the average is.*" – P01
- "*I can't think of others at the moment. I believe that the ones I used were the best to represent.*" – P02
- "*No, at the moment, I can't think of anything. Regarding the annotations part, I found the two tools to be very complete.*" – P03
- "*Maybe make the graph more interactive, for example, click on the line, and the exact value appears.*" – P04
- "*Maybe in a bar chart, you could add a bar of the average value to compare with the total.*" – P05
- "*(...) It would be interesting if the legend was on the markdown and not on the left and text on the right. To me, it makes more sense that the text and the visualization are in the same container.*" – P06
- "*I think the visual representations that VisStoryMaker showed me represent the information well. I did miss changing the line thickness.*" – P07
- "*Not at the moment (...)*" – P08
- "*Yes, it could be an arrow, circle, different shape options, or just like Tableau's options.*" – P09
- "*No.*" – P10
- "*I don't think so. (...) I think the label, in other views, would not be the most appropriate.*" – P11
- "*The color scale chart I would like to be able to change.*" – P12
- "*Manually selecting on the graph, being able to make textual annotations on the graph or in the story.*" – P13
- "*I do not think so. I thought the guidance on how to highlight that type of graph was good.*" – P14

- "*From the tools I have already used, I thought the options offered were very good. (...) I think this is a very good resource for those who work with data. I liked very much the way of highlighting the data and the options that the user has.*" – P15
- "*I missed seeing the quantities of the categories.*" – P16
- "*It would be interesting if there was something to edit the graph, to add some textual annotation, a balloon.*" – P17
- "*To avoid polluting the visualization, it would be interesting to give the option to highlight the mean value on the graph's axis. Sometimes, we add so much information that it ends up polluting visually. I think one of the biggest challenges of visualization is to make it good enough for the person to see the information instantly.*" – P18
- "*Maybe show it as a legend, on the side.*" – P19
- "*No, maybe change the orientation of the media lines.*" – P20
- "*I would like to make a custom label, like, to select a point or bar and write some context information.*" – P21
- "*I thought one thing you could have, is kind of like put a comment, like a balloon to add some context information. I really liked the suggestion of facts about additional data, it's just that when I add it's like it replaces the previous one, I wanted the two to be kept.*" – P22
- "*Yes, I think VisStoryMaker limits a lot in this sense. I think I would like to change the type of the line, the way the colors it is presented.*" – P23
- "*It would be interesting to include an average line in any graph I want, similar to Tableau.*" – P24
- "*I don't know. Maybe one thing that would make it easier is to click on the chart to open it, rather than clicking on the 'open chart' button.*" – P25
- "*I think maybe a little more simplified representation. For example, drawing lines on the graph could perhaps confuse more than help understanding. It could be a simpler graphical element than a line, a dotted line, an arrow, a little balloon that you can describe.*" – P26
- "*Maybe you could mark the average with a dot, maybe it could be more visually unobtrusive. One thing I like is to color each bar a different color, I would like to have that option.*" – P27
- "*I would like to have the option to change the orientation of the axes. I missed making the numbers more evident.*" – P28

5. **Would you like to share any additional comments?**

- "*I think maybe filter. Let's suppose: if I wanted to filter an item; how would I do that in VisStoryMaker? If I wanted to filter, it would be interesting to have the option.*" – P01
- "*I do not think so.*" – P02
- "*No.*" – P03
- "*On VisStoryMaker, I had some difficulties choosing the graphic from the list. I thought the symbol was cluttered. Perhaps if you could click on the thumbnail graphic and display it in the main visualization.*" – P04
- "*No.*" – P05
- "*No.*" – P06
- "*I had difficulty interpreting the 'open chart' icon in VisStoryMaker; it seemed like an icon to expand the visualization and not to select the chart. It would be interesting to use another symbol, perhaps a pencil symbol, or allow one to click on thumbnail visualization to select it.*" – P07
- "*No.*" – P08
- "*I have a suggestion: since the data facts are listed in sequence, suddenly, it would be interesting to separate the simpler facts (min, max, median) from the more complex ones (outliers, distribution).*" – P09
- "*No.*" – P10
- "*Quando eu cliquei no botão de sair, o VisStoryMaker saiu direto. Seria interessante ter um pop-up com confirmação para sair.*" – P11
- "*No. I had never used either tool before. VisStoryMaker, despite its limitations, I liked using it to explore the data. It may not be the best for presentation, but it is definitely better for exploring the data.*" – P12
- "*No.*" – P13
- "*No.*" – P14
- "*No, I think for the available time I had, I enjoyed both tools.*" – P15
- "*No.*" – P16
- "*No.*" – P17
- "*No.*" – P18
- "*I do not think so.*" – P19
- "*No. I liked it; I thought it was very interesting these data facts and the questions. I thought it was so good.*" – P20
- "*Improve the processing of data facts.*" – P21
- "*(...) it would be good to have some form of instruction within the tool (tutorial, onboarding) for people to be able to guide themselves (...) I found Tableau's story-building functionality very immature,*

my perception is that it allows you to do few things. I found that Tableau provides very few features for writing with data. Another thing that bothers me in Tableau is the number of tabs that I need to open to do something; For instance, when I want to generate other visualizations, I need to keep creating other worksheets. In a real company context, people will have to manipulate a lot of views, so they have to create like 300 sheets? This bothered me a lot, and I thought it was not useful." – P22

- "*I think it would be interesting if the tools had dynamic visualizations, similar to animations.*" – P23
- "*No.*" – P24
- "*I do not think so.*" – P25
- "*No, I thought that these are two very useful tools to facilitate access to information. I thought it was cool.*" – P26
- "*I do not think so.*" – P27
- "*I do not think so.*" – P28