

Integrating Usability and Data Visualization in Open Science: An Evaluation of the dataWASHES Dashboard

Victor Gonçalves¹ , Antonio Souza¹ , Davi Viana² ,
Rodrigo Pereira dos Santos³  e Allysson Alex Araújo¹ 

¹Universidade Federal do Cariri (UFCA)
Juazeiro do Norte, Ceará – Brasil

²Universidade Federal do Maranhão (UFMA)
São Luís, Maranhão – Brasil

³Universidade Federal do Estado do Rio de Janeiro (UNIRIO)
Rio de Janeiro, Rio de Janeiro – Brasil

victor.lima@aluno.ufca.edu.br,
antonio.souza@aluno.ufca.edu.br,
davi.viana@ufma.br, rps@uniriotec.br
allysson.araujo@ufca.edu.br

Abstract. *Open Science promotes transparency and collaboration through open data sharing. The dataWASHES initiative supports this goal by providing an API for accessing WASHES workshop proceedings but lacked an interactive visualization tool. This paper presents a dashboard that enhances data analysis, evaluated through qualitative inspection based on Tufte's and Dowding and Merrill's principles and usability testing using the System Usability Scale (SUS). The dashboard achieved clarity, consistency, and strong spatial organization, with a SUS score of 91.25 and 96.4% user satisfaction. This work applies visualization and usability principles to Open Science dashboards, reinforces user-centered design, and extends dataWASHES with an interactive interface. Therefore, this work contributes by (1) applying Tufte's principles and Dowding and Merrill's principles to the design of Open Science dashboards, (2) reinforcing the role of user-centered design and data visualization in the engineering of Open Science tools, and (3) enhancing dataWASHES with an interactive dashboard that transforms research data into actionable findings. From an Information Systems perspective, the dashboard supports sensemaking by enabling users to interpret and contextualize scientific data through integrated visual representations.*

Keywords. *dataWASHES; Open Science; Usability; Data Visualization; WASHES.*

1. Introduction

Open Science has established itself as a fundamental pillar in advancing research practice, nurturing transparency, scientific development, data sharing, and collaboration among different stakeholders. According to Mendez *et al.* (2020), Open Science encompasses the dissemination of software source code (open source), data (open data), analysis scripts (open materials), and study manuscripts (open access). In this scenario of advancements in Open Science, open infrastructure also stands out for its role in operationalizing these principles, providing tools and platforms that facilitate data access and the reuse of produced knowledge [UNESCO 2021].

Aiming to strengthen Open Science initiatives within the Workshop on Social, Human, and Economic Aspects of Software (WASHES), dataWASHES¹ was introduced as a public, academic, and open-source application programming interface (API) designed to provide the community with a convenient tool for systematically and programmatically querying the WASHES proceedings data [Araújo et al. 2024]. However, despite its initial contribution, there is a relevant opportunity for the evolution of dataWASHES: the development of a dashboard, leveraging the existing API, to enable the community to visualize and explore WASHES proceedings data in a more accessible and interactive manner.

In particular, when assessing the current landscape of Open Science, it becomes evident that data visualization techniques, including dashboards, have a large potential by enabling researchers, professionals, and students to interact with information in an intuitive and efficient manner [Wang et al. 2015]. Essentially, dashboards are visual tools that present data in a clear and organized manner, facilitating analysis, monitoring, and decision-making [Laubheimer 2017]. Within the Information Systems (IS) field, dashboards may be understood as socio-technical artifacts that mediate the interaction between users and data, translating information into supporting knowledge creation, organizational learning, and decision processes [Revina 2021]. Building on this potential, the primary objective of this work is to present a dashboard for dataWASHES as well as its evaluation, with a focus on usability and data visualization, both of which are fundamental when discussing the social and human aspects of software. Based on this context, we defined the following research question: *How do usability and data visualization principles shape the design and perceived usability of an Open Science dashboard?*

To evaluate the dashboard, this study adopted a mixed-methods approach. First, a qualitative and observational inspection was conducted to assess the dashboard's adherence to Tufte's (2001) visualization principles and the information visualization usability principles proposed by Dowding and Merrill (2018). Tufte's principles emphasize simplicity and clarity in data representation, aligning with the evaluative goals of this study. Complementarily, Dowding and Merrill's principles highlight aspects such as spatial organization, information coding, flexibility, consistency, and the removal of extraneous visual elements, key factors ensuring that visual interfaces effectively support analytical reasoning. Moreover, an empirical evaluation was conducted to examine user perceptions through usability testing with 28 students. Data were collected using a semi-structured questionnaire based on the System Usability Scale (SUS) [Brooke et al. 1996], a widely

¹<https://gesid.github.io/datawashes>

adopted and reliable tool for usability evaluation that provides a comprehensive complement to the qualitative inspection.

We highlight that this article extends our previous publication awarded at WASHES 2025 [Gonçalves et al. 2025]. In this extended version, we introduce four major advancements. First, we provide a more detailed explanation of the dashboard, covering both its architectural design and visualization components. Second, we extended the result analysis through a qualitative inspection grounded in information visualization usability principles [Dowding and Merrill 2018]. Third, we include a new section dedicated to lessons learned, offering practical reflections for future research and tool development. Finally, we expand the manuscript with a Background and Related Work section, and enrich the Discussion section by addressing broader implications of our findings.

This study offers contributions to both academia and practice within the IS field, particularly concerning the social and human dimensions of software and data-driven systems. Academically, it provides a systematic examination of how Tufte's visualization principles [Tufte 2001] and the information visualization usability principles of Dowding and Merrill (2018) can inform the design of Open Science dashboards, expanding IS knowledge on how visualization design supports sensemaking, usability, and transparency in socio-technical environments. The usability evaluation using the SUS reinforces the importance of user-centered design, aligning with IS traditions that emphasize the interaction between people, technology, and information. From a practical standpoint, the work enhances dataWASHES with an interactive and user-oriented interface that democratizes access to scientific data, offering a reusable model for IS-driven Open Science infrastructures across research communities.

This article is structured as follows: Section 2 presents the background and related work. Section 3 presents the method, while Section 4 discusses the scope and demonstration of the dashboard. The results (Section 5) are followed by the discussion (Section 6) and final remarks (Section 7).

2. Background and Related Work

2.1. Introducing Open Science and Open Infrastructure

Open Science has become an important movement in contemporary research, encouraging transparency, collaboration, and access to knowledge. Its adoption has grown across several disciplines, including fields such as IS and Software Engineering (SE), where research often depends on digital artifacts, data, and software. The principles of openness aim to make research processes and outcomes more reproducible, verifiable, and widely usable [of Sciences et al. 2018].

According to Mendez *et al.* (2020), Open Science involves sharing research artifacts such as source code (open source), datasets (open data), analysis scripts (open material), and publications (open access). These practices strengthen the scientific process by allowing others to validate, reuse, and extend existing work. Maedche *et al.* (2024) argue that Open Science helps broaden access to knowledge and supports inclusive innovation. In line with UNESCO's framework, Open Science rests on key pillars: open access to sci-

entific knowledge, open infrastructures, effective communication, engagement of societal actors, and dialogue with diverse knowledge systems [UNESCO 2021].

In the IS context, Open Science can be seen as a socially-constructed approach that combines human, organizational, and technological factors to support the creation and dissemination of knowledge [Doyle et al. 2019]. It intersects with IS research topics such as data governance, transparency, and digital collaboration, emphasizing how systems design can promote openness and ethics [Schöpfel et al. 2022]. A key component of this ecosystem is *Open Infrastructure*, which refers to the technological tools and services that enable Open Science practices [UNESCO 2021]. These include repositories, data platforms, and collaborative systems that facilitate the sharing, preservation, and accessibility of research outputs. Sellanga (2023) highlights that Open Infrastructure promotes interoperability and transparency by encouraging the adoption of open standards. Many of these initiatives are community-driven and not-for-profit, reflecting a collective effort to maintain scientific knowledge as a public good [Kags 2023].

Therefore, Open Science represents an evolution in how research is produced and shared [Fecher et al. 2014]. In other words, it emphasizes the need for infrastructures and tools that make data and knowledge not only open but also usable, supporting collaboration and informed decision-making. Therefore, this study aligns with that perspective by developing and evaluating an open and data-driven dashboard that enhances the accessibility of scientific information.

2.2. The Role of Data Visualization and Dashboards in Information Systems

Data visualization has long been a fundamental element in IS, enabling the translation of complex and abstract data into comprehensible representations [Dilla et al. 2010]. In IS research and practice, visualizations are important not only for communication but also for analytical reasoning, decision support, and knowledge creation. They allow users to detect trends, recognize correlations, and interpret patterns that would otherwise remain hidden within raw data [Ware 2019]. This capability has positioned visualization as a cornerstone in domains such as business intelligence, digital transformation, and scientific research [Burnay et al. 2019]. Dashboards occupy a key role within this scope since they integrate multiple visualizations and data sources into a unified, interactive interface, offering a concise and coherent view of key indicators [Few 2013]. Dashboards serve diverse functions (monitoring organizational performance, facilitating research transparency, or supporting decision-making) in data-intensive environments [Chen et al. 2012]. As boundary-spanning tools, dashboards foster communication between stakeholders with differing technical and analytical backgrounds, reinforcing their value in collaborative and interdisciplinary settings.

However, the quality and interpretability of dashboards depend heavily on the design principles that govern their creation. Edward Tufte's seminal work on information design [Tufte 2001] provides enduring guidance for data visualization. Tufte advocates for maximizing the data-ink ratio, which means that every visual element should serve a meaningful purpose in communicating information. His principles emphasize simplicity, integrity, and clarity, encouraging designers to eliminate unnecessary visual clutter (so-called *chartjunk*), use small multiples for comparative analysis, and display data variation

rather than decoration. Tufte also highlights the importance of narrative coherence: visualizations should tell a truthful, data-driven story while respecting perceptual efficiency and cognitive economy. These ideas are particularly relevant for IS dashboards, where users often rely on concise visual summaries to make rapid decisions.

Complementing Tufte's principles, Dowding and Merrill (2018) developed a set of usability principles specific to information visualization. Their framework emphasizes core aspects: (1) spatial organization, ensuring logical and consistent placement of visual elements; (2) information coding, using colors, shapes, and symbols that enhance comprehension without ambiguity; (3) flexibility, allowing different user types to tailor visualizations to their needs; (4) consistency, maintaining uniform visual and interaction patterns; and (5) removal of extraneous elements that do not directly support cognitive or analytical tasks. These heuristics align with human-computer interaction principles by ensuring that dashboards are cognitively ergonomic and visually coherent.

As we can see, dashboard design in IS also benefits from attention to perceptual and cognitive processes. Visual hierarchies, Gestalt grouping principles, and contrast mechanisms guide users' attention to critical information while reducing cognitive load [Card et al. 1999]. By aligning visual design with how humans process visual information, dashboards can support analytical reasoning and decision-making with greater efficiency. This user-centered approach reflects a broader IS concern with the usability, accessibility, and interpretability of digital systems. To evaluate the user experience of dashboards, empirical methods such as the *System Usability Scale* (SUS) are widely applied [Brooke et al. 1996]. The SUS is a standardized and ten-item questionnaire that provides a reliable and simple measure of perceived usability across systems. It has been extensively used in IS to assess web interfaces, enterprise systems, and data platforms [Ependi et al. 2019]. In dashboard research, combining SUS with heuristic evaluation and qualitative feedback offers a holistic understanding of how effectively visual interfaces support user interaction, learning, and decision-making [Nazemi et al. 2015].

In summary, we advocate that dashboards in IS represent integrative socio-technical artifacts that merge principles of data visualization, usability, and cognitive ergonomics [Vornhagen et al. 2018]. The thoughtful application of frameworks such as Tufte's visualization principles and Dowding and Merrill's usability heuristics (complemented by instruments as SUS) could ensure that dashboards not only present data effectively but also facilitate trust and informed action. These dimensions make dashboards relevant tools for bridging the technical, human, and organizational components of IS.

2.3. Related Work

Research connecting dashboards and Open Science spans IS, Human-Computer Interaction (HCI), and SE areas. We grouped these studies into two main strands: (i) empirical approaches to evaluating dashboards and (ii) the assessment of digital infrastructures designed to support Open Science practices.

Evaluation of Dashboards. Dashboard evaluations have been widely reported across fields such as healthcare, education, and business intelligence, reflecting sustained inter-

est in how visual analytics tools affect interpretation, decision-making, and user satisfaction. A systematic literature review by Almasi *et al.* (2023), covering 29 empirical studies, found that standardized instruments (including SUS) remain dominant due to their reliability and comparability. More recent works, however, complement such quantitative measures with qualitative and observational analyses to deepen understanding of user experience. Rossi *et al.* (2025) emphasize integrating usability testing with iterative co-design and implementation science methods to improve sustainability in real settings. Likewise, Gardner *et al.* (2025) combined user feedback with usage analytics in evaluating a recruitment dashboard, showing how interaction data expose comprehension and discoverability issues. In turn, Mezzone *et al.* (2025) proposed a formative assessment combining heuristic evaluation and user testing to guide incremental refinement. These studies highlight the value of hybrid methodologies that pair usability metrics with contextual inquiry to assess both performance and interpretability. However, methodological diversification continues to advance this field. Lam *et al.* (2011) advocate combining qualitative and quantitative approaches to evaluate cognition, analytical reasoning, and interpretive accuracy. Extending this view, Alhamadi *et al.* (2025) incorporated behavioral and eye-tracking data to identify usability barriers in complex dashboard environments. These works underline that dashboard evaluation benefits from mixed methods that bridge empirical usability testing with cognitive and contextual findings.

Evaluation of Open Science Tools. Research evaluating Open Science infrastructures has primarily focused on adoption, transparency, and technical performance rather than user experience. Among these, the Open Science Framework (OSF) stands out as one of the most extensively assessed platforms, consistently recognized for enhancing reproducibility, collaboration, and structured research workflows across disciplines [Foster and Deardorff 2017]. Institutional initiatives such as OpenAIRE Monitor [Manghi *et al.* 2019], alongside frameworks proposed by Cobey *et al.* (2023), emphasize macro-level indicators but seldom examine usability or interaction design. Moreover, Patra *et al.* (2025) identify similar shortcomings in FAIRness evaluation tools, which tend to privilege technical accuracy over human-centered assessment. Fecher and Friesike conceptualize Open Science as a socio-technical transformation involving open access, infrastructure, collaboration, and evaluation. From this lens, the usability and interpretability of Open Science tools become critical to ensuring accessibility and sustained engagement. Yet, despite the proliferation of dashboards that monitor institutional openness and compliance, few studies have empirically examined how users perceive their visualization quality or overall usability. This gap underscores the need for evaluations that integrate technical performance with user-centered and design-oriented perspectives.

Positioning of this Work. While dashboard evaluations typically focus on usability metrics, they often overlook how visualization design principles influence comprehension and analytical reasoning. On the other hand, assessments of Open Science tools tend to emphasize infrastructure, compliance, and policy indicators rather than user experience or interaction quality. Few studies attempt to integrate these complementary perspectives within a single evaluation approach. This work addresses that gap by combining heuristic

inspection grounded in visualization theory with SUS-based usability testing to evaluate an Open Science dashboard. By bridging design-centered and user-centered approaches, it offers a replicable mixed-method approach for assessing open data tools.

3. Methodological Procedures

This study is characterized as applied research, with both qualitative and quantitative nature, focused on the development and evaluation of the dataWASHES dashboard. In this context, the study seeks to answer the following research question: *How do usability and data visualization principles shape the design and perceived usability of an Open Science dashboard?* As illustrated in Figure 1, the research design was organized into four main stages: (1) literature analysis, (2) dashboard development, (3) qualitative inspection based on the principles of Tufte [Tufte 2001] and Dowding and Merrill [Dowding and Merrill 2018], and (4) dashboard evaluation with a usability testing with users based on SUS [Brooke et al. 1996].

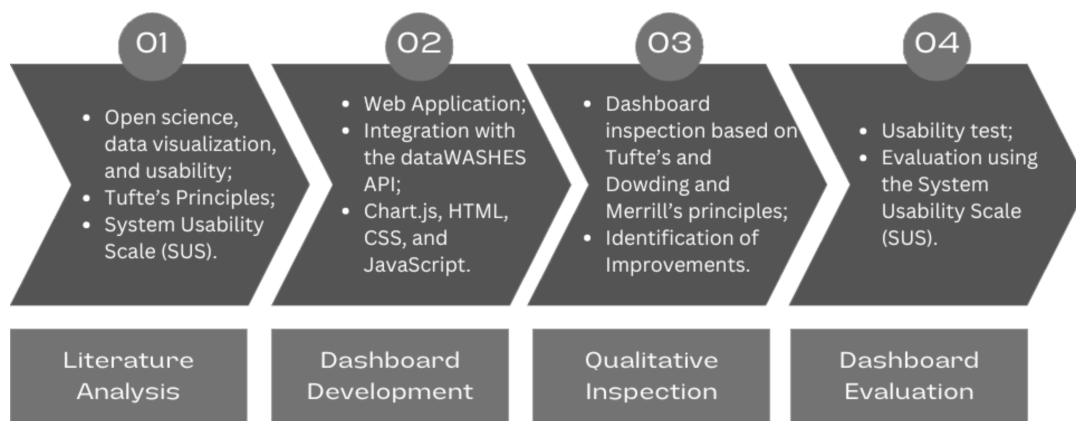


Figure 1. Research design.

The **first stage** involved a literature analysis on the concepts of Open Science, open infrastructure, data visualization, and usability evaluation of dashboards. This analysis aimed to identify best practices and gaps in the literature that could guide the development and evaluation of the dataWASHES dashboard. As a result of this stage, the relevance of Tufte's (2001) principles, such as graphic integrity and minimization of non-essential or decorative elements, was identified. The analysis also highlighted the role of the SUS as a widely used scale for the empirical evaluation of the usability of digital interfaces [Grier et al. 2013]. As a complementary step following the publication of our previous paper [Gonçalves et al. 2025], the information visualization usability principles proposed by Dowding and Merrill (2018) were incorporated as an additional analytical layer of analysis.

The **second stage** consisted of the development of the dashboard using HTML, CSS, and JavaScript. Using the Chart.js library, which is specific for data visualization, the dashboard aimed to integrate the functionalities of the dataWASHES API with a set of interactive visualizations, such as charts and dynamic tables. The dashboard included

key features to facilitate the visualization and analysis of data from WASHES publications, such as author rankings, publication distribution by Brazilian states, award-winning WASHES papers, and more.

The **third stage** consisted of a qualitative inspection of the dashboard to assess its adherence to established visualization and usability principles. This analysis focused on two complementary perspectives: Tufte's data visualization principles [Tufte 2001] and the information visualization usability principles proposed by Dowding and Merrill (2018). To ensure rigor, one co-author independently conducted the qualitative evaluation, followed by a cross-validation of findings by another co-author. The inspection guided by Tufte's framework emphasized graphical integrity (ensuring the accurate and proportionate representation of information) and the minimization of non-essential elements, such as redundant gridlines or decorative borders, thereby promoting clarity and focus. Complementarily, Dowding and Merrill's principles provided a heuristic structure encompassing five critical dimensions: (1) spatial organization, concerning the logical arrangement and visibility of information elements; (2) information coding, addressing the adequacy and perceptual appropriateness of symbols and graphical representations; (3) flexibility, relating to users' ability to adapt or configure displays to their analytical needs; (4) consistency, referring to the uniformity of interface elements, labels, and navigation structures; and (5) removal of extraneous ink, which promotes presenting the greatest amount of data with minimal visual clutter. This stage was important for identifying design refinements and ensuring that the dashboard aligned with principles of visual economy, clarity, and usability heuristics that enhance interpretability and analytical reasoning prior to user testing.

Finally, the **fourth stage** involved evaluating the dashboard with a group of students from the Systems and Analysis Development course of the Federal University of Cariri (UFCA). The test was conducted online on February 4, 2025, between 8:30 PM and 9:40 PM, with the participation of 28 students. Before the test, participants read and accepted an informed consent form. Following this step, an overview of the dataWASHES dashboard was presented, highlighting its main features. After this explanation, participants interacted freely with the dashboard, with the goal of exploring its functionalities without additional instructions, allowing for a more autonomous experience.

After the interaction time with the dashboard, which lasted at least three minutes, participants filled out a questionnaire with three main sections: 1) Characterization and Initial Perceptions, 2) SUS, and 3) Overall Satisfaction and Final Considerations. The interaction time was defined to ensure that participants had enough time to explore the dashboard's functionalities. The analysis of quantitative data was performed using descriptive statistics, including mean and median, with the results presented in stacked bar charts. Qualitative data were analyzed using open coding, organizing the responses into categories and recurring themes. It is worth noting that, prior to the user test, a pilot test was conducted with one volunteer to validate the test script and the questionnaire. Although the data from this pilot were not used in the final analysis, the adjustments made during this phase ensured greater clarity in the instructions and testing procedure with the participants. No major issues were identified. All the instruments and data used in the study are openly available in the supporting repository for this project [Gonçalves et al. 2025].

Regarding the general characterization of the participants, information was extracted concerning age, education level, and familiarity with the use of dashboards. The participants' ages ranged from 20 to 51 years, with an average age of approximately 31 years and a median of 30. In terms of education, the majority of participants (60.7%) were pursuing their undergraduate degree. Those with a completed high school education accounted for 17.9%, while 10.7% had technical or technological training. In addition, 7.1% of participants had a completed undergraduate degree, and only 3.6% were pursuing a postgraduate degree. Regarding familiarity with dashboards, 67.9% of participants had some prior exposure to the technology. Of this total, half reported having used dashboards a few times, while 17.9% stated they used them frequently. In contrast, 32.2% had never used a dashboard, although, among these, 55.6% had heard of the topic.

4. Scope and Demonstration of the dataWASHES Dashboard

The dataWASHES dashboard² was developed to provide an interactive interface that facilitates access, visualization, and interpretation of data from WASHES publications. Its scope includes presenting data in a clear and accessible manner, allowing researchers, students, and professionals in the field to interact with publication data without the need for manual queries or complex data processing. Based on data visualization principles [Tufté 2001, Dowding and Merrill 2018], the dashboard aims to offer an intuitive and informative user experience.

The dashboard was designed to integrate directly with the dataWASHES API [Araújo et al. 2024], ensuring programmatic access to the latest WASHES data. This integration allows the dashboard to present data dynamically and in real-time, continuously reflecting the most recent publications and research findings in the field. The interface design was structured to provide a seamless navigation experience, featuring filters and interactive charts that enable users to explore various aspects of the publications. Notable aspects include the ranking of authors, the geographical distribution of publications across Brazilian states, and the award-winning papers from past WASHES editions. The goal is to make the interface intuitive enough that even users with no prior experience in data visualization can navigate and utilize its features easily and effectively.

As illustrated in Figure 2, the dashboard architecture follows a modular design based on a RESTful API and the Model–View–Controller (MVC) pattern. The backend layer was implemented using Flask, a lightweight Python web framework, and its extension Flask-RESTX, which facilitates the rapid development of RESTful APIs, assists in data modeling, and provides integrated documentation tools. It is responsible for handling API requests, managing routes, and communicating with the data layer that stores the WASHES dataset, which consists of JSON files. The REST API exposes endpoints that return data in JSON format; however, instead of generating additional traffic through API calls, the dashboard employs the same methods used by the API to request data directly from the underlying dataset. This approach ensures efficient data retrieval and smooth integration between the backend and the client-side components. The frontend layer was developed using HTML, CSS, and JavaScript, providing an interactive and responsive interface. The visualization components were built primarily with the Chart.js

²<https://gesid.github.io/datawashes/dashboard>

library, which supports a variety of dynamic charts such as bar, line, and donut plots used throughout the dashboard. Additionally, the GeoJSON format was employed to represent geographical data and render the choropleth map of Brazil, allowing the visualization of publication distributions across states.

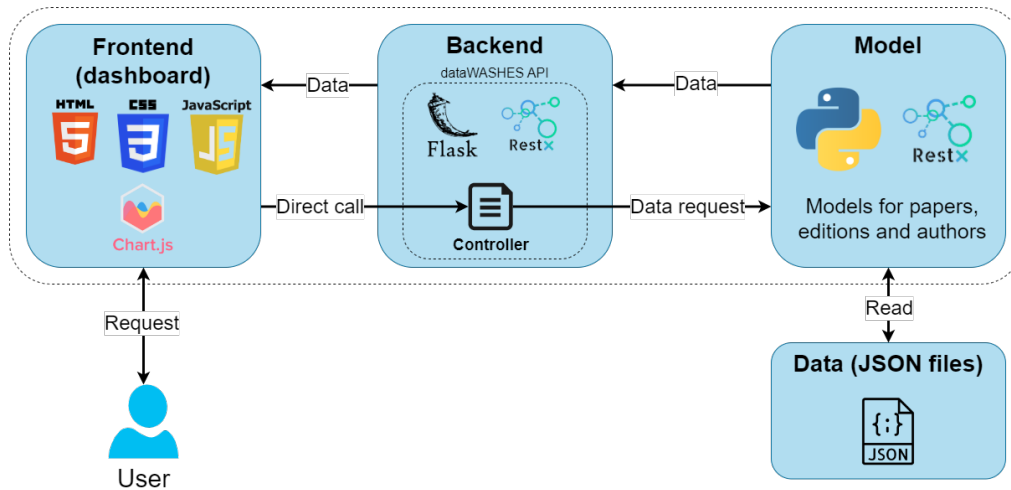


Figure 2. DataWASHES dashboard architectural model.

As illustrated in Figure 3, the architecture encompasses features for interactive and visual analysis. In contrast to the API's output (e.g., json files or spreadsheets) the dashboard focuses on data visualization, enabling users to view and compare retrieved data in a clear and objective manner. Through dynamic charts and tables, users can access information on the number of publications, author count, relevant research topics, and trends over the years. Finally, interactive analysis is a key feature of the dashboard, enabling users to hover over charts and tables to access detailed information. It is important to emphasize that the dashboard does not replace the API, nor does the API render the dashboard unnecessary. Each solution has its own purpose and specific use case.

The dashboard is currently composed of a total of 13 visualizations, divided into visualization cells. At the top of the dashboard, visualizations related to the number of papers published in each edition of WASHES are displayed; for this information, a bar chart was selected. Next to it, there is a visualization showing the number of papers per year and by language, allowing a comparison of paper production according to the language chosen for submission. This visualization is presented through a line chart, in which each line represents the number of papers in a given language per year/edition of WASHES. The subsequent visualizations present more detailed information about the papers featured in the event.

In the second row of the dashboard, two ranking visualizations are displayed: one showing the number of papers published by institution and another by author. These visualizations aim to highlight which entities, institutions or authors, have the greatest impact on the works published in WASHES. In both cases, a horizontal bar chart was used, as this type of visualization better emphasizes the ranking concept, with the top bars indicating higher values.

The following visualizations detail two additional aspects of the papers: the most frequently used keywords and the geographical distribution of the authors' affiliations. The first visualization was created using a word cloud chart, which displays all the keywords while adjusting the size of each term according to its frequency; thus, more frequent words appear larger than less common ones. Next to it, there is a visualization based on a choropleth map representing Brazil. In this map, each state is shaded in varying tones of blue: states with fewer publications are shown in lighter shades, while those with a higher number of papers appear in darker blue tones.

Following these visualizations, in the fourth row of the dashboard, there is a table displaying the papers awarded in each edition of WASHES. In every edition, papers compete for the best paper awards; therefore, a table was created containing information such as the paper title, authors, ranking position, and a direct link to the Brazilian Computer Society, in Portuguese *Sociedade Brasileira de Computação (SBC)*, webpage where the file can be accessed. This table is divided into multiple pages, one for each edition of WASHES. By clicking on each page, users can view the awarded papers for that specific edition. Finally, the last two rows present donut charts, each representing a different classification of WASHES papers: by approach, by objective, by procedure, by data collection method, by quantitative data analysis method, and by qualitative data analysis method. Each slice of the donut chart displays one category corresponding to the represented classification.

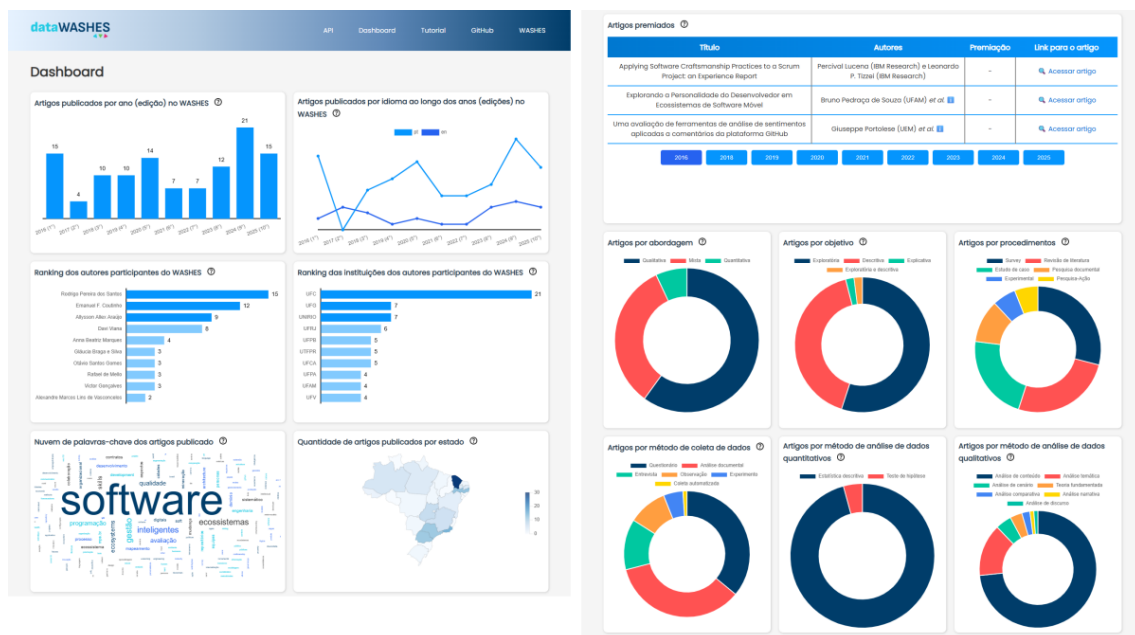


Figure 3. Overview of the dataWASHES dashboard.

5. Results and Analysis

To evaluate the proposed dashboard, two complementary approaches were employed: (1) a qualitative inspection to assess its adherence to Tufte's visualization principles and the

information visualization usability principles of Dowding and Merrill, and (2) a user-based evaluation using SUS.

5.1. Qualitative Inspection following Tufte's Principles

The qualitative and observational inspection of the dashboard was carried out with the objective of assessing its adherence to six graphical integrity principles and minimization of non-essential or decorative elements proposed by Tufte (2001). We evaluated each principle through an individual analysis of each graph, using a checklist to measure adherence. For each case, a justification was provided indicating whether the graph aligned with the corresponding principle. These principles emphasize the importance of clarity, simplicity, and efficiency in the presentation of data, with the aim of minimizing the use of unnecessary graphical elements.

Regarding the achievement of graphical integrity, Tufte outlines six principles aimed at ensuring an accurate graphical representation of the data [Tufte 2001]. The first principle requires faithfully and proportionally representing data without distortion or ambiguity. Our analysis revealed that Chart.js maintains accurate proportions in numerical values, ensuring that visual differences in charts correspond to actual data variations. Furthermore, the use of labels and explanatory text allows for clear identification of information, contributing to the accuracy and comprehension of the charts, and aiming to achieve adherence to the second principle, which defends the use of these elements to defeat graphical distortion and ambiguity. The third principle advocates for prioritizing data variation over design variation. In this regard, an effort was made to minimize the use of chart variants, focusing on common designs (bars, lines etc.) and introducing other variants only when they enhanced contextual understanding and comprehension. The fourth principle, related to time series displays, was not applicable, as these representations were not part of this study. The fifth principle states that a graph should not have more dimensions than the data it represents. This principle was followed in all representations, except for the word cloud. Although this visualization type inherently adds an extra visual dimension by representing the frequency of words through scaling in two dimensions, its inclusion was justified by its communicative power in presenting keyword prominence. Finally, with regard to the sixth principle, not quoting data out of context, all visualizations are free from any omission of data representation or temporal references that could create ambiguity or misinterpretation, thereby adhering to this guideline.

Moreover, the concept of data-ink ratio, proposed by Tufte, represents the proportion of “ink” (or pixels) dedicated to displaying the data in relation to the total used in constructing the graph. In particular, Tufte advocates for maximizing this metric in order to minimize the use of non-data-ink, which is “ink” used to represent unnecessary elements, those that do not contribute to understanding the data and are often chartjunk. The dashboard design was observed to be aligned with the principle of maximizing the data-ink ratio. The interface was designed to display graphical representations with minimal use of visual elements, keeping the focus on essential information and removing chartjunk (decorative visual elements), such as borders, grids, and lines that provided no informational value.

In conclusion, the qualitative inspection in light of Tufte's principles revealed that

the dataWASHES dashboard generally adheres to clarity and efficiency in data visualization. We have provided a supplementary file in our repository [Gonçalves et al. 2025] with these examples to enhance clarity. The evaluation indicated that the interface is well-structured, with a focus on minimizing non-essential elements and presenting information in an objective manner, as suggested by Tufte (2001).

5.2. Qualitative inspection following the information visualization usability principles proposed by Dowding and Merrill

To guide the evaluation of the proposed dashboard, this study also investigated the information visualization usability principles described by Dowding and Merrill (2018). In their research, the authors developed and validated a checklist of heuristics tailored to assess the usability of dashboards and visualization systems. The method for creating and validating this checklist involved combining general usability heuristics, adapted from Nielsen's classical principles [Nielsen 1995], with visualization-specific heuristics originally proposed by Forsell and Johansson (2010). Twelve experts in informatics and data visualization assessed the relevance of each usability factor, leading to a refined set of ten principles supported by forty-nine factors.

During the inspection, each principle was examined individually, and every visualization element was systematically analyzed according to the principles of spatial organization, information coding, flexibility, consistency, and graphical minimalism. We selected these principles because they represent core information visualization usability principles and their associated usability factors directly linked to data visualization. Each visualization element of the dataWASHES dashboard was systematically analyzed according to the guiding questions associated with these principles, as proposed by Dowding and Merrill (2018). Observations and justifications were recorded for each principle to assess the degree of adherence and to identify potential usability or design issues. This analytical process aimed to determine whether the dashboard effectively supports intuitive data exploration, maintains visual clarity, and promotes efficient interaction in alignment with best practices in information visualization design.

The analysis of the dashboard's spatial organization shows strong adherence to the corresponding principle. The interface features a grid structure that distributes components in a balanced and hierarchical manner, aiding navigation and comprehension. High-level metrics, such as the number of articles per year and by language, are positioned at the top, offering an immediate overview, while more detailed visualizations (e.g., author, institution, and article classification rankings) are arranged in lower sections. This logical and progressive layout helps reduce cognitive load and enhances visual clarity.

Regarding information coding, the chart types employed are appropriate for the data being presented. Bar and line charts effectively represent comparisons and temporal trends, while the choropleth map offers an intuitive visualization of the geographic distribution of publications. However, the use of multiple donut charts may compromise precision when comparing categories. Furthermore, although the color palette maintains aesthetic coherence, the absence of semantic coding limits the immediate association between colors and categories, which could be improved to enhance visual interpretation.

Finally, the principles of graphical minimalism and consistency are met. The dashboard features a proper use of white space and an absence of unnecessary elements such as grids, borders, or three-dimensional effects. The only exception is the word cloud, whose aesthetics are appealing but whose informational precision is limited. The consistency across visualization cards, which maintain standardized positions for titles and icons, reinforces the interface's predictability and cohesion. However, flexibility remains an opportunity for improvement: the inclusion of interactive features, such as cross-filters and dynamic table sorting, would expand the dashboard's exploratory potential, transforming it into a more dynamic tool geared toward discovering patterns in the data.

The qualitative inspection of the dataWASHES dashboard, conducted according to the usability principles proposed by Dowding and Merrill (2018), indicates that the interface mostly aligns with core information visualization principles. The dashboard exhibits clear spatial organization, generally appropriate information coding, and consistent application of graphical minimalism. Although flexibility could be enhanced through additional interactive features, such as cross-filters and dynamic table sorting, the interface overall supports data exploration and maintains visual clarity. A supplementary file in our repository [Gonçalves et al. 2025] provides an expanded analysis, including detailed observations and justifications for each principle, allowing readers to further examine examples of adherence and potential areas for improvement.

5.3. User Testing

This section presents an analysis of the questionnaire results obtained during user testing. The findings are structured into three perspectives: perceived usefulness and relevance, system usability as measured by SUS, and overall satisfaction, including results from open-ended responses.

5.3.1. Analysis of Perceived Usefulness and Relevance

After filling out the profile characterization questions, the students answered two questions (on a scale from 0 to 5, where 0 means "Totally Disagree" and 5 means "Totally Agree"), one regarding the perceived usefulness of dashboards in research activities and the other regarding the relevance of the information displayed on the dashboard, both within the context of the WASHES research. When we asked, "Do you believe that using dashboards would be useful for your research activities (if they involved the WASHES context)?", 26 students (92.9%) responded positively (4 and 5), meaning they agreed that dashboards are useful for research activities. Only one student strongly disagreed (1), and another gave a neutral response (3). Regarding the relevance of the information, all participants, when answering the question "Do you believe the information displayed on the dataWASHES dashboard is relevant for research involving the WASHES context?", indicated agreement (ratings of 4 or 5) with the relevance of the data presented.

5.3.2. Analysis of the System Usability Scale

After answering the questions in Section 1 (Characterization and Initial Perceptions), the participants proceeded with the 10 SUS questions, rated on a Likert scale from 1 to 5, where 1 represents “Totally Disagree” and 5 represents “Totally Agree.” Figure 4 provides an overview of the results obtained, which will be discussed below.

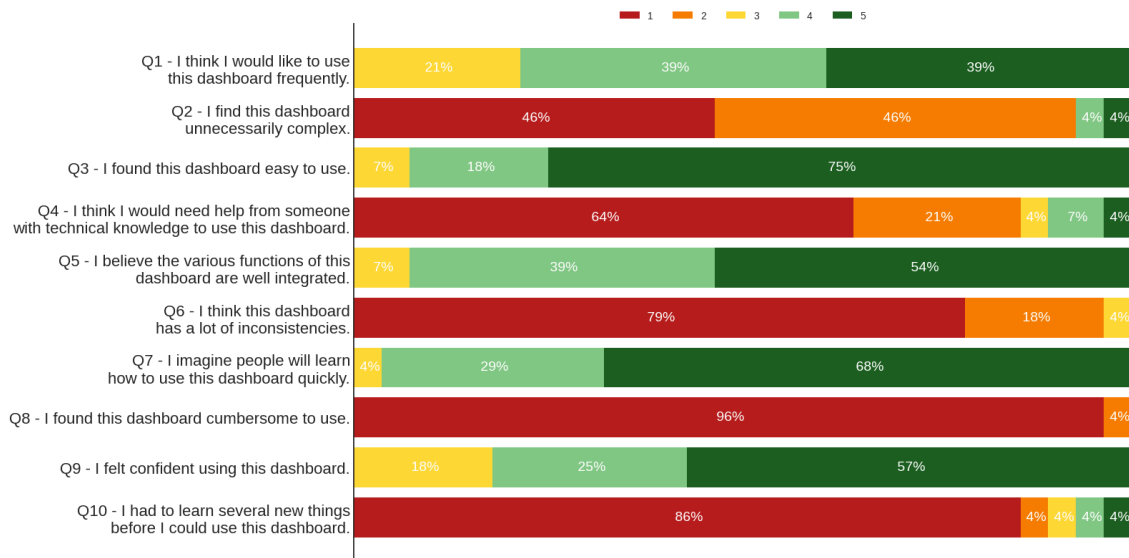


Figure 4. Results based on SUS.

The results indicate a high level of satisfaction among participants with the dashboard. The intention for future use, addressed in Q1 (“I think I would like to use this dashboard frequently”), showed strong receptivity: approximately 39% totally agreed with the statement that they would like to use it frequently, and another 39% chose option 4, indicating partial agreement, while 21% adopted a neutral stance. Q9 (“I felt confident using this dashboard”) reinforces this positive perception, with 57% of respondents feeling totally confident using it and another 25% indicating partial confidence.

In turn, the simplicity and learning curve of the interface were also highlighted. Q4 (“I think I would need help from someone with technical knowledge to use this dashboard”) revealed that the vast majority of users disagreed with the need for assistance: 64% totally disagreed and 21% expressed partial disagreement, showing that 85% of participants did not feel the need for technical support to use the dashboard. This suggests that the interface is intuitive and easy to learn. This finding is directly corroborated by Q3 (“I found this dashboard easy to use”), with 75% of participants totally agreeing that the dashboard is easy to use, 10% indicating partial agreement, and the remaining participants adopting a neutral stance.

Ease of use also stands out positively in the perception of the participants. Q2 (“I find this dashboard unnecessarily complex”) showed that 92% of participants disagreed with the idea that the dashboard is unnecessarily complex, pointing to an intuitive design. Similarly, Q6 (“I think this dashboard has a lot of inconsistencies”) revealed that nearly

97% of participants did not perceive the dashboard as inconsistent, with 79% totally disagreeing with the statement, reinforcing the dashboard cohesion.

Learning and accessibility indicators also reflected highly positive results. Q7 (“I imagine people will learn how to use this dashboard quickly”) supports this finding, with nearly all participants (97%) agreeing to some extent that the learning process is straightforward. Moreover, Q10 (“I had to learn several new things before I could use this dashboard”) demonstrated that 86% totally disagree with the statement, indicating that most users were able to interact with the dashboard without requiring prior technical preparation. These results highlight a smooth and accessible learning curve, which is important for a tool intended for a broad academic audience.

The dashboard’s efficiency and cohesion were also confirmed by the responses to Q5 and Q8. In Q5 (“I believe the various functions of this dashboard are well integrated”), 93% of participants expressed some degree of agreement, suggesting a strong perception of consistency among the dashboard’s components. Additionally, 96% of respondents disagreed with the statement in Q8 (“I found this dashboard cumbersome to use”), which demonstrates that users experienced a fluid and obstacle-free interaction. These findings collectively indicate that the dashboard achieves an effective balance between usability, efficiency, and structural coherence.

Finally, the SUS score for the dashboard reached 91.25, a value classified as “Excellent” according to the adjective scale by Bangor et al. (2009). This result confirms that the tool effectively meets the users’ expectations, being highly satisfactory and usable.

5.3.3. Analysis of Overall Satisfaction and Open-Ended Answers

After completing the SUS questions, participants moved on to the third and final section of the questionnaire, which addressed overall satisfaction and final considerations. When evaluating their overall satisfaction (using a Likert scale from 1 to 5), 96.4% indicated being satisfied with the application, with 50% selecting option 5, expressing high satisfaction. Regarding the clarity and usefulness of the information presented on the dashboard, all participants rated it positively (options 4 or 5), with 60.7% expressing total satisfaction with this issue.

Regarding recommending the dashboard to other researchers or students, 100% of participants expressed agreement (4 or 5), reflecting a positive perception from the users. In this sense, when asked about what they liked most about the dashboard, participants highlighted the clarity, usability, and interactivity of the tool. P9 described the dashboard as “*An application that is very intuitive and interactive, with easy access and a clear understanding of the information*”. P23 noted that the interface had “*Simplicity and a clean visual*” while P4 mentioned that the aspect they liked most was its “*Ease of use*”. Some components of the dashboard were highlighted as differentiators, making navigation more efficient and adding value to the experience. P21 remarked that “*The option to go directly to the published papers is very interesting*”, while P26 pointed out that “*The informative icons that explain in detail the purpose of the presented graph were also very useful, eliminating the need to search for external tutorials*”.

Finally, when we asked to suggest improvements, participants primarily recommended enhancing the responsiveness of components such as the word cloud, the publication map by state, and the donut charts, which displayed inconsistencies on certain screens. They also suggested improving table readability, with P27 mentioning that they “*Experienced some difficulty reading the titles due to their central alignment*”, as well as refining charts, particularly the font used in the word cloud. Design-related suggestions included adjustments to the donut charts to improve color differentiation, as P23 noted: “*Despite the clean visual design, some colors seem similar*”, along with displaying values directly rather than requiring user interaction. Participants also mentioned the inclusion of a dark mode and customization options, as well as the addition of new search and filtering options, enabling more precise refinements across all WASHES papers.

5.4. Lessons Learned

The development and evaluation of the dataWASHES dashboard provided practical and methodological learning. This section summarizes the main lessons learned throughout the process, which may serve as guidance for future projects at the intersection of Open Science, data visualization, and usability.

Combining a qualitative inspection based on theoretical principles [Tufte 2001, Dowding and Merrill 2018] with a quantitative usability test (SUS) proved to be promising. The SUS score of 91.25 indicated excellent acceptance and ease of use, but the qualitative analysis revealed nuances that could not be captured solely by satisfaction metrics. For example, the inspection identified limited accuracy in the word cloud and potential difficulties in comparing multiple donut charts. These findings provided a clear roadmap for future refinements, demonstrating that mixed evaluation approaches offer a more complete understanding of interface performance.

Moreover, user feedback and the analysis based on Dowding and Merrill’s principles converged the need for greater interactivity. Although the dashboard effectively presents the data, users expressed a desire for features that enable deeper exploration and customization, such as dynamic filters and adjustable visual settings. The main lesson was that a successful Open Science dashboard should be a tool that empowers users to ask their own questions, discover patterns, and generate insights.

From an IS perspective, these lessons reinforce the socio-technical nature of Open Science infrastructures since their effectiveness depends as much on usability, interaction design, and user empowerment as on their underlying data and technical architectures. Integrating these human-centered dimensions contributes to more sustainable, meaningful, and participatory scientific ecosystems.

6. Discussion

This study addressed the presentation and evaluation of the dataWASHES dashboard, a tool for visualizing proceedings data related to WASHES. This work fits within the growing need for tools that facilitate access to and understanding of scientific information, aligning with the principles of Open Science. In this regard, Wilkinson (2005) argues that the “grammar of graphics” should serve not only aesthetics but, most importantly, the

effective communication of scientific data, a principle that guided the development of dataWASHES. Below, we discuss how our findings connect with related literature, the contributions for IS research and practice, and the threats to validity.

6.1. Answering our Research Question and Connecting our Findings to Related Literature

The results of this study provide a clear answer to the research question by demonstrating that the systematic application of data visualization and usability principles positively contributes to the design quality and perceived usability of an Open Science dashboard. By grounding the dashboard's visual structure in visualization principles and assessing user perceptions through empirical usability testing, the findings show that principled design choices were instrumental in promoting clarity, interpretability, and ease of use in Open Science tools. From a visualization standpoint, the qualitative inspection revealed strong adherence to Tufte's principles [Tufte 2001], particularly with respect to graphic integrity and the minimization of non-essential elements. This perspective finds parallels in the work of Few (2009), who also advocates for "visual eloquence" through simplicity and clarity. From a usability perspective, the empirical evaluation corroborates these findings. The user evaluation showed positive results, with a SUS score of 91.25 (classified as "Excellent" [Bangor et al. 2009]), as well as high levels of overall satisfaction (96.4%) and willingness to recommend dataWASHES. Participants also highlighted clarity, usability, and interactivity as strengths, while improvement opportunities were focused on aspects of responsiveness, readability, and refinements in the design of specific graphs. As emphasized by Nielsen (2012), successful interfaces combine ease of learning and efficiency, characteristics evident in the participants' responses, with 85% not feeling the need for technical support and 97% not perceiving inconsistencies.

Additionally, the qualitative inspection of the dashboard aligns with the work of Dowding and Merrill (2018), whose approach is based on information visualization heuristics refined from previous research, such as that of [Forsell and Johansson 2010]. Our analysis identified adherence to several of these principles, such as spatial organization and graphical minimalism. On the other hand, the opportunity for improvement identified in terms of flexibility (the absence of interactive filters) not only contrasts with Dowding's heuristic but also with the fundamental mantra of visual information seeking by Shneiderman (1996): "Overview first, zoom and filter, then details-on-demand". The implementation of such filters would transform the dashboard from a static presentation tool into a dynamic exploration platform, aligning with best practices in the field. This perspective demonstrates that while the dashboard's visual presentation is robust, its analytical and interactive potential can be expanded, a diagnosis that emerges from the intersection of these different theoretical perspectives. In other words, the findings indicate that grounding dashboard design in visualization and usability principles is not merely a design preference, but an important factor in enabling interpretable and effective Open Science tools.

6.2. Contributions for IS Research and Practice

The contributions of this work are multifaceted, providing academia with a practical case of applying usability and information visualization principles with empiri-

cal validation in the context of Open Science tools, as well as a hybrid evaluation method that combines theoretical inspection and user testing. The dataWASHES dashboard exemplifies how the systematic application of information design principles, combined with a user-centered approach, can result in tools that are valuable to the scientific community, making a tangible contribution to Open Science. From an IS perspective, the dashboard supports sensemaking processes by enabling users to interpret, compare, and contextualize scientific data through integrated visual representations [Namvar et al. 2025, Alabi 2021, van Elten et al. 2022].

Consistent with socio-technical perspectives in IS, the findings suggest that the effectiveness of Open Science dashboards depends not only on technical correctness or data availability, but also on usability, interaction design, and users' ability to explore and appropriate the system within their analytical practices. As noted by Fekete et al. (2008), well-designed visualizations transform data into actionable knowledge, a function that the dashboard fulfills by offering multiple perspectives on the scientific production of WASHES.

From the perspective of IS research, this work contributes a methodological approach that integrates qualitative inspection based on established data visualization principles [Tufte 2001, Dowding and Merrill 2018] with empirical user-centered evaluation. The systematic application of these theoretical frameworks in an Open Science context demonstrates how information design principles can be operationalized to evaluate emerging scientific tools. Furthermore, our results expand the body of knowledge on academic dashboards, offering empirical evidence that adherence to information design principles is directly associated with user-perceived satisfaction and usability, as reflected in the SUS score. The availability of data and evaluation instruments in an open repository strengthens the transparency and replicability of the study, as well as contributes to building a repository of cases that can guide future investigations.

From a practical perspective, dataWASHES represents an illustrative case study for IS professionals who develop and manage research Open Science solutions. The results highlight how dashboards can support informed decision-making and accountability in open data ecosystems, offering design insights for IS practitioners developing scientific and institutional data-driven platforms. Moreover, the demonstration that the application of information design principles can yield high usability outcomes offers a concrete roadmap for similar scenarios. The tool illustrates how dashboards goes beyond the function of data presentation to become instruments for scientific exploration, open science, and discovery, facilitating the identification of trends, gaps, and collaboration opportunities within the academic community. Lastly, the identified improvement opportunities (especially the implementation of interactive filters) provide practical directions for the evolution of similar platforms in the IS context, reinforcing that iteration based on user feedback is fundamental for the maturation of digital scientific tools and for strengthening Open Science principles in the practice of systems development.

6.3. Threats to Validity

Despite the methodological rigor adopted, this study faces threats to validity that were considered and mitigated as much as possible. Regarding **internal validity**, a poten-

tial bias lies in the qualitative observational inspection, as the evaluation of adherence to data visualization principle [Tufté 2001, Dowding and Merrill 2018] was conducted by the researchers themselves. To mitigate this threat, an independent validation process was implemented, where a second researcher critically reviewed the findings of the initial inspection. Moreover, the principles were applied systematically and documented, reducing the subjectivity of the analysis. As for **external validity**, the sample of participants consisted exclusively of students, which may limit the generalizability of the results to other audiences, such as experienced researchers or industry professionals. However, it is important to note that the primary focus of this evaluation was on the usability of the API. A future study involving domain experts and researchers in the areas covered by WASHES could be necessary to assess the effectiveness and practical impact of the solution in other research contexts. To minimize this limitation, it is emphasized that a reasonable number of students with varying levels of familiarity with dashboards participated. Studies suggest that 5-15 participants can identify most critical issues in usability testing [Bevan et al. 2003].

Regarding **construct validity**, the use of SUS as an evaluation tool may not capture all dimensions of usability, especially aspects related to the perception of utility or relevance and overall satisfaction. However, to address this limitation, a complementary qualitative analysis was incorporated, including open-ended questions to capture more detailed insights from participants. Furthermore, conducting a pilot before the main study ensured that the evaluation script was clear and well-structured, reducing potential errors in data collection. Regarding **conclusion validity**, the main threat lies in the possibility of misinterpretation of results due to the sample size and the subjective nature of the participants' perceptions. It is also worth noting that the participation of students was anonymized to minimize potential biases. Finally, the availability of the tools used and the collected data in an open repository [Gonçalves et al. 2025] contributes to the transparency of the study, allowing for future replications and further exploration. While there are threats to validity, the strategies adopted minimized their impact and strengthened the reliability of the findings.

7. Final Remarks

Open Science has become a fundamental element for the advancement of research across different fields, including IS. In this context, the dataWASHES dashboard emerges as a tool aligned with the principles of Open Science, providing an interactive and visual interface to explore data from papers published in the proceedings of WASHES workshop. Guided by the research question of how data visualization and usability principles contribute to the design and perceived usability of an Open Science dashboard, this study aimed to present and evaluate the dataWASHES dashboard through a qualitative inspection grounded in Tufté's visualization principles [Tufté 2001] and the information visualization usability principles proposed by Dowding and Merrill [Dowding and Merrill 2018], followed by an empirical usability evaluation with 28 students. Data for this evaluation were collected using a semi-structured questionnaire addressing perceived usefulness and relevance, the System Usability Scale (SUS), and overall user satisfaction.

The results indicated that the dashboard adheres to Tufte's data visualization principles, featuring a clear and efficient interface, with an emphasis on minimizing non-essential elements and directly communicating the data. In regard to Dowding and Merrill's information visualization usability principles, the dashboard showed adherence to spatial organization, information coding, and consistency, while graphical minimalism was achieved through clean layouts and balanced use of white space. However, flexibility remained limited, suggesting opportunities for future enhancements through interactive features that could expand users' exploratory capabilities. In terms of usability, user perceptions were highly positive based on the SUS, with high satisfaction regarding ease of use, confidence, and clarity of information. However, qualitative feedback highlighted some areas for improvement, including the responsiveness of certain components, such as the word cloud and interactive charts, as well as the need for adjustments in the colors of some charts and suggestions for new functionalities, such as personalized viewing modes and refined filters.

This study contributes both to academia and practice by expanding the understanding of applying data visualization and usability principles in the design of dashboards for Open Science. Furthermore, the usability evaluation through the SUS emphasizes the importance of user-centered design for solutions aimed at Open Science. From a practical perspective, the enhancement of the dataWASHES provides a more interactive and accessible tool for the community, facilitating the analysis of strategic data related to WASHES. Beyond usability and visual clarity, the dataWASHES dashboard functions as a decision-support artifact that enables sensemaking by transforming research data into interactive visualizations. By offering integrated views of authorship, topics, and temporal trends, the dashboard supports analytical reasoning and contributes to organizational learning within the WASHES community, enabling reflection on past editions and informing future research and organizational decisions. Overall, this study contributes to the IS field by demonstrating how user-centered dashboards grounded in visualization and usability principles can strengthen Open Science infrastructures, supporting data governance, decision-making, and knowledge creation in socio-technical systems.

Future work includes implementing the improvement suggestions provided by users and expanding research on the intersection of data visualization, usability, and Open Science tools. In addition, further exploration of heuristic evaluation techniques to enhance user experience and accessibility in this domain could be approached. Moreover, we propose reassessing a new version of the dashboard with a larger and more diverse target audience, aiming to gather more generalizable feedback.

Artifacts Availability

To promote transparency and reproducibility, all materials supporting this study are openly available in our public repository [Gonçalves et al. 2025], including Appendix A (Expanded Inspection Analysis Based on Tufte's Visualization Principles), Appendix B (Expanded Inspection Analysis Based on Dowding and Merrill's Visualization Usability Principles), Appendix C (Informed Consent Form and Questionnaire), and Appendix D (Questionnaire Responses).

Acknowledgments

We thank all participants for their valuable time and contributions to this study. This research was supported by the Brazilian Federal Agency for Support and Evaluation of Graduate Education – CAPES (Finance Code 001), the Brazilian Research Council - CNPq (Grants 316510/2023-8 and 311533/2025-6), the Carlos Chagas Filho Foundation for Research Support of the State of Rio de Janeiro - FAPERJ (Grant E-26/204.404/2024), and Foundation for Research and Scientific and Technological Development of Maranhão - FAPEMA (Grant BEPP-03906/23). We also acknowledge institutional support from the Federal University of Cariri (UFCA), including the Graduate Program in Business Administration (PPGA), UNIRIO, and UFMA.

References

- Alabi, H. (2021). Sensemaking with learning analytics visualizations: Investigating dashboard comprehension and effects on learning strategy.
- Alhamadi, M., Alsayahani, H., Clinch, S., and Vigo, M. (2025). Behavioural indicators of usability in visual analytics dashboards. *ACM Transactions on Interactive Intelligent Systems*, 15(2):1–35.
- Almasi, S., Bahaadinbeigy, K., Ahmadi, H., Sohrabei, S., and Rabiei, R. (2023). Usability evaluation of dashboards: a systematic literature review of tools. *BioMed Research International*, 2023(1):9990933.
- Araújo, A. A., Farias, I., Gonçalves, V., Santos, R., Viana, D., and Steinmacher, I. (2024). dataWASHES - Towards an Application Programming Interface of WASHES proceedings data. In *Workshop sobre Aspectos Sociais, Humanos e Econômicos de Software (WASHES)*, pages 158–162. SBC.
- Bangor, A., Kortum, P., and Miller, J. (2009). Determining what individual sus scores mean: Adding an adjective rating scale. *Journal of usability studies*, 4(3):114–123.
- Bevan, N., Barnum, C., Cockton, G., Nielsen, J., Spool, J., and Wixon, D. (2003). The “magic number 5” is it enough for web testing? In *CHI’03 extended abstracts on Human factors in computing systems*, pages 698–699.
- Brooke, J. et al. (1996). SUS - A quick and dirty usability scale. *Usability evaluation in industry*, 189(194):4–7.
- Burnay, C., Dargam, F., and Zarate, P. (2019). Data visualization for decision-making: an important issue. *Operational Research*, 19(4):853–855.
- Card, S. K., Mackinlay, J. D., and Shneiderman, B. (1999). *Readings in information visualization: using vision to think*. Morgan Kaufmann, San Francisco, CA, USA.
- Chen, H., Chiang, R. H., and Storey, V. C. (2012). Business intelligence and analytics: From big data to big impact. *MIS quarterly*, pages 1165–1188.
- Cobey, K. D., Haustein, S., Brehaut, J., Dirnagl, U., Franzen, D. L., Hemkens, L. G., Presseau, J., Riedel, N., Strech, D., Alperin, J. P., et al. (2023). Community consensus on core open science practices to monitor in biomedicine. *Plos Biology*, 21(1):e3001949.

- Dilla, W., Janvrin, D. J., and Raschke, R. (2010). Interactive data visualization: New directions for accounting information systems research. *Journal of Information Systems*, 24(2):1–37.
- Dowding, D. and Merrill, J. A. (2018). The development of heuristics for evaluation of dashboard visualizations. *Applied clinical informatics*, 9(03):511–518.
- Doyle, C., Luczak-Roesch, M., and Mittal, A. (2019). We need the open artefact: design science as a pathway to open science in information systems research. In *International Conference on Design Science Research in Information Systems and Technology*, pages 46–60. Springer.
- Ependi, U., Kurniawan, T. B., and Panjaitan, F. (2019). System usability scale vs heuristic evaluation: a review. *Jurnal Simetris*, 10(1):65–74.
- Fecher, B., Bartling, S., and Friesike, S. (2014). Opening science: The evolving guide on how the internet is changing research, collaboration and scholarly publishing. *Impact of Social Sciences Blog*.
- Fekete, J.-D., Van Wijk, J. J., Stasko, J. T., and North, C. (2008). The value of information visualization. *Information visualization: human-centered issues and perspectives*, pages 1–18.
- Few, S. (2009). *Now you see it: simple visualization techniques for quantitative analysis*. Analytics Press.
- Few, S. (2013). *Information dashboard design: Displaying data for at-a-glance monitoring*, volume 5. Analytics Press Burlingame.
- Forsell, C. and Johansson, J. (2010). An heuristic set for evaluation in information visualization. In *Proceedings of the International Conference on Advanced Visual Interfaces*, pages 199–206.
- Foster, E. D. and Deardorff, A. (2017). Open science framework (osf). *Journal of the Medical Library Association: JMLA*, 105(2):203.
- Gardner, L. L., Raeisian Parvari, P., Seidman, M., Holden, R. J., Fowler, N. R., Zarzaur, B. L., Summanwar, D., Barboi, C., and Boustani, M. (2025). Improving the user interface and guiding the development of effective training material for a clinical research recruitment and retention dashboard: Usability testing study. *JMIR Formative Research*, 9:e66718.
- Gonçalves, V., Viana, D., Santos, R., and Araújo, A. A. (2025). Bridging open science and data visualization: Evaluating the usability of datawashes dashboard. In *Workshop sobre Aspectos Sociais, Humanos e Econômicos de Software (WASHES)*, pages 48–59. SBC.
- Gonçalves, V., Souza, A., Viana, D., dos Santos, R. P., and Araújo, A. A. (2025). Supporting dataset for: Integrating Usability and Data Visualization in Open Science: An Evaluation of the dataWASHES dashboard. Available at: <https://doi.org/10.5281/zenodo.17467439>.

- Grier, R. A., Bangor, A., Kortum, P., and Peres, S. C. (2013). The system usability scale: Beyond standard usability testing. In *Proceedings of the human factors and ergonomics society annual meeting*, volume 57, pages 187–191. SAGE Publications Sage CA: Los Angeles, CA.
- Kags, A. (2023). Building community driven open infrastructure. In *Open Infrastructure Fund/Fondo de Infraestructura Abierta*.
- Lam, H., Bertini, E., Isenberg, P., Plaisant, C., and Carpendale, S. (2011). Empirical studies in information visualization: Seven scenarios. *IEEE transactions on visualization and computer graphics*, 18(9):1520–1536.
- Laubheimer, P. (2017). Dashboards: Making charts and graphs easier to understand. Accessed: 2025-02-22.
- Maedche, A., Elshan, E., Höhle, H., Lehrer, C., Recker, J., Sunyaev, A., Sturm, B., and Werth, O. (2024). Open science: Towards greater transparency and openness in science. *Business & Information Systems Engineering*, pages 1–16.
- Manghi, P., Bardi, A., Atzori, C., Baglioni, M., Manola, N., Schirrwagen, J., Principe, P., Artini, M., Becker, A., De Bonis, M., et al. (2019). The openaire research graph data model. *Zenodo*.
- Mendez, D., Graziotin, D., Wagner, S., and Seibold, H. (2020). Open science in software engineering. *Contemporary empirical methods in software engineering*, pages 477–501.
- Mezzone, A., Oxenham, P., and Ranaweera, J. (2025). Formative usability assessment of a digital dashboard designed in a british basketball league club. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, page 17543371251324816.
- Namvar, M., Im, G. P., Li, J., and Chung, C. (2025). Data-driven sensegiving and sensemaking: a phenomenological investigation. *Information Technology & People*, 38(7):2637–2663.
- Nazemi, K., Burkhardt, D., Hoppe, D., Nazemi, M., and Kohlhammer, J. (2015). Web-based evaluation of information visualization. *Procedia Manufacturing*, 3:5527–5534.
- Nielsen, J. (1995). 10 usability heuristics for user interface design. <https://www.nngroup.com/articles/ten-usability-heuristics/>. Accessed: 2025-10-09.
- Nielsen, J. et al. (2012). Usability 101: Introduction to usability.
- of Sciences, N. A., Medicine, Affairs, G., on Research Data, B., and on Toward an Open Science Enterprise, C. (2018). Open science by design: Realizing a vision for 21st century research.
- Patra, P., Di Pompeo, D., and Di Marco, A. (2025). An evaluation framework for the fair assessment tools in open science. *arXiv preprint arXiv:2503.15929*.
- Revina, A. (2021). Exploring dashboards as socio-technical artifacts: Literature review-based insights. *ICE-B*, pages 207–218.

- Rossi, F. S., Adams, M. C., Aarons, G., and McGovern, M. P. (2025). From glitter to gold: recommendations for effective dashboards from design through sustainment. *Implementation Science*, 20(1):16.
- Schöpfel, J., Azeroual, O., and De Castro, P. (2022). Research information systems and ethics relating to open science. *Procedia Computer Science*, 211:36–46.
- Sellanga, J. (2023). Accelerating adoption and investment in open infrastructure world-wide through collaboration with networks. *Invest in Open*. Accessed: 2024-03-14.
- Shneiderman, B. (1996). The eyes have it: A task by data type taxonomy for information visualizations. In *Proceedings of the 1996 IEEE symposium on visual languages*, pages 336–343. IEEE.
- Tufte, E. R. (2001). *The visual display of quantitative information*, volume 2. Graphics Press Cheshire, CT.
- UNESCO (2021). *UNESCO Recommendation on Open Science*. United Nations Educational, Scientific and Cultural Organization.
- van Elten, H. J., Sülz, S., van Raaij, E. M., and Wehrens, R. (2022). Big data health care innovations: performance dashboarding as a process of collective sensemaking. *Journal of Medical Internet Research*, 24(2):e30201.
- Vornhagen, H., Davis, B., and Zarrouk, M. (2018). Sensemaking of complex sociotechnical systems: the case of governance dashboards. In *Proceedings of the 19th Annual International Conference on Digital Government Research: Governance in the Data Age*, pages 1–2.
- Wang, R., Perez-Riverol, Y., Hermjakob, H., and Vizcaíno, J. A. (2015). Open source libraries and frameworks for biological data visualisation: A guide for developers. *Proteomics*, 15(8):1356–1374.
- Ware, C. (2019). *Information visualization: perception for design*. Morgan Kaufmann.
- Wilkinson, L. (2011). The grammar of graphics. In *Handbook of computational statistics: Concepts and methods*, pages 375–414. Springer.