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Research Paper

Design Patterns to Support the Usability and User Experience Evaluation of Dashboards for Decision Support Systems

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Abstract Dashboards are essential tools for real-time monitoring and decision support; however, their design and evaluation often rely on generic usability heuristics that fail to address the specific complexities of data visualization. To address this gap, this paper presents DP-DASHBOARD, a set of structured design patterns aimed at improving the usability and User Experience (UX) of decision support dashboards. The proposed patterns were developed through a methodological process involving an exploratory literature review to identify quality attributes and a Systematic Mapping Study (SMS) to consolidate existing design knowledge. The resulting artifact was empirically evaluated with 21 computer science students to assess its comprehensibility and perceived usefulness. The results indicate a high level of acceptance, confirming that the patterns serve as an effective guide for identifying interface problems and implementing user-centered solutions. The study concludes with the refinement of the patterns based on qualitative feedback, offering a robust framework to assist designers and developers in creating more consistent and intuitive dashboards.

Keywords: Dashboards, Decision Support Systems, Usability, User Experience, Design Patterns

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1 Introduction

Dashboards are visual representations of data, typically composed of charts, tables, gauges, and other visual elements that provide summarized and real-time information about the performance of a system, process, project, or organization [Cahyadi and Prananto, 2015]. The importance of dashboards lies in their ability to simplify the interpretation and communication of complex data, allowing users to easily understand essential information and identify relevant trends, patterns, or anomalies [Costa, 2018]. Beyond static summarization, dashboards are also explored as a medium for narrative and storytelling approaches to data, which can further enhance user engagement and comprehension through explanatory elements such as annotations, highlights, and guided sequences [Borges *et al.*, 2022]. The use of such tools has grown significantly in recent years [Praharaj *et al.*, 2022], being recognized by companies, academic institutions, and government organizations as essential for supporting evidence-based strategic decisions [Vazquez-Ingelmo *et al.*, 2019].

Beyond their widespread adoption, it is essential that dashboards are not only visually appealing but also effective, usable, and comprehensible. Usability plays a crucial role in dashboard use, as it directly affects users' ability to understand, interact with, and extract insights from the data presented [Richter Lagha *et al.*, 2020; Enache, 2021]. According to [Best and Smyth, 2011], usability is an indicator of a system's efficiency and effectiveness, assessing its ease of use and the user's ability to successfully complete tasks. User experience (UX), in turn, encompasses perceptions, emotions, and attitudes that emerge during product interaction, influencing satisfaction and engagement [Maia *et al.*, 2020]. Therefore, the quality of the experience provided by a dashboard becomes a decisive factor for its success and adoption.

As discussed by [Camargo and Farina, 2024], both usability and UX are essential to the performance and acceptance of interactive systems. The ISO 9241-210 standard reinforces that user-centered design makes systems more usable and useful, enhancing effectiveness, efficiency, and accessibility while reducing negative impacts on health, safety, and performance [ISO/IEC, 2019]. Studies such as [Rahman and Jyoti, 2022] demonstrate that investing in usability significantly reduces maintenance and support costs while increasing employee productivity. Improvements in user experience can also generate expressive gains in performance and business outcomes, enhancing user satisfaction and boosting conversion and retention indicators [Rahman and Jyoti, 2022]. The quality of the experience provided directly influences user satisfaction and brand perception [Paneru *et al.*, 2024], and recent systematic reviews confirm that this experience significantly impacts customer loyalty and retention, highlighting that investing in UX is not merely a design best practice but a strategic imperative for organizational sustainability and competitiveness [Andia-Reyna and Malasquez-Villanueva, 2025].

Although various studies have addressed dashboard development and user experience, the number of methodological approaches specifically focused on these interfaces remains limited [Almasi *et al.*, 2023; Silva *et al.*, 2018]. The evaluation methods most commonly employed rely on generic heuristics, such as Nielsen's heuristics, or standardized metrics, such as the System Usability Scale (SUS), which fail to address dashboard-specific characteristics, such as visual clarity, consistency among multiple views, and efficiency in conveying insights [Hassan and Galal-Edeen, 2017]. This limitation reveals the lack of domain-adapted guidelines and recommendations for complex data visualizations, hindering the development of more effective and user-oriented solutions. Scenario-based guideline approaches have been proposed to address similar gaps in adjacent visualization domains, such as the Vis2Learning guidelines for educational data visualizations, validated through end-user evaluation [Macedo *et al.*, 2022], reinforcing the need for equivalent domain-adapted artifacts targeting dashboards for decision support.

To address this gap, this paper introduces a set of Design Patterns, named **DP-DASHBOARD**, developed through the consolidation of quality attributes specific to dashboards and a systematic mapping of the literature. This proposal aims to provide practical, standardized design guidelines that assist design and development teams in creating more usable, consistent, and efficient interfaces. The patterns are organized into coherent categories such, as data information, metainformation, visual representation, layout, structure, interaction, and color usage and documented in a structured format describing the problem, context, and recommended solution, inspired by the approaches of [Vora, 2009] and [Gomes *et al.*, 2021]. This proposal consolidates and extends a research effort initiated in an industry–academia collaboration, in which preliminary versions of the evaluation instruments were applied to redesign the dashboard of a decision support system in the energy sector [Nunes *et al.*, 2025].

The proposed artifact was empirically evaluated to verify the comprehensibility and perceived usefulness of the patterns within the context of dashboard design, allowing the identification of refinement opportunities and continuous improvement. This experimental evaluation included qualitative analyses of users' and developers' perceptions regarding the clarity, relevance, and applicability of the proposed solutions, contributing to the theoretical and practical strengthening of the artifact. The results indicate that the systematization of design patterns specifically for dashboards can significantly support user-centered design processes, fostering more coherent, intuitive, and user-aligned visual solutions.

The remainder of this paper is structured as follows: Section 2 presents the **Background and Related Work**, discussing previous research on dashboard design and the identified gaps. Section 3 details the **Identification of Quality Attributes** specific to dashboards. Section 4 introduces the set of **Design Patterns DP-DASHBOARD**, while Section 4.3 presents a complementary subsection with examples under the category **DP-DASHBOARD**. Section 5 describes the **Evaluation and Improvements** of these patterns, including **Assessment Results** and subsequent refinements. Finally, Section 7 discusses the main findings and limitations, followed by the **Conclusions** in Section 8.

1.1 Ethical Issues

This research integrated ethical considerations throughout all its phases, from planning and artifact construction to evaluation and reporting, in accordance with the Brazilian Computer Society's Code of Conduct and the core practices of the Committee on Publication Ethics (COPE). The empirical evaluation engaged voluntary participants recruited in an educational context to assess the comprehensibility and perceived usefulness of the proposed **DP-DASHBOARD** patterns. Before participating, all individuals received clear information about the study's objectives, procedures, and the non-intrusive nature of the activities, and each participant read and agreed to a Free and Informed Consent Form. Furthermore, participants enrolled in the course received a small bonus credit contingent on the effort and depth of the written justification accompanying their evaluation of each pattern, independent of whether the assessment was favorable or unfavorable. Offering bonus credit for research participation is a documented practice in empirical studies with student subjects [Liebel and Chakraborty, 2021], and prior evidence indicates that such incentives do not, by themselves, compel participation [Padilla-Walker *et al.*, 2005]. This was also observed in the present study: of the 21 students who attended the session, two chose not to take part in the research despite being offered the same bonus credit, and one additional participant did not complete the full activity, resulting in 18 participants who fully completed the study. The researchers did not submit this study to a formal ethics review committee. This position is consistent with the broader debate on ethics committee submission raised within the Brazilian HCI community [Amorim *et al.*, 2019; Carvalho *et al.*, 2022], where the explicit justification of non-submission is treated as part of a legitimate ethical trajectory for scientific communication involving human participants. Future studies building on this research, particularly those involving industry practitioners, will be submitted to a formal ethics committee.

Beyond human participation, the researchers reflected on the broader societal impact of the work. By proposing domain-specific design patterns for dashboards, this research seeks to promote more usable, comprehensible, and responsible data visualization practices, reducing risks related to misinterpretation, cognitive overload, and misleading representations in decision-support systems. The research process followed principles of scientific integrity, including faithful reporting of methods and results, acknowledgment of limitations, and transparency regarding refinements derived from participant feedback. The authors limited the use of artificial intelligence tools to language support and text refinement, in accordance with JIS policies, recognizing that no research is ethically neutral and aiming to align methodological rigor with social and professional accountability.

2 Background and Related Work

This section reviews the related literature to contextualize the proposal of this study, which focuses on the development and structuring of Design Patterns aimed at improving the usability and user experience of dashboards. There is an increasing concern in the literature with developing systems that present information effectively and objectively [Praharaj *et al.*, 2022]. In this context, the analysis of related work is divided into two main areas: first, studies focused on the evaluation of usability and user experience in dashboards [Almasi *et al.*, 2023;

Maceli and Yu, 2020]; and second, research that investigates the application of design patterns and visualization structures for the construction of these tools [Smuts *et al.*, 2015; Enache, 2021; Bach *et al.*, 2022].

The study by [Almasi *et al.*, 2023] stands out for reviewing questionnaires used for the evaluation of dashboard usability. The authors proposed evaluation criteria involving aspects such as utility, operability, satisfaction, and system capabilities. This contribution is relevant as it provides a structured framework for analyzing dashboards. However, the study presents limitations, as it does not address attributes specific to dashboards, treating usability in a broad and generic way, similar to evaluations in other domains.

[Enache, 2021] illustrates the application of the System Usability Scale (SUS) to a dashboard designed for runners. This study shows how general-purpose usability instruments can be adapted to specialized contexts, offering a practical example of applicability. However, it also highlights a major limitation: generic scales such as SUS fail to capture domain-specific nuances, especially those related to data visualization, cognitive load, and interaction models inherent to dashboards. Thus, while useful for preliminary assessment, these tools require complementary approaches focused on dashboard-specific attributes.

[Maceli and Yu, 2020] contribute by conducting heuristic evaluations based on Nielsen's principles, adapting a well-established inspection method to identify usability problems in dashboards. This reinforces the relevance of tailoring traditional heuristics to specific visualization contexts. Nonetheless, their approach also reveals the lack of methodologies and structured solutions capable of guiding the design process itself, rather than solely diagnosing problems in existing interfaces.

From a design-oriented perspective, [Smuts *et al.*, 2015] investigate the challenges of designing dashboards for novice users, emphasizing the cognitive difficulties faced by non-expert audiences in interpreting and interacting with complex visual data. Their findings underscore the importance of cognitive accessibility and conceptual simplicity in dashboard design. However, the study remains descriptive, without formalizing actionable strategies or reusable design knowledge that could guide practitioners in overcoming such challenges. In the field of design patterns, [Sarikaya *et al.*, 2018] conducted a multidisciplinary review aimed at identifying and classifying different types of dashboards. Their main contribution lies in synthesizing and organizing scattered approaches into a taxonomy that characterizes dashboard design practices across contexts. Although useful for conceptual understanding, the taxonomy does not provide practical guidelines for design or implementation, limiting its impact on applied development.

More recently, [Bach *et al.*, 2022] proposed a process for creating dashboard design patterns based on a systematic review and the analysis of 144 dashboards, of which 83 were examined in depth. Their study resulted in a collection of patterns applicable in practice, offering structured guidance for dashboard design. This contribution is particularly significant, as it bridges academic research and professional practice. Nonetheless, the authors do not fully adopt the formalized structure suggested by [Vora, 2009], which recommends that each pattern include the problem, context, and implementation details. Instead, most proposed patterns focus primarily on describing the solution, without detailing how it should be applied or adapted to varying dashboard contexts.

The analysis of these studies reveals two main research gaps. First, evaluation approaches and interface models for dashboards still rely heavily on general usability methods, such as Nielsen's heuristics and the SUS scale, which were not designed to address the specific quality attributes of these interfaces. Second, research on design patterns recognized as carriers of quality and design knowledge [Leite *et al.*, 2017], shows methodological limitations, as most proposals lack formal structure and fail to incorporate empirical validation or domain-specific contextualization. Among the analyzed works, only [Bach *et al.*, 2022] presents a more consistent structuring and categorization of patterns; however, a limited set of studies addressing design patterns focused on usability and User Experience (UX) in dashboards was identified.

In response to these limitations, this paper proposes a comprehensive set of structured Design Patterns for dashboards, referred to as **DP-DASHBOARD**, developed through the consolidation of dashboard-specific quality attributes and a systematic mapping of the literature. These patterns are documented according to a consistent format including problem, context, and solution, to support design decisions that enhance usability, user experience, and visual coherence in data-driven systems.

3 Identification of Quality Attributes

This section presents the literature review conducted to identify, within the scientific literature, key quality attributes relevant to dashboards. The execution of the review and the results obtained are detailed. In addition, this section includes a systematic mapping of the literature aimed at identifying design patterns related to dashboards. These two approaches, namely the identification of quality attributes and the investigation of design patterns, are essential to support the development of evaluation technologies and to foster more effective design of these interactive tools.

In this paper, we distinguish four related concepts. A quality attribute is a quality-related item extracted from a primary study, such as stated requirements, survey questions, or measurable characteristics (e.g., usability, performance, security) that influence the success of a system. A requirement, in the scope of this paper, is the consolidated statement obtained by merging quality attributes that address the same subject, item, or category. A design pattern is a requirement expressed in the structured format proposed by Vora [2009]: the **Problem** describes the difficulties that arise when the requirement is not met; the **Solution** corresponds to the requirement itself; the **How** explains how the requirement is satisfied in practice; and the **Example** illustrates its application through screenshots of real dashboards. Finally, *categories* group requirements and patterns by their design concern (e.g., layout, color, interaction). Not every requirement was converted into a pattern: highly subjective or system-level requirements were excluded, as detailed in Section 4.2.

3.1 Exploratory Study of Usability Attributes in Dashboards

The development process of the proposed design patterns began with an exploratory review of the scientific literature, conducted to better understand the research area and identify relevant studies addressing quality aspects applicable to the development and conception of dashboards. This initial stage made it possible to understand the state of the art of the topic and to gather theoretical and practical foundations related to usability, user experience, and other essential attributes for building effective interfaces. From this first contact with the field, it was possible to consolidate the focus of the investigation and move toward a more targeted systematic mapping, whose results served as a basis for the formulation of the associated design pattern items.

The search terms included keywords such as *"Control Panel"* or *"Dashboard"*, *"Design Patterns"*, *"Quality Attributes"*, *"User Experience"*, *"User Interface"*, and *"Usability"*. No specific search string was defined, as the adopted strategy consisted of freely exploring combinations of these terms across databases in order to broaden the scope of relevant studies. The searches were conducted in different digital libraries and scientific databases, including IEEE Xplore, Scopus, ACM Digital Library, SpringerLink, SBC Open Lib (SOL) and Google Scholar.

The inclusion criteria considered papers published in the last ten years, written in English, that described quality attributes related to usability or user experience in dashboards, available for free access, and with full content accessible for data extraction. Duplicated, paid, or incomplete studies were excluded.

After the initial screening, papers were evaluated based on their title and abstract. When relevance could not be determined solely from these elements, the full text was read for final decision. As a result, ten papers reporting quality attributes relevant to dashboard development were selected: A001 – [Maceli and Yu, 2020]; A002 – [Almasi *et al.*, 2023]; A003 – [Smuts *et al.*, 2015]; A004 – [Enache, 2021]; A005 – [Raza *et al.*, 2019]; A006 – [Shakeel *et al.*, 2022]; A007 – [Rahman *et al.*, 2016]; A008 – [Bera, 2016]; A009 – [Silva-Rodríguez *et al.*, 2022]; and A010 – [Peters *et al.*, 2019].

During the analysis, studies directly addressing the use of design patterns in dashboards, such as [Sarikaya *et al.*, 2018] and [Bach *et al.*, 2022], were also identified. However, for organizational and structural coherence, these works were examined in a subsequent subsection dedicated to the specific systematic mapping on design patterns.

Initially, 165 attributes were identified. These attributes were listed in a document and, when similar, were grouped and consolidated into a single attribute, formulated as a quality requirement to be considered in the context of dashboard development. For instance, requirement OP-R02 (“The dashboard should provide access to data at different levels of aggregation, allowing multi-step exploration with on-demand details, appropriate filtering, and adaptation to the information level required for each task, avoiding information overload and ensuring clear and strategic navigation between meso and micro data.”) was formed by merging three attributes identified in the reviewed studies:

1. (A002-A08) Data accessible at different aggregation levels; visibility and availability of filters applied to the data.
2. (A006-A01) Material-oriented logic requires multi-step exploration with different levels of detail.
3. (A007-A07) Access patient meso data; access patient micro data.

Table 1. Requirements and Source Papers

Code	Requirement	Paper
LE-R01	The dashboard should include a FAQ section with clear, concise, and audience-tailored answers to common questions about system use, such as metric interpretation, visualization customization, and data export, organized logically to facilitate navigation and quick information retrieval.	A001, A002
LE-R02	The dashboard should avoid excessive simplifications when displaying complex data, ensuring that metrics and representations are sophisticated enough to accurately reflect the nuances of the analyzed problems.	A001, A004, A010
LE-R03	The dashboard should ensure that information, options, and actions are easily visible or retrievable, minimizing the need for memorization, with an intuitive interface that promotes learning through familiar terminology and visual cues, making the system accessible even to occasional users.	A002, A003, A004
EC-R01	The dashboard should provide real-time alerts about anomalies with clear and actionable notifications, maintain users informed about the current status through appropriate feedback, and present constructive error messages with guidance for quick problem resolution.	A001, A002, A003, A007

During the grouping process, the most comprehensive attribute was selected and/or complemented with details from others. After consolidation, 21 distinct attributes were identified and organized into categories covering crucial aspects for dashboard design and evaluation. These categories were not created *ad hoc*: several of the source studies already organized their quality attributes into named categories and, since identical or closely related category names recurred across different papers, this convergence was preserved during consolidation. Each consolidated attribute was then assigned to the existing category that best matched its design concern, which also facilitated the merging step, as semantically similar attributes from different studies frequently belonged to equivalent categories. The resulting categories are Learning (LE), System Capabilities (SC), Error Control and Utility (EC), Ease of Use

(EU), Flexibility (FL), Interactions (IN), Operability (OP), Structural Patterns (SP), Metainformation Patterns (MP), Visual Representation Patterns (VR), and Utility (UT). This categorization, derived from the identified studies, provides a comprehensive overview of the main quality requirements within the analyzed context.

These two-letter acronyms are used consistently throughout the paper as prefixes in the identifiers of both requirements and design patterns: the prefix denotes the category, while the suffix distinguishes consolidated requirements (`-Rnn`, e.g., LE-R01 in Table 1) from design pattern items (`-Inn`, e.g., LE-I01 in Section 4.4). As defined at the beginning of this section, requirements and patterns are closely related but distinct artifacts: each pattern corresponds to a requirement documented in the structured format of Vora [2009], in which the problem expresses the impact of not meeting the requirement, the solution states the requirement itself, and the how and example demonstrate its application in real dashboards. Requirements considered highly subjective or system-level, however, were not converted into patterns, as detailed in Section 4.2.

Table 1 presents examples of the requirements generated from the quality attributes extracted from the selected papers. The complete version of this table is available in the footnote[1]. These requirements represent the contributions of this exploratory review and served as the initial foundation for the formulation of the Design Patterns described in the next section.

3.2 Systematic Mapping of the Literature in Search of Design Patterns for Usability and UX in Dashboards

A preliminary literature review identified design patterns with practical improvement potential for dashboards, describing how to implement specific elements and offering contextualized examples for applying usability and user experience (UX) requirements. Based on this, a Systematic Mapping Study (SMS) was conducted, following [Kitchenham, 2004] and the update by [Kitchenham *et al.*, 2023], focusing on locating studies that presented patterns capable of improving usability and UX in dashboards. In this scope, design patterns are also understood as quality attributes, since they operate as guidelines that support system efficiency and usefulness [Larsson, 2004], in line with other evaluation techniques such as checklists, scales, and heuristics [Gomes *et al.*, 2021].

The protocol considered one main question identifying existing design patterns that address usability and UX in the development of dashboards and two subquestions: (i) to verify whether such patterns were organized into specific categories and what they are; and (ii) to map the theoretical foundations underpinning the proposed patterns. To operationalize the search, a string was defined with terms and synonyms derived from related work [de Cássio Lemes *et al.*, 2023; Gomes *et al.*, 2021; Martins *et al.*, 2013; Cabrejos *et al.*, 2018]. Preliminary tests ensured that the string adequately covered the main question and retrieved the largest possible number of relevant studies. The data source was the Scopus Digital Library, chosen for its breadth and credibility, including indexing from ACM, Springer, Science Direct, and IEEE [Codina, 2005].

Table 2. Data-Extraction Form

Publication ID:	A001
Full Reference of the Publication:	
What are the design patterns?	The design patterns identified in the publication
Design patterns in their respective categories:	Detail the categories mentioned in the publication
What is the theoretical basis of the proposed design patterns?	Explain the theoretical or conceptual basis used in the publication to propose the patterns

The final string was: *(Dashboard" OR Data Panel" OR Indicators Panel") AND (Design Patterns" OR Design Templates") AND (User eXperience" OR User Interface" OR Usability" OR UX" OR UI")*, applied in Scopus. Rigorous inclusion and exclusion criteria were defined to prioritize the most relevant studies: include papers that describe design patterns for dashboards (IC1) and exclude works that did not address patterns, were not in English, were not accessible, were not scientific papers (e.g., abstract only, workshop, book), or were duplicates. To organize and standardize extraction, a form with fields guided by the literature [Cabrejos *et al.*, 2018] was used, presented in Table 2.[2]

The search ran from August to December 2024, returning 209 publications. After title/abstract screening (Filter 1), 69 studies remained; the full-text screening (Filter 2), applying the selection criteria, resulted in 3 publications eligible for data extraction. In summary, the final sample concentrated studies that indeed document design patterns for dashboards with a focus on usability and UX, enabling consolidation of evidence on recurring elements, proposed categories, and theoretical bases.

The final studies with patterns were A001 - [Bach *et al.*, 2022], A002 - [Rossi and Lenzini, 2020], and A003 - [Sarikaya *et al.*, 2018]. Among them, only [Rossi and Lenzini, 2020] explicitly structured its design suggestions around a specific theoretical framework ([Haapio and Passera, 2017]). To standardize documentation, basic elements proposed by [Vora, 2009] were adopted: (a) **Code** of the pattern (identification and application category); (b) **Pattern Name** (short, descriptive title); (c) **Problem** (definition of the issue addressed); (d) **Solution** (proposal aligned with quality attributes); (e) **How** (good practices and variants); and (f) **Example** (illustration of application in real interfaces). In terms of findings, [Bach *et al.*, 2022] highlighted recurrent design elements and provided a website with category-based recommendations; [Sarikaya *et al.*, 2018] analyzed 83 dashboards in a multi-domain review, offering insights into typical implementations and their effects on user experience.

[1] Full table available at: `https://doi.org/10.5281/zenodo.21121325` - Table_Requirements and Source papers_.xlsx

[2] Data Extraction Form: `https://doi.org/10.5281/zenodo.21121325`

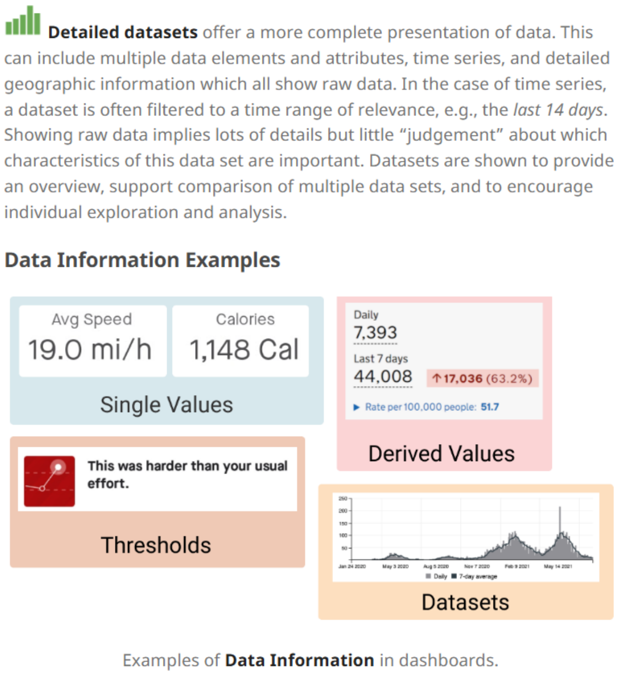


Figure 1. Design Pattern presented by [Bach *et al.*, 2022]

Among the illustrative examples, Figure 1 synthesizes a pattern described by [Bach *et al.*, 2022]. In turn, the work by [Rossi and Lenzini, 2020] proposes, among others, a pattern for effective *FAQs*, emphasizing clear and concise answers tailored to the target audience, organized in a logical and accessible way; *FAQs* complement (but do not replace) direct contact or more detailed documents and are useful for explaining processes (e.g., data protection) and simple instructions (e.g., account deletion), as shown in Figure 2.

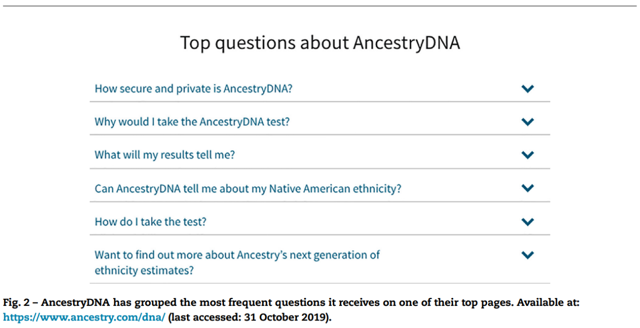


Figure 2. Design Pattern presented by [Rossi and Lenzini, 2020]

Figure 3, in turn, illustrates a pattern highlighted by [Sarikaya *et al.*, 2018]: the use of reference indicators (benchmarks) gauges, arrows, status lights, or labels to signal when thresholds are reached or exceeded, assisting rapid assessments against performance targets.

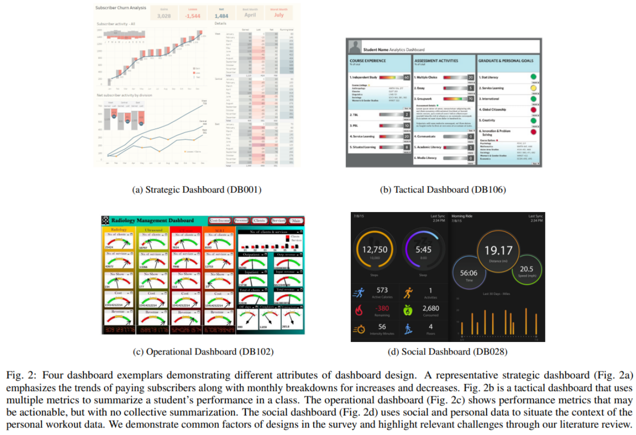


Figure 3. Design Pattern presented by [Sarikaya *et al.*, 2018]

As for categorization (SQ1), only [Bach *et al.*, 2022] described explicit categories that can guide the organization of recommendations: *Data Information Patterns*, *Meta Information Patterns*, *Visual Representation Patterns*, *Page Layout Patterns*, *Screenspace Patterns*, *Structure Patterns*, *Interaction Patterns*, and *Color Patterns*. Regarding the theoretical foundation (SQ2), each study employed its own design, summarized in Table 3: [Bach *et al.*, 2022] and [Sarikaya *et al.*, 2018] rely on systematic analysis of examples and documentation, defining design spaces (objectives, levels of interaction, and associated practices), while [Rossi and Lenzini, 2020] is anchored in [Haapio and Passera, 2017] to substantiate its proposals.

Table 3. Data-Extraction Form

ID	Theoretical Foundation
A001	The paper was based on a systematic analysis of examples and documentation about the use of dashboards. Additionally, a literature review on dashboards was used to build a design space, identify the main types of dashboards, and characterize their design objectives, levels of interaction, and associated practices.
A002	The theoretical foundation was based on the work of [Haapio and Passera, 2017], which explores fundamental changes in the world of contracts, including the impact of technologies.
A003	This paper presents a multi-domain literature review on practices related to dashboards, analyzing examples and related documentation. It defines a design space characterizing dashboards in terms of design objectives, levels of interaction, and associated practices.

In summary, the mapping confirms the existence of a small yet significant set of studies documenting design patterns focused on usability and UX in dashboards. It also reveals: (i) recurrence of certain design elements and practical recommendations (A001, A003); (ii) one proposal explicitly anchored in a contracts-based theoretical framework to make communication clearer and more transparent to users (A002); (iii) a taxonomy of categories that can serve as an organizational basis for deriving evaluation artifacts and design guidance; and (iv) a pattern documentation scheme that facilitates reproducibility and real-world application by articulating problem, solution, rationale, and examples.

4 Design Patterns DP-DASHBOARD

Design Patterns are reusable guidelines created to address recurring problems in technology design. They are derived from the analysis of common challenges and provide clear, structured solutions [Van Duyne *et al*., 2007]. As noted by [Vora, 2009], patterns are tightly coupled with the context of use, supporting designers in deciding when, where, and how to apply a given solution. They also embed best practices and quality principles into the creation process.

4.1 The Process of Developing the Design Patterns

Based on literature reviews covering both quality attributes and design patterns, we developed a set of design patterns to improve usability and user experience (UX) in dashboards for decision-support information systems. The process comprised:

1. Identification of dashboard quality attributes related to Usability and UX, as described in Section 3. In this step, the attributes were integrated with patterns reported in the literature so that each pattern encapsulated best practices, concrete implementation examples, and actionable guidance for dashboard development.
2. Detailed analysis of attributes and patterns to group similar elements, transform them into conceptual requirements, and organize them into a structured set of design patterns.

The development steps were inspired by the methodology of Frazão et al. (2021), which consolidates theoretical evidence from scientific literature.

4.2 Integration of Quality Attributes and Design Patterns for Usability and UX in Dashboards

The identification of quality attributes focused on Usability and UX is presented in Section 3, Subsections 3.1 (R1 – Review 1) and 3.2 (R2 – Review 2). The reviews yielded 224 attributes.

We observed identical, similar, or closely related items, motivating consolidation to reduce redundancy and generalize design principles. Example of similarity:

- (R2_A001) – *Personalization interactions allow users to reset and reconfigure the information shown on a dashboard.*;
- (R2_A003) – *Many dashboards allow users to modify the construction and composition of visualizations.*;
- (R1_A002) – *Adjust and arrange on-screen information according to users' tasks.*;

These converge on personalization, arrangement, and display of information. Likewise, items related to filtering were grouped:

- (R2_A001) – *Filtered: shows a subset of the original data (detailed), e.g., last 14 days or another simple rule to show a subset of the data.*;
- (R1_A002) – *Availability of filters applied to the data.*;
- (R1_A003) – *It was easy to filter the data displayed on dashboards.*;
- (R1_A007) – *Filter data at group level based on injury groups. Filter patients by name. Filter patients by group.*;

After consolidation, the 224 attributes resulted in 56 distinct elements that grounded the formulation of the patterns. A second researcher acted as technical reviewer, participating in analysis meetings to validate merges, discuss meanings and subtle differences, and ensure textual and conceptual coherence. Figure 4 illustrates the consolidation process (e.g., **R1: Ease of Use** and **R2: Easy to Use** unified). The resulting items were standardized and later expressed as *design pattern* descriptions. The complete list of the 56 requirements generated after the merging process can be accessed at the following link Table - Complete list of requirements after merging attributes_.xlsx: click here

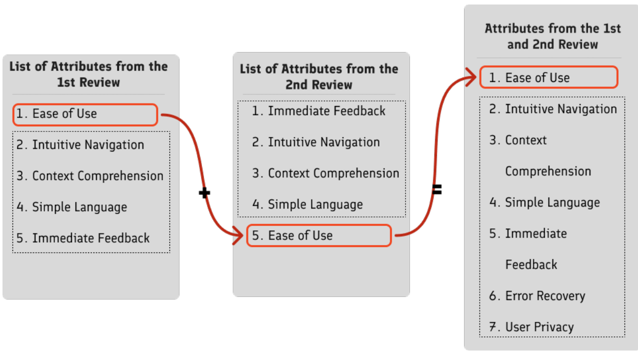


Figure 4. Process of Consolidating Attributes and Generating Design Patterns

4.3 Examples of Monitoring and Management Dashboards

To ground improvement opportunities that inform the proposed interface design patterns, we surveyed web applications for dashboard development. Selection criteria included free access, content in Portuguese, or mention in the literature review; additional websites were located via an ad hoc Google search. Ten dashboards were considered:

- DSH01 - Educational Indicators Panel - Tribunal de Contas do Estado do Acre (click here). Accessed: 24 August 2026.;
- DSH02 - Dashboard on Educational Inequalities - Lemann Foundation & IEDE (click here);
- DSH03 - ENEM 2022 Survey – Study habits in the pandemic (click here). Accessed: 24 August 2026.;
- DSH04 - INEP – ENEM Dashboards (click here);
- DSH05 - University 360º Dashboard (click here). Accessed: 24 August 2026.;

- DSH06 - Higher Education Census Statistical Dashboard (click here). Accessed: 24 August 2026.;
- DSH07 - State/Municipal Educational Dashboard (click here);
- DSH08 - Special Education Indicators Dashboard (click here). Accessed: 24 August 2026.;
- DSH09 - Observatory of Public Education in Paraná - SEED-PR (click here). Accessed: 24 August 2026.;
- DSH10 - Overview of Programs Dashboard – UFMA (click here). Accessed: 24 August 2026..

The educational domain is pertinent to this research due to its complexity in monitoring, data analysis, and decision support, and aligns with our prior publication proposing initial dashboard design patterns [Nunes *et al.*, 2023]. We also analyzed a public finance oversight panel (Tribunal de Contas) whose prominent numerical highlights, percentages, and interactive filters mirror educational dashboards. Across cases, visual clarity, information hierarchy, and suitable graphic elements proved decisive for comprehension, reinforcing principles of consistency, legibility, and intuitive interaction that guided the DP-DASHBOARD patterns. In addition, an inspection activity was conducted to verify which requirements were met by the dashboards selected as examples; this verification is summarized in Table 4, and the full version of the table can be accessed in the footnote[3].

Most publicly available examples used Microsoft Power BI, likely due to its popularity, free tier, data-integration breadth, and ease of interactive visualizations. However, platform constraints, layout customization, component changes, and element reorganization, limit aesthetic and functional refinement. Despite these constraints, adopting Power BI supported practical feasibility and methodological coherence, enabling observation of real-world usability challenges and underscoring the need for platform-agnostic design patterns emphasizing clarity, informational efficiency, and flexibility.

4.4 The Set of Design Patterns

To document the patterns, we adopted the elements suggested by [Vora, 2009]. Each pattern comprises:

- (a) **Code:** Identifier by category;
- (b) **Name:** Short, descriptive title;
- (c) **Problem:** Brief statement of the addressed issue;
- (d) **Solution:** Proposal grounded in the identified quality attribute;
- (e) **How:** Best-practice instructions and variants;
- (f) **Example:** Image of a real interface implementing the pattern.

We then instantiated each element by systematically cataloging the associated quality attributes and concrete examples extracted from the analyzed material. During this process, some quality attributes could not be directly linked to a specific design pattern, particularly those related to highly subjective constructs such: as user satisfaction or learnability when not supported by explicit visual or interaction resources, as well as attributes associated with system-level concerns, including performance and response time, which fall outside the scope of interface-level design solutions. These exclusions helped preserve the conceptual clarity and applicability of the pattern catalog.

[3]Table4 - Summary of requirements satisfied by the analyzed dashboards.xlsx : `https://doi.org/10.5281/zenodo.21121325`

Figure 5. Design Pattern LE-I01

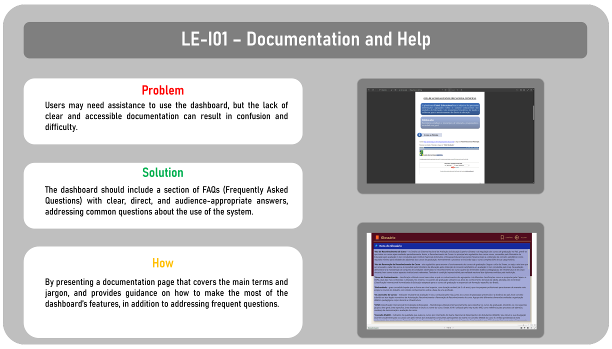


Figure 6. Design Pattern EC-I01

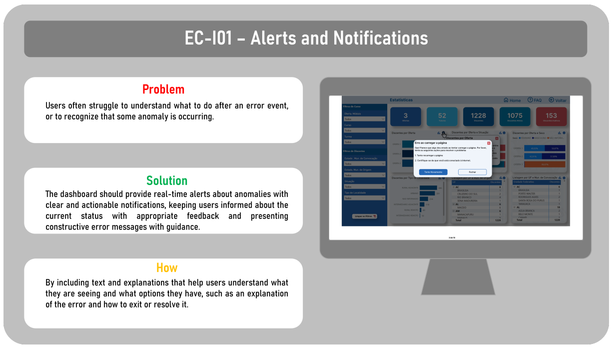
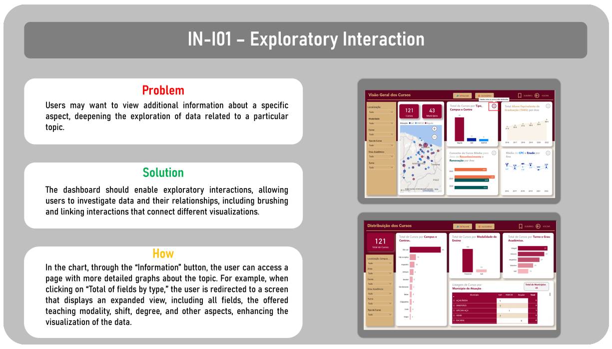


Figure 7. Design Pattern IN-I01



In total, we identified 53 design patterns distributed across categories derived from real-world dashboards, reflecting recurring solutions to common design problems in practice. Although most patterns emerged directly from the empirical analysis of surveyed dashboards, six patterns were not observed in the collected examples. Instead, we derived these patterns from well-established conceptual and theoretical contributions in the literature, particularly the works of [Sarikaya *et al.*, 2018], [Bach *et al.*, 2022], and [Rossi and Lenzini, 2020]. These patterns (PL-I01, PL-I03, MP-I02, MP-I05, VR-I04, and VR-I07) address design concerns that, while not explicitly instantiated in the analyzed dashboards, represent relevant and recommended practices for transparency, interpretation, and user guidance in dashboard design.

Figures 5, 6, and 7 present representative examples of the developed design patterns. Figure 5 illustrates the pat-

Table 4. Summary of requirements satisfied by the analyzed dashboards.

ID	Requirement	DSH10	DSH06	DSH08	DSH01	DSH09	DSH02	DSH05	DSH07	DSH03	DSH04	Occurrence
DI-I02	The dashboard must display derived values calculated from the dataset, such as trends or key performance indicators (KDIs), providing an abstraction layer over raw data.	X	X	X	X	X	X	X	X	X	X	10
IN-I02	The dashboard must allow navigation interactions, enabling users to explore different facets of information in an ordered or free manner using navigation elements such as tabs, navigation buttons, clickable links, and animated transitions.	X	X	X	X	X	X	X	X	X	X	10
OP-I04	The dashboard must follow consistent patterns, ensuring a cohesive and smooth experience, with well-integrated functionalities that support intuitive navigation and predictable task execution.	X	X	X	X	X		X	X	X	X	9
OP-I02	The dashboard must provide access to data at different aggregation levels, supporting multi-step exploration with details-on-demand, appropriate filtering, and clear navigation between meso and micro levels.	X	X	X	X	X	X			X	X	8
MP-I03	The dashboard must provide high-level descriptions of displayed data, explaining what each visualization represents and its context through labels and visual cues.	X	X	X		X	X		X			6
VR-I09	The dashboard must include visible benchmarks, thresholds, or status indicators to show when limits are exceeded and support comparison across views.				X		X	X		X	X	5
DI-I04	The dashboard must allow defining and displaying thresholds for data points, categorizing them as good, bad, or neutral automatically.				X		X					2
UT-I01	The dashboard must include a useful chart recommendation feature to help users select appropriate visualizations.											0

tern related to the FAQ (Frequently Asked Questions) section, which provides guidance on how to organize and present clear, accessible answers to users' recurring questions within the dashboard. Figure 6 highlights the pattern focused on the display of alerts and notifications, emphasizing the importance of communicating critical information efficiently and in context. Meanwhile, Figure 7 addresses user interaction with the dashboard, encompassing aspects such as data filtering, clicking, and navigation between pages. To explore the complete set of developed patterns, it is recommended to refer to the footnote[4], where a link to the booklet containing all project Design Patterns is available.

5 Evaluation and Improvements

The objective of this evaluation was to analyze the design recommendations for dashboards in order to verify whether the proposed technology meets the indicators of comprehensibility and usefulness defined according to [Gomes *et al.*, 2021]. The study was conducted in February 2025 with the participation of undergraduate students enrolled in the Software Testing course of the Computer Science Program at UFMA. All participants formally agreed to take part in the study by signing the Informed Consent Form (ICF).[5]

5.1 Experimental Setup

This research originated in the context of an industry–academia collaboration project with an energy company, in which an earlier stage of this paper applied a checklist to inspect the dashboard interface of a decision support information system with practitioners [Nunes *et al.*, 2025]. However, the consolidation and systematization of the DP-DASHBOARD catalog were only concluded after the end of that project. Although we attempted to engage industry professionals to evaluate the final version of the patterns, their participation could not be arranged within the scope and time frame of the study, reflecting a well-known challenge in empirical software engineering regarding the recruitment of practitioners [Falessi *et al.*, 2018].

A particular difficulty was finding professionals with experience in the specific context of the project to carry out the evaluation. Once the collaboration had ended, the practitioners who had worked on the project were no longer available, as they had already been reassigned to other initiatives. Likewise, specialists who understood the application domain were engaged in different projects, and their limited availability made their participation unfeasible within the study's time frame. Therefore, the evaluation was conducted with undergraduate students in the advanced stages of the Computer Science program, most of whom had prior experience in internships or software development projects. It is worth noting that this audience falls within the intended scope of the patterns, since DP-DASHBOARD was designed to support not only experienced designers but also novice and less experienced developers in building usable dashboards. In this sense, the choice of participants is aligned with the recommendation that the suitability of a sample should be judged according to the goals and target population of each specific study, rather than by the binary distinction between students and professionals [Falessi *et al.*, 2018].

To assess the feasibility and perceived value of the proposed patterns, a questionnaire was designed using Google

[4]Access the Design Patterns (Catalog_DP_Dashboard.pdf) guide:`https://doi.org/10.5281/zenodo.21121325`

[5]Informed Consent Form: `https://drive.google.com/file/d/1SpAwtIryRmA9gREoQZ3xiHUDwuRbaetq/view?usp=sharing`. Accessed: 24 August 2026.

Forms, based on the studies of [Iacob, 2011] and [Gomes *et al.*, 2021]. The Evaluation Form[6] was structured into three parts: the first section focused on collecting participants' demographic data; the second addressed the individual evaluation of the comprehensibility and usefulness of each proposed design pattern; and the third gathered an overall evaluation of the set of patterns.

We acknowledge that the questionnaire is extensive, as it includes specific questions for each of the proposed patterns, and that its length may be tiring for participants and could potentially affect the quality of the responses. To mitigate this concern, several measures were adopted to encourage careful and complete participation. Participants were motivated to engage with the evaluation and were given sufficient time to complete the form without pressure, allowing them to reflect on each pattern individually. In addition, thoughtful and well-justified responses were rewarded with extra course credit. It is important to emphasize that this reward was based solely on the robustness of the justification provided, regardless of whether the response was positive or negative, so that participants were not penalized for expressing critical opinions and were encouraged to substantiate their assessments. These strategies aimed to reduce the impact of the questionnaire's length on the reliability of the collected data.

Regarding the **comprehensibility** aspect, each participant was asked: *"How do you evaluate the comprehensibility (ease of understanding) of each pattern?"*. For the **usefulness** aspect, the question was: *"How do you evaluate the usefulness of each pattern?"*. In addition, the questionnaire included questions about the overall usefulness of the patterns in: (1) identifying problems to be avoided in dashboard development; (2) seeking solutions to problems encountered during the development process; and (3) understanding interface design proposals focused on Usability and User Experience (UX).

The experiment was conducted in person during the regular class schedule under constant supervision to ensure the absence of external interference or communication among participants. The instructions were designed to minimize potential biases, with strict control of entry and exit from the classroom and continuous monitoring throughout the activity.

During the session, the students were introduced to the DP-DASHBOARD design patterns, which describe best practices and recurring solutions aimed at improving usability and user experience in dashboards. Based on these patterns, participants were guided to propose corrections and enhancements to the analyzed dashboard *Diversa – Special Education Indicators Dashboard* [7], developing low-fidelity prototypes that illustrated possible solutions according to the principles presented in the patterns.

This methodological approach allowed the students to understand, in a practical and applied way, how usability and UX issues could be addressed through the proposed design guidelines, promoting an integrated experience of pattern-oriented redesign and usability improvement.

At the end of the activity, each participant submitted their proposed improvements and completed the Design Patterns Evaluation Form, which aimed to gather perceptions regarding the clarity, applicability, and relevance of the DP-DASHBOARD patterns. Of the 21 students who attended the session, two chose not to take part in the research, resulting in 19 participants who carried out the initial analysis of the dashboard. Of these, one participant completed only the initial stage and did not conclude the pattern-oriented redesign; therefore, 18 participants completed the redesign activity with the DP-DASHBOARD patterns and fully completed the post-activity evaluation. All results reported in this section refer to these 18 complete responses.

5.2 Quantitative analysis

To provide a more rigorous account of the quantitative data and to examine whether the participants' background influenced their perception of the patterns, each participant's ordinal answers were converted into a numerical scale (Very comprehensible/Very useful = 4; Comprehensible/Useful = 3; Slightly comprehensible/Slightly useful = 2; Not comprehensible/Not useful = 1). For each of the 18 participants who completed the redesign, we computed the mean comprehensibility and mean usefulness across all evaluated patterns, obtaining a single comprehensibility and usefulness score per participant. All analyses were performed in IBM SPSS Statistics, adopting a significance level of $\alpha = 0.05$.

Table 5. Descriptive statistics for comprehensibility and utility, including mean, median, standard deviation, standard error, and minimum and maximum values.

Dimension	Group	N	Mean	Median	SD	SE	Min	Max
Compreh.	Overall	18	3.52	3.63	0.341	0.080	2.79	3.91
	Low experience	12	3.47	3.61	0.378	0.109	2.79	3.87
	Medium experience	6	3.64	3.68	0.240	0.098	3.21	3.91
Usefuln.	Overall	18	3.50	3.63	0.428	0.101	2.68	4.00
	Low experience	12	3.44	3.61	0.477	0.138	2.68	4.00
	Medium experience	6	3.62	3.68	0.316	0.129	3.17	4.00

Considering the whole sample, the patterns were perceived positively: comprehensibility reached a mean of 3.52 (SD = 0.34; median = 3.63) and usefulness a mean of 3.50 (SD = 0.43; median = 3.63) on the 1–4 scale. These values indicate that, on average, participants rated the patterns between "comprehensible/useful" and "very comprehensible/very useful". Tables 5 report the descriptive statistics for the whole sample and by development experience, where N is the number of participants, SD the standard deviation, SE the standard error of the mean, and Min and Max the minimum and maximum observed scores.

Considering the context of this quantitative analysis, we sought to understand whether the collected data established any relationship between the participants' experience and

[6] Design Patterns Evaluation Form in Portuguese: `https://doi.org/10.5281/zenodo.21121325`

[7] Diversa – Special Education Indicators Dashboard: `https://diversa.org.br/indicadores/`, Accessed: 24 August 2026.

their perception of the patterns. To this end, the independent variable, named *Experience (XP Dev)*, is qualitative ordinal, defined to indicate the participants' level of experience, with three possible groups: *Low*, *Medium*, and *High* [Shankar and Singh, 2014]. To enable the statistical analysis, this variable was treated quantitatively, assigning the value 0 to the Low-experience group, 1 to the Medium-experience group, and 2 to the High-experience group. The experience dimension used was the participants' *development experience*, collected in the characterization form, since it was the most balanced dimension (Low, $n = 12$; Medium, $n = 6$); the specific dashboard-development experience was not adopted as the main grouping factor because of its imbalance (Low, $n = 14$; Medium, $n = 2$; High, $n = 2$). The dependent variables *Comprehensibility* and *Usefulness* correspond to the per-participant mean scores (1–4 scale). The data are unpaired, as the participant groups are independent, with no repetition of individuals across measurements.

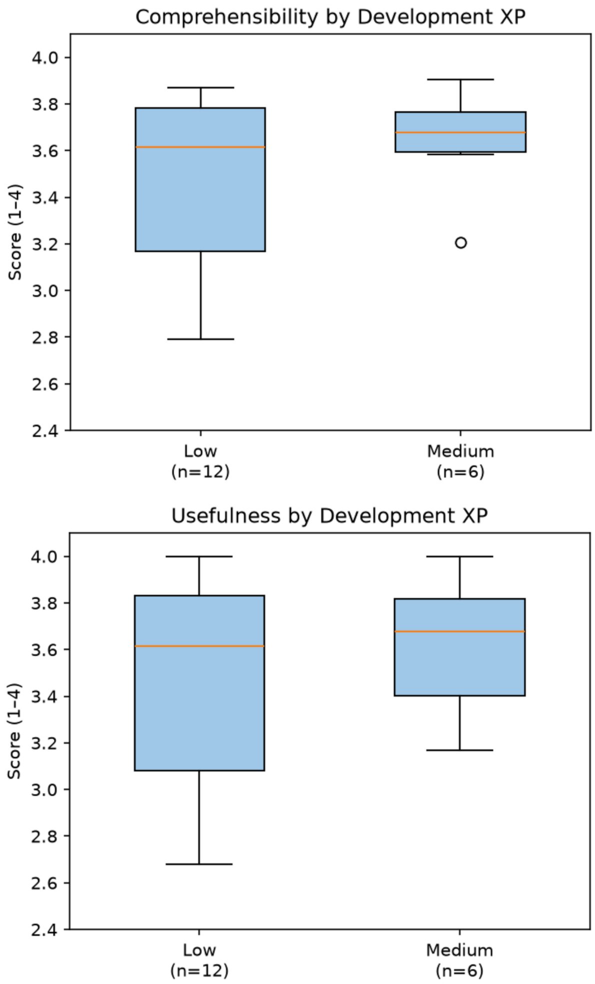
To verify whether the data met the normality assumption, the Shapiro–Wilk test was applied, as recommended for samples with fewer than 50 observations. The results were $W = 0.876$, $p = 0.022$ for Comprehensibility and $W = 0.903$, $p = 0.065$ for Usefulness. Since the significance value for Comprehensibility is below the critical level of 0.05, this variable departs from a normal distribution; therefore, the data were treated as non-parametric. Based on this, group comparisons were performed with the Mann–Whitney U test, the non-parametric counterpart of the t-test, which is appropriate for comparing two independent groups with small samples and ordinal-derived data. The hypotheses established for each dependent variable were:

- H_0: The distributions of the scores (comprehensibility/usefulness) are equal between the groups with different levels of development experience.
- H_1: The distributions of the scores differ between the groups with different levels of development experience.

The Mann–Whitney test applied to Comprehensibility resulted in $U = 29.0$, $Z = -0.66$, exact $p = 0.553$ (Low: median = 3.61; Medium: median = 3.68), and the test applied to Usefulness resulted in $U = 28.0$, $Z = -0.75$, exact $p = 0.494$ (Low: median = 3.61; Medium: median = 3.68). As both significance values are above the critical level of 0.05, no statistically significant differences were found between the groups. Therefore, the null hypothesis (H_0) was retained for both variables. As a complementary check, the same test applied using the specific dashboard-development experience (comparing the Low group, $n = 14$, with the participants who reported some experience, $n = 2$) also yielded no significant differences (comprehensibility $U = 3.0$, $Z = -1.75$, exact $p = 0.100$; usefulness $U = 4.0$, $Z = -1.59$, exact $p = 0.150$), although this particular comparison should be read with caution given the strong group imbalance.

Figure 8 presents the distribution of the comprehensibility and usefulness scores by development experience group. The boxplots illustrate the pattern indicated by the statistical tests: the medians of the two groups are close in both dimensions (3.61 for the Low-experience group and 3.68 for the Medium-experience group), and the interquartile ranges overlap substantially. The Low-experience group shows greater dispersion, with scores ranging from 2.79 to 3.87 for comprehensibility and from 2.68 to 4.00 for usefulness, whereas the Medium-experience group presents more concentrated ratings, with a single lower outlier (3.21) in the comprehensibility dimension. Notably, even the lowest observed scores remain above the midpoint of the 1–4 scale, indicating that no participant, regardless of experience level, evaluated the patterns negatively on average. This visual evidence reinforces the outcome of the Mann–Whitney tests: the slightly higher and more homogeneous ratings of the more experienced participants do not constitute a systematic difference between the groups, and the positive perception of the DP-DASHBOARD patterns holds across both experience levels.

Figure 8. Boxplots of comprehensibility and usefulness scores (1–4 scale) by development experience (Low, $n = 12$; Medium, $n = 6$)



Additionally, a Spearman rank correlation analysis was performed between the ordinal experience level and the scores, as the non-parametric counterpart of the Pearson correlation. Considering the development-experience level, the coefficients were $\rho = 0.16$ ($p = 0.528$) for Comprehensibility and $\rho = 0.18$ ($p = 0.470$) for Usefulness. Considering the specific dashboard-development experience, the coefficients were $\rho = 0.08$ ($p = 0.745$) for Comprehensibility and $\rho = 0.26$ ($p = 0.300$) for Usefulness. All correlations were weak and statistically non-significant. In addition, comprehensibility and usefulness were strongly correlated with each other ($\rho = 0.90$, $p < 0.001$), indicating that patterns perceived as more comprehensible also tended to be perceived as more useful.

Taken together, these findings indicate that, although participants with greater experience presented slightly higher scores (as observed in the descriptive statistics), there was no statistical evidence that development experience significantly affected the comprehensibility or usefulness attributed to the patterns. In other words, participants evaluated the DP-DASHBOARD patterns positively regardless of their prior experience, and no systematic difference was found between novice and more experienced participants.

The objective responses obtained formed the basis for the analysis of the technological acceptance of the patterns, focusing on the constructs of *Comprehensibility* and *Perceived Usefulness*, as presented in Table 6. These results reflect the participants' judgments regarding the ease of understanding and effectiveness of the patterns in addressing usability and UX problems in dashboards, demonstrating how the design principles systematized by the DP-DASHBOARD contribute to guiding practical improvements in decision-support interfaces.

To complement the evaluation of the DP-DASHBOARD artifact, a specific form was administered to analyze participants' perceptions of the comprehensibility and usefulness of the design patterns (DP-DASHBOARD). The results presented in Table 6 indicate generally positive acceptance of the patterns, although a few exceptions warrant attention.

The results indicate an overall positive perception of the DP-DASHBOARD patterns. The strongest evaluations were concentrated on patterns related to data description, table layout, chart selection, documentation, and color specification. Conversely, a small group of patterns, especially those related to emotional colors, chart recommendation, data sets, and visualization interaction, received lower comprehensibility or usefulness ratings and were therefore prioritized for refinement.

- **MP-I03 – Data Description**: Rated as very comprehensible by 14 participants and very useful by another 14, with no negative evaluations.
- **PL-I02 – Table Layout**: Received 15 ratings as very comprehensible and 12 as very useful, with no negative evaluations at all.
- **VR-I05 – Chart Types** was also widely recognized as both comprehensible and useful.

Regarding comprehensibility, three items were marked by at least one participant as *not comprehensible*: **EU-I01 – Flexible Accessibility**, **DI-I06 – Data Set**, and **UT-I01 – Recommend Chart**. Participants' comments were consulted to identify the reasons for these evaluations, but no direct explanations were provided. One noteworthy point is the evaluation of **OP-I01 – Visualization Interaction** and **SP-I01 – Hierarchical Structure**, which were considered slightly comprehensible by 6 and 5 participants, respectively. Although no specific descriptive comments were recorded for these items, both were flagged by four inspectors as priorities for revision in the questionnaire responses.

The analysis of responses regarding the usefulness of the design patterns (DP-DASHBOARD), presented in Table 7, shows that most patterns were well received by the participants, with particular emphasis on those that achieved consistently high evaluations. The **MP-I03 – Data Description** pattern received 14 ratings as "very useful" and no negative evaluations, also being highly comprehensible according to previous analyses. Likewise, the patterns **CO-I03 – Specific Colors** and **LE-I01 – Documentation and Help** received, respectively, 14 and 15 ratings as "very useful," and were also considered easy to understand, suggesting good integration between textual definition, visual representation, and context of use.

Other patterns also stood out positively, such as **PL-I02 – Table Layout**, **VR-I05 – Chart Types**, and **DI-I06 – Data Set**, which showed broad acceptance regarding usefulness, even though some received isolated lower scores in comprehensibility. For instance, **DI-I06**, despite being considered "very useful" by 12 participants and receiving no negative evaluations in this regard, was rated as "not comprehensible" by one participant.

On the other hand, some patterns require greater attention regarding the clarity of their formulation. The **CO-I05 – Emotional Colors** pattern received the highest number of negative evaluations, with five ratings as "slightly useful" and one as "not useful." This result aligns with previous observations of its low comprehensibility, indicating that participants may have difficulty understanding the purpose or practical application of using emotionally charged colors in dashboards. A similar situation occurred with the **UT-I01 – Recommend Chart** pattern, which also received four "slightly useful" ratings and was considered "not comprehensible" by at least one participant. These cases point to the need for deeper revisions of the descriptive texts and images associated with these patterns.

Based on the analysis of Questions 11 and 12 from the DP-DASHBOARD design patterns evaluation form, a strong consensus emerged regarding the relevance of the proposed patterns. In Question 11, where each participant was asked to select five patterns considered priorities in the dashboard development process, there was a high recurrence of patterns such as LE-I01 (Documentation and Help), IN-I02 (Navigation), IN-I03 (Information Display), and EC-I02 (Functionality Explanation). These patterns stood out for addressing core aspects of comprehensibility, user support, and clarity in information presentation, factors directly related to usability and user experience. Additionally, patterns such as MP-I03 (Data Description), UT-I01 (Recommend Chart), and CO-I02 (Color Palette) were also frequently mentioned, reinforcing the importance of visual and explanatory best practices in the design of decision-support dashboards.

In Question 12, which investigated whether any pattern should be removed from the list, there was a high level of agreement among participants regarding the overall adequacy of the set. Thirteen out of eighteen participants explicitly stated that no pattern should be removed, representing 72% of the total. Among the few removal suggestions, the most cited were VR-I10 and VR-I11 (Color Distractions), CO-I05 (Emotional Colors), PL-I03 (Layered Layout), and MP-I05 (Annotation and Highlight), suggesting that some evaluators perceived conceptual overlap among certain visual patterns or low practical applicability in specific dashboard contexts.

Table 6. Results on the comprehensibility of the DP-DASHBOARD design patterns

	Comprehensibility			
	Very comprehensible	Comprehensible	Slightly comprehensible	Not comprehensible
LE-I01 – Documentation and Help	9	7	2	0
LE-I02 – Expressing Nuances	9	5	4	0
LE-I03 – Functionality Explanation	13	3	2	0
EC-I01 – Alerts and Notifications	11	4	3	0
EC-I02 – Functionality Explanation	11	4	3	0
EU-I01 – Flexible Accessibility	9	7	1	1
FL-I01 – Customize Appearance	11	6	1	0
IN-I01 – Exploratory Interaction	8	6	4	0
IN-I02 – Navigation	10	7	1	0
IN-I03 – Information Display	10	7	1	0
IN-I04 – Information Display	9	7	2	0
OP-I01 – Visualization Interaction	8	4	6	0
OP-I02 – Level of Detail	11	4	3	0
OP-I03 – Dynamic Interactions	8	7	3	0
OP-I04 – Consistent Patterns	10	6	2	0
CO-I01 – Distinct Colors	11	7	0	0
CO-I02 – Color Palette	10	8	0	0
CO-I03 – Specific Colors	11	7	0	0
CO-I04 – Semantic Colors	11	7	0	0
CO-I05 – Emotional Colors	11	5	2	0
SS-I01 – Interactive Controls	11	5	2	0
SS-I02 – Multiple Pages	11	4	3	0
SS-I03 – Screen Space	13	4	1	0
SP-I01 – Hierarchical Structure	7	6	5	0
DI-I01 – Representative Individual Values	8	8	2	0
DI-I02 – Derived Values	7	8	3	0
DI-I03 – Interactive Controls	12	5	1	0
DI-I04 – Limits	11	4	3	0
DI-I05 – Aggregated Data	11	7	0	0
DI-I06 – Data Set	13	4	0	1
PL-I01 – Open Layout	12	6	0	0
PL-I02 – Table Layout	15	3	0	0
PL-I03 – Layered Layout	9	8	1	0
PL-I04 – Grouped Layout	12	5	1	0
PL-I05 – Schematic Layout	12	3	3	0
MP-I01 – Information Source	13	5	0	0
MP-I02 – Disclaimer	9	6	3	0
MP-I03 – Data Description	14	4	0	0
MP-I04 – Update	12	6	0	0
MP-I05 – Annotation and Highlight	11	7	0	0
VR-I01 – Highlighted Numbers	12	6	0	0
VR-I02 – Trend Arrows	12	5	1	0
VR-I03 – Pictograms	10	7	1	0
VR-I04 – Progress Bar	12	6	0	0
VR-I05 – Chart Types	14	4	0	0
VR-I06 – Raw Data	11	5	2	0
VR-I07 – Text List	14	4	0	0
VR-I08 – Relevant Metrics	13	3	2	0
VR-I09 – Benchmarks	11	6	1	0
VR-I10 – Color Distractions	13	5	0	0
VR-I11 – Illustrative Examples	14	3	1	0
VR-I12 – Timeline	11	7	0	0
UT-I01 – Recommend Chart	12	4	1	1

Even so, the limited number of removal suggestions demonstrates that the set of patterns was widely validated by participants, reflecting coherence, relevance, and applicability of the DP-DASHBOARD elements in guiding best design practices for interactive and informative dashboards.

Finally, beyond the correlation between usefulness and comprehensibility, the analysis of Questions 11 and 12 revealed an overall positive perception regarding the maintenance and relevance of the DP-DASHBOARD design patterns. The predominance of responses indicating that no pattern should be removed demonstrates the conceptual consistency and practical pertinence of the proposed set, validating its usefulness as a support instrument for dashboard development. The few removal suggestions were concentrated on visual or aesthetic patterns considered less applicable or thematically overlapping, indicating specific opportunities for refinement but without compromising the overall structure of the catalog. Thus, participants recognized the importance and scope of the patterns, reinforcing the suitability of DP-DASHBOARD as a solid foundation to guide clearer, more consistent design practices aligned with real user needs.

5.3 Qualitative Analysis

For the qualitative evaluation, we analyzed the open-ended responses from the design pattern assessment form to understand difficulties in using the artifact and to identify suggestions for improving the DP-DASHBOARD design patterns. A thematic analysis (clarity, applicability, practical relevance) indicates an overall positive perception of the patterns, with comments reviewed individually to highlight strengths, limitations, and opportunities for refinement.

User-centered support and practical guidance. Inspectors emphasized that the patterns effectively guide dashboard design toward user needs, promoting clarity, accessibility, and data understanding: "*These patterns support*

Table 7. Results on the usefulness of the DP-DASHBOARD design patterns

	Usefulness			
	Very useful	Useful	Slightly useful	Not useful
LE-I01 – Documentation and Help	15	2	1	0
LE-I02 – Expressing Nuances	11	7	0	0
LE-I03 – Functionality Explanation	13	5	0	0
EC-I01 – Alerts and Notifications	10	6	2	0
EC-I02 – Functionality Explanation	13	5	0	0
EU-I01 – Flexible Accessibility	10	6	2	0
FL-I01 – Customize Appearance	11	2	5	0
IN-I01 – Exploratory Interaction	13	4	1	0
IN-I02 – Navigation	12	5	1	0
IN-I03 – Information Display	12	5	1	0
IN-I04 – Information Display	12	6	0	0
OP-I01 – Visualization Interaction	12	6	0	0
OP-I02 – Level of Detail	12	4	2	0
OP-I03 – Dynamic Interactions	12	3	3	0
OP-I04 – Consistent Patterns	13	5	0	0
CO-I01 – Distinct Colors	13	5	0	0
CO-I02 – Color Palette	11	4	3	0
CO-I03 – Specific Colors	14	3	1	0
CO-I04 – Semantic Colors	10	5	3	0
CO-I05 – Emotional Colors	6	6	5	1
SS-I01 – Interactive Controls	11	5	1	1
SS-I02 – Multiple Pages	9	7	2	0
SS-I03 – Screen Space	13	4	1	0
SP-I01 – Hierarchical Structure	9	9	0	0
DI-I01 – Representative Individual Values	12	3	3	0
DI-I02 – Derived Values	9	6	3	0
DI-I03 – Interactive Controls	12	5	1	0
DI-I04 – Limits	9	7	2	0
DI-I05 – Aggregated Data	10	7	1	0
DI-I06 – Data Set	12	6	0	0
PL-I01 – Open Layout	9	6	2	1
PL-I02 – Table Layout	12	3	3	0
PL-I03 – Layered Layout	8	5	5	0
PL-I04 – Grouped Layout	11	3	4	0
PL-I05 – Schematic Layout	13	4	1	0
MP-I01 – Information Source	13	4	1	0
MP-I02 – Disclaimer	13	2	3	0
MP-I03 – Data Description	14	4	0	0
MP-I04 – Update	13	5	0	0
MP-I05 – Annotation and Highlight	10	6	1	1
VR-I01 – Highlighted Numbers	11	5	2	0
VR-I02 – Trend Arrows	10	6	2	0
VR-I03 – Pictograms	9	6	2	1
VR-I04 – Progress Bar	10	5	3	0
VR-I05 – Chart Types	10	7	0	1
VR-I06 – Raw Data	9	7	2	0
VR-I07 – Text List	10	7	1	0
VR-I08 – Relevant Metrics	13	4	1	0
VR-I09 – Benchmarks	11	5	2	0
VR-I10 – Color Distractions	6	7	4	1
VR-I11 – Illustrative Examples	9	4	4	1
VR-I12 – Timeline	10	7	1	0
UT-I01 – Recommend Chart	10	4	4	0

dashboards focused on users' needs... [I19]"; "*They help developers with a guide to build an interface users can easily understand [I09].*" The structured template, problem, solution, how-to, and example was repeatedly praised for easing understanding and application: "*The structure is well built… you see why the pattern exists and how to resolve it [I02],*" and "*Problem, solution, how-to, and an example are essential [I18].*" Participants also viewed the patterns as diagnostic tools that help locate and fix issues: "*They present solutions for identified defects and speed up correction [I03],*" "*They help start a dashboard and correct possible defects [I12].*" As a practical guide, they assist both novices and experienced designers: "*… these patterns strongly guide dashboard design toward user needs with direct solutions [I14]*"; "*The designer can use them as a guide [I11]*"; "*They work as assistance to developers with proposed solutions [I04].*"

UX improvements and coverage. Participants highlighted clearer layouts, intuitive navigation, and consistent visuals: "*They ensure a clear layout, intuitive navigation, and accessible, comprehensible data [I19],*" "*Visual consistency colors, layouts, hierarchy, supports a pleasant experience [I08].*" They also noted broad coverage colors, personalization, layout, feedback, data semantics: "*… the patterns cover crucial aspects like layout, colors, real-time feedback, and clarity [I06],*" "*They consider colors, element placement, and data malleability (personalization) [I15].*" Clear guidance reduces rework and focuses effort: "*They make the problem and direct solutions explicit, avoiding rework and focusing on what matters [I14].*"

Main improvement opportunities. Recurrent suggestions include: (i) **security and data privacy** guidance for sensitive information; (ii) **high data volume and real-time performance** scenarios; (iii) **user profiles and access layers**; (iv) **responsiveness/mobile** patterns and limits for information density to avoid cognitive overload. Participants asked for more cohesive visual examples (ideally one reference dashboard), easy access to documentation during evaluation (e.g., contextual links/summaries), and additional fields per pattern (application context, limitations, risks) to aid adaptation across domains: "*Add application context… possible limitations or risks [I06]*," "*Show the rationale for the choice [I14]*." They recommended expanding **visual accessibility** (e.g., color-blind support via textures/high contrast) "*Add accessibility, like color blindness [I15]*" reviewing possible **redundancy** among color-related patterns ("*Redundant… could be one [I13][I08]*"), and reassessing **case-specific** patterns (e.g., pictograms, raw data) as optional/ situational: "*Do not apply to most scenarios [I03]*." Some also noted survey fatigue ("*Tiring form… [I17]*") and, conversely, expressed sufficiency: "*Wouldn't add [I10, I11]*," "*All are useful [I12]*," "*Nothing to add [I09, I05, I03, I04, I13, I16]*."

Items needing clarification. A few patterns received low comprehensibility (**EU-I01 – Flexible Accessibility**, **DI-I06 – Data Set**, **UT-I01 – Recommend Chart**) and, in the case of **CO-I05 – Emotional Colors**, low ratings in both comprehensibility and usefulness, suggesting that descriptions and/or examples require clearer intent and application. Topics such as security, encryption, and performance are important but extend beyond interface-oriented design patterns into architectural/technical domains. Accordingly, these were flagged for future work alongside mobile responsiveness and accessibility enhancements. Color-related guidance was reviewed to align more explicitly with visual accessibility recommendations.

In sum, while the current patterns are widely regarded as complete, well-structured, and practically helpful, the feedback points to focused refinements such, security/privacy context, performance under load, role-based views, mobile responsiveness, and information density that can strengthen DP-DASHBOARD as a comprehensive, accessible, and contextually adaptable framework for user-centered dashboard design, without altering the intent or scope of the existing catalog.

6 Refinement of Design Patterns

The evaluation form for the DP-DASHBOARD technology included open-ended questions aimed at collecting suggestions for modifications and improvements to the presented design patterns. The qualitative analysis revealed the need for targeted adjustments to certain patterns, primarily concerning redundancy, clarity, and applicability.

One of the most frequently mentioned patterns was **VR-I10 – Color Distractions**, cited by multiple evaluators (I08, I13, I14, and I17) as redundant, repetitive, or unclear in its description. As noted by I08, "*some seem repeated in their solutions... they could be merged into one*." Similarly, I13 classified the pattern as redundant, I14 suggested reviewing overlaps with related patterns, and I17 considered it irrelevant in its original form.

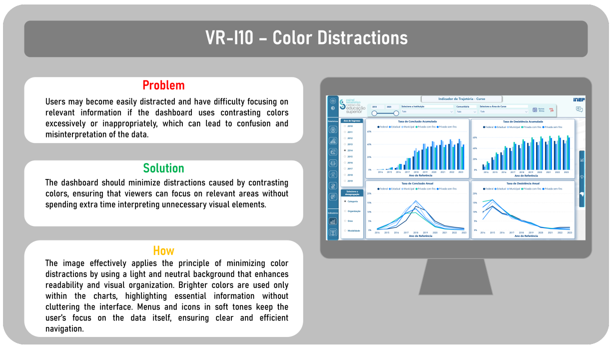


Figure 9. Design Pattern VR-I10 (previous version)

In response to these observations, both the textual description and visual representation of the pattern were reformulated to make it more concise, comprehensible, and distinct from other color-related patterns. Figure 9 presents the updated version of the pattern, highlighting the implemented improvements in structure and content, while Figure 10 displays the previous version for direct comparison between the revisions and the original format.

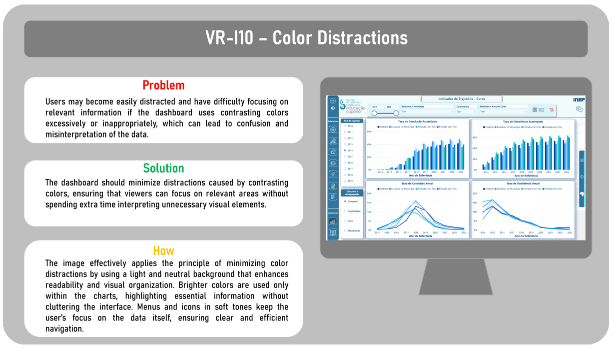


Figure 10. Design Pattern VR-I10 (updated version)

In addition, several other patterns were revised based on participant feedback. The items **EU-I01 – Flexible Accessibility**, **DI-I06 – Data Set**, **UT-I01 – Recommend Chart**, **OP-I01 – Visualization Interaction**, and **SP-I01 – Hierarchical Structure** had their descriptions and illustrations refined, with visual highlights (in red) used to indicate the modifications applied, as shown in Figure 11.

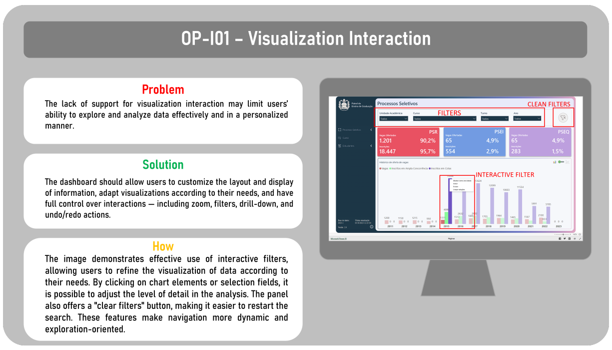


Figure 11. Design Pattern OP-I01 (updated version)

Patterns such as **PL-I02 – Table Layout**, **VR-I05 – Chart Types**, and again **DI-I06 – Data Set** also received negative evaluations regarding their usefulness, prompting improvements to their explanatory content and visual examples. Notably, the pattern **CO-I05 – Emotional Colors** obtained the highest number of low-utility ratings, with five participants marking it as "somewhat useful" and one as "not useful," indicating a clear need for refinement.

Although there were no direct comments specifying the expected changes, the overall feedback suggested the importance of systematically reviewing these patterns from a technical and design perspective to enhance their clarity, consistency, and practical relevance. This systematic revision process allowed a reassessment of the coherence, applicability, and alignment of the design patterns with the usability and user experience goals defined in the study.

A similar situation was observed for **UT-I01 – Recommend Chart**, which also received negative evaluations. Accordingly, substantial adjustments were made to its textual description and visual examples to clarify its intent and practical application. The complete set of updated design patterns resulting from this refinement process is available in the supplementary material.[8]

7 Discussion and Limitations

The literature review highlighted two central points: (i) dashboard evaluation still relies mostly on generic heuristics (e.g., Nielsen) and standardized instruments (e.g., SUS), which scarcely capture specifics such as multiple coordinated views, cognitive overload, and visual consistency across panels; and (ii) studies on design patterns for dashboards remain fragmented, with useful taxonomies and collections that are not always documented with the full problem–context–solution structure and are rarely validated empirically in the domain. This scenario reinforced the gap for actionable, domain-specific guidelines capable of linking quality attributes (learnability, utility, operability, visual representation, metainformation, layout, and interaction) to reusable solutions that guide both design and inspection.

Methodologically, the study addressed this gap by consolidating quality attributes mapped in the literature and translating them into a structured catalog of patterns (**DP-DASHBOARD**), documented according to classic pattern elements (code, name, problem, solution, how, and example). The process involved an exploratory study to collect and refine 224 attributes, semantic merging into 56 elements, and the derivation of 53 patterns distributed across categories consistent with the dashboard design space. The strategy favored technological neutrality (agnostic to tools such as Power BI) and conceptual traceability (explicit linkage between quality requirement and design solution), fostering reuse and academic auditability. This combination of theoretical synthesis and practical formalization aimed to maximize transferability to educational and decision-support contexts.

In the evaluation, conducted in February 2025 with 21 students (18 complete responses), the patterns were judged for *Comprehensibility* and *Perceived Usefulness*. Overall, acceptance was positive, with emphasis on items such as *Data Description*, *Table Layout*, and *Chart Types*, while some (e.g., *Emotional Colors*, *Recommend Chart*) required textual and example revisions. Open-ended responses indicated practical gains in layout clarity, navigation, and visual consistency, while suggesting future extensions (advanced accessibility, privacy/security, performance under high data volume, mobile responsiveness, and reduction of redundancies among color patterns). In summary, the evaluation corroborates the viability of **DP-DASHBOARD** as an artifact supporting user-centered design and outlines a clear roadmap of incremental refinements, preserving the catalog's coherence and expanding its applicability in real dashboard projects.

Some limitations must be acknowledged when interpreting the results. First, regarding *external validity*, the evaluation was conducted with undergraduate students from a single institution rather than industry practitioners. As discussed in Section 5, this was a consequence of the conclusion of the industry project in which this research originated [Nunes *et al.*, 2025] and of the difficulty of recruiting professionals within the time frame of the study. Nevertheless, the participants were students in advanced semesters, many with internship or project experience, a profile consistent with the novice and less experienced developers who constitute part of the target audience of the DP-DASHBOARD patterns. Following [Falessi *et al.*, 2018], we understand that the suitability of participants should be assessed in light of the study goals and of the portion of the developer population they represent; even so, the results should be interpreted as preliminary evidence of acceptance, and an evaluation with experienced industry practitioners remains necessary to broaden the generalization of the results.

Second, regarding *conclusion validity*, the sample size (21 participants, 18 complete responses) does not support inferential statistical analyses with adequate power. For this reason, and because the evaluation was designed as a feasibility study focused on the constructs of comprehensibility and perceived usefulness [Gomes *et al.*, 2021], the quantitative data were analyzed descriptively, using frequency distributions on ordinal scales, and were triangulated with the qualitative analysis of open-ended responses. We recognize that a summative evaluation with a larger sample, hypothesis testing, and appropriate statistical measures (e.g., inter-rater agreement and non-parametric tests) is necessary to strengthen the evidence, and this is planned as future work. Finally, the evaluation addressed the perception of the patterns rather than their effective use in real development projects, which constitutes another avenue for longitudinal studies with practitioners. These forthcoming evaluations with industry practitioners, to be conducted within the scope of ongoing graduate research, are planned to be submitted for prior appreciation by a Research Ethics Committee (CEP), given the broader institutional engagement and participant recruitment anticipated at that stage.

8 Conclusions

The present study sought to contribute to the improvement of the quality of intelligent dashboards by proposing and evaluating a structured set of design recommendations focused on usability and user experience (UX). Based on the analysis of quality attributes identified in the literature, the research led to the creation of a catalog of interface design patterns, the DP-DASHBOARD, which provides guidelines, recommendations, and visual examples intended to assist developers

[8]Updated DP-DASHBOARD catalog: `https://doi.org/10.5281/zenodo.21121325`

in designing dashboards that are clearer, more efficient, and user-centered.

The DP-DASHBOARD patterns were developed to address recurring design challenges in decision-support dashboards, such as information clarity, interaction consistency, accessibility, and effective visual communication. Each pattern was documented with an identifier, name, problem description, proposed solution, implementation guidance, and examples of real dashboards that illustrate its application in practice. The empirical evaluation conducted with computer science students demonstrated that the proposed patterns were well accepted, being perceived as useful and understandable by the majority of participants. The feedback collected highlighted the patterns' contribution to guiding design decisions, supporting the identification of interface issues, and promoting solutions aligned with usability principles.

The results also revealed that the DP-DASHBOARD patterns function as practical tools for both novice and experienced designers, serving as a reference framework for organizing and structuring dashboard interfaces. The participants emphasized that the patterns facilitate comprehension through their standardized structure presenting, the problem, solution, and implementation examples and that they enhance learning by offering explicit, actionable design guidance. Furthermore, the patterns were recognized as effective in improving the user experience, particularly in aspects related to navigation, layout organization, and visual consistency.

Despite the positive results, some opportunities for refinement were identified. A few patterns, such as those related to color use and data representation, required adjustments to reduce redundancy, clarify their descriptions, or improve visual examples. Patterns like **VR-I10 – Color Distractions** and **CO-I05 – Emotional Colors** were revised to ensure conceptual distinctiveness and clearer guidance. Others, including **EU-I01 – Flexible Accessibility**, **UT-I01 – Recommend Chart**, and **DI-I06 – Data Set**, were reformulated to strengthen their explanations and visual applicability. These refinements aimed to enhance the patterns' clarity and alignment with the study's usability and UX objectives.

In summary, the research achieved its goal of proposing a systematic and empirically validated framework for improving dashboard design practices. The DP-DASHBOARD patterns constitute a concrete contribution to the field of software engineering and human–computer interaction, supporting the development of decision-support dashboards that are not only functional and visually coherent but also accessible and user-centered.

Future work will focus on expanding the empirical validation of the DP-DASHBOARD with industry practitioners, including UX professionals, designers, and developers of decision support systems. Since the industrial project in which this research originated [Nunes *et al.*, 2025] was concluded before the consolidation of the catalog, this evaluation with professionals remains an open gap and is already planned as an extension of this study. In particular, we intend to expand the sample size considerably, both to include a broader and more diverse set of participants and to enable the use of inferential statistical measures, thereby strengthening the validity and generalizability of the findings. Additional efforts may also include enriching the catalog with real-world dashboard examples, integrating adaptive patterns for mobile and high-data-volume contexts, and exploring the creation of *anti-patterns* that illustrate design practices to be avoided.

Ultimately, this research demonstrates the potential of design patterns as an effective methodological resource for guiding the creation of intuitive, consistent, and user-oriented dashboards, contributing to the advancement of usability and UX design practices in interactive data visualization systems.

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Declarations

Authors' Contributions

Kennedy Nunes contributed to the Conceptualization, Methodology, Investigation, Data Curation, Writing – Original Draft, and Writing – Review & Editing. Sabryna Araujo, Vitor Sousa, Davi Viana, and Walter Nakamura contributed to the Validation, Investigation, and Writing – Review & Editing. Luis Rivero contributed to the Supervision, Conceptualization, and Methodology. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests regarding the publication of this paper.

Further relevant information

Use of Artificial Intelligence Tools: The authors acknowledge the use of generative Artificial Intelligence tools, including Claude, to support grammar refinement, academic writing improvement, LaTeX consistency checking, and preliminary verification of bibliographic references during the preparation of this manuscript. These tools were not used to collect empirical data, administer the questionnaire, analyze participants' responses, or make methodological decisions. All AI-assisted suggestions were critically reviewed, validated, and edited by the authors, who take full responsibility for the final content, arguments, results, and references presented in this manuscript.

Ethical Considerations: This study evaluated the proposed dashboard through a questionnaire administered to participants, who provided the minimum amount of data possible. The research did not involve clinical procedures, invasive interventions, sensitive personal data, or experiments that could expose participants to risk. The participants voluntarily answered the questionnaire and took part in the analysis of the proposed dashboard. The information used in the analysis was aggregated and abstracted to avoid identifying individual participants or confidential details of real cases. Based on the nature and scope of the study, the authors understood that formal approval by a Research Ethics Committee was not required. Nevertheless, the study followed ethical principles of voluntary participation, confidentiality, anonymity, and responsible handling of information.

Citation Diversity Statement: In compiling the references for this paper, we sought to include a diverse and relevant set of sources, combining international literature on usability and user experience evaluation, data visualization, dashboard design, design patterns, and software quality models with Brazilian studies and institutional sources related to human-computer interaction and educational technology. We also included sources from Brazilian venues and repositories, especially those associated with the Brazilian Computer Society, to situate the study within the national research context. The selection of references was guided primarily by relevance, verifiability, methodological adequacy, and direct connection to the claims made in the manuscript. We recognize that citation practices may reproduce broader academic biases, especially regarding geographic, institutional, gender, and racial representation. No automated inference of author gender, race, or ethnicity was performed, since such procedures may introduce misclassification and do not reliably capture authors' identities. Future versions of this paper may include a more systematic quantitative assessment of citation diversity.

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