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Adopting Human-data Interaction Guidelines and Participatory Practices for Supporting Inexperienced Designers in Information Visualization Applications

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Abstract Nowadays, voluminous data support may influence decision-making. People with varied profiles need to interact with data to gain valuable insights. There is a need for software tools to support the understanding and management of information to favor Human-Data Interaction (HDI) with a richer user experience. This study explores the combination of HDI design guidelines and participatory approaches to improve user experience in data interaction. We defined a design process to support the activities and adapted participatory practices to facilitate HDI design. We conducted workshops with inexperienced designers developing information visualization applications for common-sense domains. They generated and analyzed several application prototypes. Results suggest that design guidelines help generate HDI-based prototypes with a good user experience.

Keywords: Human-data interaction, Interaction design, Design process, Participatory design

1 Introduction

Individuals, companies, and organizations are increasingly leveraging data-based decision-making. This context has motivated the development of data-driven systems as specialized solutions for acquiring, managing, and presenting information [Mahjourian, 2008]. Information visualization (IV) systems support people in exploiting the potential of large data volumes and require advanced interaction techniques.

Designing software interfaces that favor Human-data Interaction (HDI) is necessary to build effective IV systems.HDI refers to enabling people to manipulate, analyze and understand large, unstructured, and complex datasets [Elmqvist, 2011]. The design of an application to support effective data interaction should provide a good user experience (UX).

The skills and knowledge necessary to design this type of software application are challenging. Properly understanding the application domain and the detailed data is essential while considering stakeholders' needs and users' profiles. Designers must be creative, visionary, logical, and analytical [Stolterman, 1992]. They need skills in interface design, data representation, requirements engineering, and a deep understanding of the domain's peculiarities. It is very unusual for an inexperienced designer to have all the knowledge and skills necessary to design visualization applications [Martín-Rodilla *et al*., 2014]. Frequently, many individuals participate in the design process with distinct roles. In Participatory Design (PD), stakeholders usually act as co-designers enrolled as design team members [Kuhn and Muller, 1993]. These approaches support stakeholders' engagement in different perspectives at various stages of the design process.

We investigate HDI in IV systems adopting the human-centered perspective proposed by Hornung *et al*. [2015]. It states that the primary goal of HDI should be to design interactions enabling stakeholders to promote desired and avoid undesired consequences of data use. The vision and perceptions of people who access and use the data directly and those who affect and are affected by the results of use must be aggregated in the design. In this context, we adopt PD techniques to involve stakeholders in the design process.

Design recommendations constitute an approach to improve design quality. Recommendations help designers predict the consequences of their design decisions and can enhance the interactive properties of the system [Dix *et al*., 2004]. Guidelines are experts' design recommendations that can help design other applications by facilitating the selection of the best appropriate solution to solve a design problem [Dix *et al*., 2004].

Several initiatives have established guidelines to improve the design quality of information visualization applications [Buchdid *et al*., 2014; Hayashi and Baranauskas, 2013]. Some investigations have focused on guidelines concerning user interaction with information visualizations [Baldonado *et al*., 2000; Elmqvist *et al*., 2011; Endert, 2014].

The use of taxonomies to analyze interaction techniques is another approach to achieve quality in IV design [Amar *et al*., 2005; Keim, 2002; Shneiderman, 1996; Yi *et al*., 2007]. It can be helpful to better understand the interaction space. The identification of interaction categories improves the consistency and standardization of the solution. It facilitates the designers' conception of a solution and the users' understanding of the system.

This article investigates the combination of design guidelines, interaction categories, and participatory practices to help inexperienced designers create information visualization applications that provide a good user experience. In particular, we consider developing IV for common sense domains (noncomplex domains that require no specific knowledge to be understood). In the study, we address a typical problem for undergraduates.

This study relies on the existing knowledge from previous investigations represented by design guidelines. We use a set of design guidelines for HDI in information visualization [Victorelli and Reis, 2020]. We explored the feasibility of adopting a set of previously selected guidelines, and a set of categories of interaction [Yi *et al*., 2007] to facilitate the work of inexperienced designers.

The investigation emphasizes how to combine them with participatory practices. The objective is to involve users without forgoing pre-existing knowledge materialized in the design guidelines. Design recommendations and participatory practices have the potential to leverage advanced interactive solutions. The combination of these two approaches is a promising research path. Although existing studies have proposed blending the two approaches [Muller *et al*., 1998], these studies were not focused on data interaction.

In a previous work, the HDI design process combined design guidelines and participatory practices [Victorelli *et al*., 2020b] in complex domains. These domains often involve intricate problems understood by few experts. The addressed design scenario required the involvement of domain specialists and experienced designers. The emphasis was on the participation of the main stakeholders in the design of visualization applications. A socially aware approach [Baranauskas *et al*., 2013] for the creation of HDI applications coordinated design guidelines with artifacts and methods from Organizational Semiotics [Liu, 2008; Stamper *et al*., 2000] and Participatory Design [Bjögvinsson *et al*., 2012; Simonsen and Robertson, 2012].

Common sense domains are less complex and enable inexperienced designers to participate in the design of data-driven applications. Less experienced designers can significantly contribute to the process, bringing new ideas without bias. However, they may have difficulties conducting participatory activities as proposed in the former HDI process [Victorelli *et al*., 2020b]. Selecting appropriate guidelines to the context as the design evolves is an example of a practice that requires designer's maturity.

This study investigated how to evolve the HDI design process so as to enable inexperienced designers to conceive IV applications.

We sought to make it easier to apply the process and conduct the practices so novice designers could design information visualization applications. To this end, we propose a new process and several new practices.

This study addresses the following research question: "How to combine participatory approaches with design guidelines to enable inexperienced designers to design data interaction in IV?" To the best of our knowledge, there are no studies on the participation of inexperienced designers in processes that combine participatory practices and design guidelines for data interaction.

This study proposes improvements to a previous proposal for the HDI design process [Victorelli *et al*., 2020b]. Thereby, less experienced designers can conduct participatory practices and apply design guidelines, learning the relevant design guidelines at the beginning of the process. In this sense, designers will start future activities with prior knowledge of the recommendations.

In addition, our investigation advanced the use of participatory practices to refine interaction with data design alternatives. A necessary approach considering that PD techniques usually consider the design object static (e.g., the BrainDraw technique helps to design a single interface at time). We needed procedures to enable participants to express the dynamic aspects of data interaction. Specifically, we proposed PD activities to support the representation of transitions between different data states.

We started this study by proposing evolutions for the HDI design process. Then, we prepared materials to facilitate the understanding of the HDI design guidelines set [Victorelli and Reis, 2020] and data interaction categories [Yi *et al*., 2007]. We presented the guidelines to the study participants (undergraduate students), who explored the recommendations on existing websites to consolidate learning. Then, they applied the guidelines in a practical context choosing a new country to live in. We organized design teams and conducted in-person workshops where participants developed navigable prototypes. Afterward, they inspected HDI guidelines usage and evaluated their user experience in the prototypes built by different design teams. Finally, they answered a questionnaire about the HDI guidelines and participatory practices.

The key contributions of this investigation include the following:

1. A design process to guide inexperienced designers to create information visualization applications.
2. Adaptation of PD techniques to deal with data interaction design.
3. A study to analyze the applicability of the proposal.

The remainder of this article is organized as follows: Section 2 presents the theoretical and methodological background in addition to the related work. Section 3 presents the proposed process detailing the practices and the experimental study overview. Section 4 presents the results of the application of our approach in the study. Section 5 reports an assessment of the research results, including user experience evaluation and participants' design process assessment. Section 6 discusses the findings, Section 7 presents our final considerations and directions for future research.

2 Background

This section describes the basic concepts and techniques explored in our research. We present the participatory design standpoint, some of its methods, and the prototyping techniques. The role of interaction in information visualization and the HDI design guidelines used in this study are explained. In addition, an overview of related works is presented.

2.1 Participatory Design and Prototyping

User-centered approaches situate the user at the core of the solution design. The focus is shifted from the technology, and the users' needs are emphasized. User involvement can occur on many levels, from being observed to actively cooperating with designers.

Participatory Design (PD) is a user-centered approach that enables a high degree of user involvement in the design process [Muller *et al.*, 1997]. Those affected by design should have a voice in the design process. End users act as effective members of the design teams. They are not only a subject of observation and experiments. Users perform practical contributions by reflecting on their perspectives and needs.

Several PD techniques support stakeholder engagement at various stages of the design process to develop a solution to a problem. The use of simple techniques and small compromise of materials are characteristics of the PD methods. PD is seen as a means of anticipating or envisioning use before actual use, as it takes place in people's life [Bjögvinsson *et al.*, 2012].

Prototyping is a strategy to deal effectively with problems that are difficult to predict. It is a practice adopted to facilitate anticipation of use. Prototyping creates approaches to express ideas quickly, easily and spontaneously, providing user feedback instantly.

Prototypes are visual representations of systems and interaction models and can elucidate the possible visual appearance of the artifacts.

The prototyping process includes applying good design, product conceptualization, user modeling, and product validation. Prototypes help to understand how users experience, feel, and behave to generate effective interactions. Interaction design is a key factor for creating successful prototypes [Preece *et al.*, 2002].

In the initial phase of design it may be convenient to create several different versions of the same idea to test which one works best. Low-fidelity static prototypes can guarantee more speed and detachment from the created solution. As confidence in the design increases, it is interesting to detail the application interactions. An interactive high-fidelity prototype can be more faithful in the interface representation and enables deepening the tests with users.

Our work focuses on specific practices involving prototypes. We improved some prototyping techniques for PD of human-data interaction. The following techniques were enhanced:

- Storyboarding is commonly used in system interface prototyping. This technique organizes sequential graphical sketches resulting in a chain of illustrations resembling comics. The user interface snapshots show the story that occurs as people interact with the interactive solution.
  Narrative storyboards are commonly applied to interaction design [Vertelney, 1989]. It provides the context in which the interaction occurs and shows what is happening in the world, complementing the interface storyboard that emphasizes what is happening on the screen [Greenberg *et al.*, 2012].
  In this work, we adapted a narrative storyboard that must be assembled in a participatory manner to materialize the interaction under design (see Section 4.3.2).
- BrainDraw supports graphic brain-storming. Drawing cycles emable quickly populating an interface design space. Each participant starts the drawing related to the solution to be developed. At the end of a certain period, each participant moves the drawing to the next participant. The participant receives a drawing from the other one and continues it. The process continues until all participants have worked through one another's ideas. Then, they discuss the solutions and generate consolidated low-fidelity prototypes [Muller *et al.*, 1997]. We adapted BrainDraw practice to emphasize data interaction (see Section 4.3.3).
- Brainwriting is an alternative for brainstorming. It is a silent, group-generated generation of ideas [VanGundy, 1984]. The process used is similar to Braindraw; however instead of making drawings, participants describe scenarios to contextualize and refine the concept of a product. In our workshops, the participants described how users would interact with data (see Section 4.3.1)

2.2 Interaction in Information Visualization Applications

In an IV application, the interaction mediates the dialogue between the user and the data. The interaction is an important support for data understanding and the decision-making process. There are studies that seek a deeper understanding of the role of interaction through the analysis of interactive resources [Elmqvist *et al.*, 2011; Dimara and Perin, 2020; Lam *et al.*, 2012; Yi *et al.*, 2007].

The studies present different approaches to help the designers of IV tools. Some studies defined interaction taxonomies [Yi *et al.*, 2007], and others proposed practical design guidelines [Elmqvist *et al.*, 2011]. In our study, we use both approaches to facilitate HDI design.

Taxonomies help organize and classify elements logically. It facilitates the creation and understanding of a solution favoring consistency and standardization.

In the literature, the taxonomies for interaction with IV present significantly different levels of granularity. Some taxonomies categorize low-level interaction techniques [Keim, 2002; Shneiderman, 1996], such as filtering out uninteresting items or viewing relationships among items. Other studies focus on users' tasks and intend to capture the benefits provided by interaction [Amar *et al.*, 2005; Yi *et al.*, 2007]. Some examples of these tasks are computing a derived value, finding extreme or anomalies, clustering, or correlating.

Yi *et al.* [2007]. Proposed seven general categories of interaction techniques for IV applications. The proposed taxonomy connects the user's objectives or intent with the interaction techniques[Yi *et al.*, 2007]. It enables the description of a significant range of existing interfaces. In our study, we used interaction categories to help detail the solution under design. We adopted seven interaction categories of the taxonomy proposed by Yi *et al.* [2007], as follows:

1. Select: mark something as interesting;

2. Explore: show me something else;
3. Reconfigure: show me a different arrangement;
4. Encode: show me a different representation;
5. Abstract/Elaborate: show me more or less detail;
6. Filter: show me something conditionally;
7. Connect: show me related items.

2.3 Design Guidelines

Guidelines constitute an approach that favors design in the context of data interaction. Recommendations based on good or bad design can help design systems with similar characteristics. The knowledge of the most experienced designers can benefit the less experienced. They can facilitate the identification of problems and the advantages of alternatives solution. Recommendations help designers determine the consequences of their design decisions enhancing the systems' interactive properties [Dix *et al*., 2004]. In this investigation, we use the term guideline broadly to refer to design recommendations regardless of their level of abstraction, generality, and authority.

Several sources provide recommendations that can represent guidelines to help designers to conceive the interaction with IV applications. A set of design guidelines for HDI brings gathers recommendations scattered in the literature [Victorelli and Reis, 2020]. The set gathers classical guidelines for HCI usability [Nielsen, 1994a]; principles for User-Centered Design [Norman and Draper, 1986]; specific design recommendations for interaction with visualizations [Baldonado *et al*., 2000; Elmqvist *et al*., 2011; Endert, 2014]; and requirements for HDI design [Victorelli *et al*., 2020a]. The conceived guidelines address various aspects involved in data interacting.

Our study employed the set of HDI design guidelines to help inexperienced designers develop applications for common-sense domains (see Sections 4.2 and 4.3). The guidelines we used in design activities are summarized below.

DG 1. Reinforce a clear conceptual model.

DG 1.1. Self-evidence in coordinated visualizations. The design should provide perceptual hints or clues to make relationships between multiple visualizations apparent to the user [Baldonado *et al*., 2000].

DG 1.2. Consistency between coordinated visualizations. Ensure consistency between the interfaces for multiple views and between the states of multiple coordinated visualizations [Baldonado *et al*., 2000].

DG 1.3. Reversible operations in visualizations. The user must be able to recover in cases of mistake [Norman, 2013].

DG 2. Use smooth animated transitions between visualizations states. Animated transitions help users maintain an accurate mental model of the current state of the system

DG 3. Immediately provide visual feedback on the interaction. Each keystroke or mouse movement, and not just for major events, such as mouse clicks and the "Enter key" must provide feedback [Elmqvist *et al*., 2011].

DG 4: Maximize direct manipulation with data.

Avoid control panels separate from the visualization When it is not possible, make them an integral part of the visualization [Elmqvist *et al*., 2011].

DG 5. Minimize information overload. Simplify users' cognitive load without compromising effectiveness and compensate for memory failures [Cook and Thomas, 2005].

DG 5.1. Show the information context. Ensure users have the information necessary to know where they are and how to go where they want [Beard and Walker II, 1990].

DG 5.2. Avoid requiring data memorization.

Avoid forcing users to store information in memory. Allow users to select, write or mark the information [Norman, 2013].

DG 6. Semantically enrich the interaction. Add semantics to various types of interaction [Endert, 2014].

DG 6.1. Semantically enrich search interaction. Use semantics dealing with synonyms, antonyms, meanings, and abstractions to retrieve information and access heterogeneous and unstructured data.

DG 6.2. Enriched feedback from humans incorporated. Incorporate into the application user's feedback on the information presented [Wilke and Portmann, 2016].

DG 6.3. Refine and train models through user feedback. Capture users' tacit knowledge when manipulating data and refining the underlying analytical models [Endert, 2014].

2.4 Related Work

Most systems use data, but what differentiates data-driven systems from others is the emphasis on data. These systems are built to facilitate human-data interaction. In this context, there has been an increasing need to understand how to design data-driven applications properly. Studies address data design from multiple perspectives, examining at different facets of this diverse topic.

A relevant focus lies at the intersection of data science and HCI. Investigations of data science working practices with a human-centered approach have improved our understanding of how specialists on data team members collaborate [Muller *et al*., 2019; Passi and Jackson, 2018]. It is essential to design tools that enable collaboration, considering what is specific and distinctive about cooperation in data science. An investigation on strategies that people in this context adopt to perform their tasks helped develop a taxonomy of work practices and open questions in the behavioral and social study of data science workers [Muller *et al*., 2019]. Data science processes and tools must address the needs of skilled users, domain experts that are not programmers, and the actual consumer of the results of data science work. They recognize that evaluating the tools' efficiency is challenging due to the diversity of scenarios and profiles. Still, they understand that methods are needed to assess the usefulness and usability of tools designed to support data analysis [Muller *et al*., 2019].

Feinberg [2017] proposes a distinct perspective on data by understanding them as design material. Data generation is situated within a design perspective and understood as a set of multiple layers of related design activities. Users are seen as data designers, not as mere data appropriators. Data are presented as a product that evolves from design decisions regarding infrastructure, collection, and aggregation. Data acquire a new character with each use, as they are manipulated to fit their new context [Feinberg, 2017].

A similar approach was proposed to view data as a "design thing" [Seidelin *et al*., 2020]. Since organizations need to deal with multiple heterogeneous data sources, the authors propose tools that help select data sources that enable advancement and innovation in their services. Data-related work practices are investigated to propose tools to support the exploration of and experimentation with data by domain experts with different data sources. Co-design is a practical approach to address the dependency between data and data to work [Seidelin *et al*., 2020].

Others found it necessary to investigate how to guide inexperienced designers. Stolterman investigated how designers think and found that experienced designers generally did not believe that teaching design skills to inexperienced designers is possible. The way to obtain such skills is "through experience" [Stolterman, 1992]. However, the most popular skills that could characterize a skilled designer were being creative, visionary, logical, and analytical. The study highlights that while these four skills are trainable and able to be mastered, they are often considered incompatible [Stolterman, 1992]. Another study contrasted the cognitive efficiency of experienced and inexperienced designers. The comparison measures designers' mental effort to achieve creativity and the creativity level of design outcome [Sun *et al*., 2014]. An approach to support novice designers in instructional systems shows that they can solve realistic, complex design problems when spending enough time and receiving adequate support.

In our study, we supported inexperienced designers with design guidelines [Verstegen *et al*., 2008]. We combined this support with participatory practices to facilitate the design of visualizations by inexperienced designers.

3 Guidelines and Participatory Practices for Information Visualization Design

We present our proposal starting with an overview of the design process in Subsection 3.1. Subsection 3.2 shows how we applied the proposal in an experimental study.

3.1 Design Process Overview

We proposed an interaction design process to enable inexperienced designers to conceive IV applications. Participatory practices combined with design guidelines and interaction categories supported design activities.

Previous research proposed an HDI design process that needed to be conducted by experienced designers [Victorelli *et al*., 2020b]. The former study exercised developing information visualization in a complex domain. The study involved a few participants with particular backgrounds, such as domain experts. The process did not include previously selected design guidelines applied during the practices. Designers chose the relevant recommendations and presented them to the participants as the design process progressed - the selection made while conducting the process required a certain maturity from the designers.

Designers with little experience lack extensive knowledge of guidelines. They would find it difficult to quickly recognize the recommendations applicable in a given situation without researching the subject. It is hard to understand the details of a new domain and, at the same time, help specialists generate prototypes. This situation would need a long time of involvement for novice designers.

In the current study, we propose an HDI design process to be applied by inexperienced designers. We involved designers with little or no experience in designing interactive visualization applications.

We simplified some aspects of the process, intending to enable inexperienced designers to conduct the activities. In this sense, we previously defined a set of design guidelines. This approach eliminated the need to select guidelines and introduce them to participants dynamically during the design phase. In our proposal, presented in Figure 1, we used a set of HDI design guidelines in IV conception activities [Victorelli and Reis, 2020]. We also introduced a set of interaction categories with information visualization to guide the designers [Yi *et al*., 2007]. We investigate how inexperienced designers could apply this predefined set of recommendations in a participatory design process.

The scenario of this study does not require the participation of domain specialists. We approached less complex design problems in common-sense domains. This context enables a significant number of participants to exercise the proposed process. The evolved HDI design process consists of four key phases, as follows:

1. **Problem Clarification.** Activities begin by clarifying a design problem (see Subsection 4.1). This step aims to identify the stakeholders, elucidate the issues and ideas regarding the decisions supported by visualizations, and state the requirements for the application.
2. **Guidelines and Interaction Categories Understanding.** Next, the participants are prepared to use the HDI design guidelines and interaction categories (see Subsection 4.2). They explore the guidelines and the interaction categories by performing pre-activities with an existing Website which helps their learning.
3. **Design Materialization.** The design materialization activities' goal is to design low-fidelity IV prototypes to support the user in making a specific decision. In this phase, participants use design guidelines and interaction categories directly in designing the application (see Subsection 4.3). These activities included design techniques adapted to the context of HDI as follows: Brainwriting for Data Interaction Design (see Sub-subsection 4.3.1); Storyboarding for Data Interaction Design (see Sub-subsection 4.3.2); and Braindraw for Data Interaction Design (see Sub-subsection 4.3.3). The designed low-fidelity prototypes are transformed into navigable prototypes (see Sub-subsection 4.3.4).
4. **Evaluation.** Finally, participants evaluate the prototypes concerning the use of the guidelines (see Subsection 5.1). Users also rate their experience with the prototypes (see Subsection 5.2). Depending on the results of

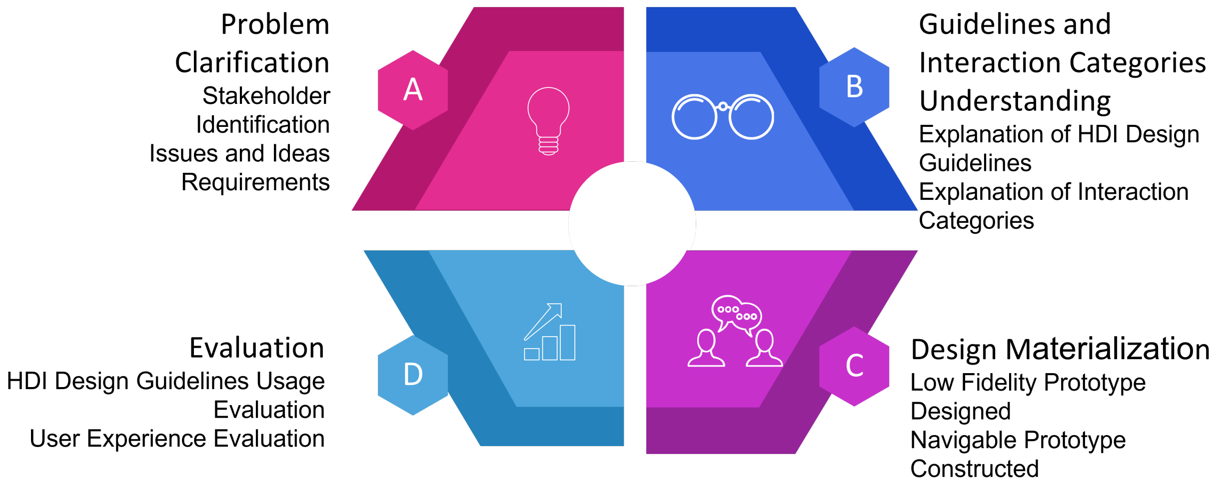

Figure 1. HDI design process combining guidelines with participatory design approaches.

this phase, it may be necessary to begin a new iteration of the process.

The main focus of our study was the phases related to understanding the recommendations and design materialization. The following subsections explain the details of each stage of the design process and the results obtained from its application in an experimental study.

3.2 Applying the proposed design process

We invited sixty-six undergraduate students to participate in our study; fifty-two agreed to participate [1]. However, not all students participated in all workshops.

Groups had a minimum of two and a maximum of five students so everyone could learn and participate. Sixteen groups participated in the activities.

The participants were students from a computer science school. They were all from the same school/undergraduate program. The participants were enrolled in the Human-Computer Interaction course. This discipline is suggested for the sixth semester of the program and has Object-Oriented Programming and Data Structures as prerequisites. Therefore, all participants had notions of computer implementation. Most of them have yet to gain experience with Information Visualization application design.

Students interested in participating as volunteers were informed about the justifications and objectives of the research, methodology, practices, procedures, benefits, and privacy of their information. It was clarified that participation was voluntary and that there would be no impact on their activities if the student decided not to participate. The participant could discontinue their participation at any time if they wished. The whole course was designed to address it. Confidential information was not collected. Data and materials obtained from subjects participating in the workshops were made anonymous. The secrecy and privacy of all information collected were guaranteed. In this sense, we believe the hierarchical aspects do not negatively affect the design activities, and the overall evaluation carried out.

[1] The Research Ethics committee of the University of Campinas approved the study under protocol No.#18927119.9.0000.5404.

Feinberg argues that any "use" of the data represents a continuation of its design. In this sense, user and designer roles are intertwined when working with data and are often performed by the same person [Feinberg, 2017]. Our study considered it relevant to involve students who could simultaneously act as users and designers. Even if the group of students was not necessarily a statistically representative sample of the whole population of inexperienced designers, they have a unique profile to test our proposal because they could simultaneously act as users and designers.

The participants had a period of four full weeks to implement the high-fidelity prototype. During recruitment to participate in the research, volunteers were previously told about all the study phases, including that they should develop high-fidelity prototypes. Implementing some of the guidelines would require code implementations regarding the semantics of data operations. Although participants' profiles were compatible with this type of implementation, this would require additional efforts to learn a subject that might not be a priority for them at that time. In this sense, such guidelines were not explored by the groups.

We chose a design problem that involved a typical decision for this group of students. As the study consists of a problem situation of interest to undergraduate students, they were potential users of the solution. Students represented both users of the product and executors of the process and practices. They played both the roles of end-user and designers. All students enrolled as participants of the design team acted as co-designers.

Our study required seven workshops that consisted of face-to-face activities bringing together most participants in person to perform tasks according to our specified process. Participants collaborated in various activities proposed for problem clarification, requirement elicitation, interface designing, and prototype creation and evaluation. The process was conducted in roughly fourteen hours of face-to-face sessions with forty participants on average. Groups needed additional twenty hours on average to complete the activities started in the workshops. In addition, the researcher's preparation of the practice required twenty hours of work. Table 1 shows the activities performed in each phase of the process, and the

Table 1. Workshops that focused on each phase of the process and the activities, practices, and techniques involved

	Process phase	Activity	Practices and Techniques Used and Adapted	See Section
WS1	Problem Clarification	Stakeholder Identification	Stakeholder Identification Diagram (SID) [Liu, 2008]	4.1
WS1	Problem Clarification	Issues and Ideas	Evaluation Frame (EF) [Baranauskas *et al*., 2005]	4.1
WS1	Problem Clarification	Requirements	Semiotic Framework (SF) [Stamper, 1973]	4.1
WS2	Guidelines and Interaction Categories Understanding	Explanation of HDI Design Guidelines	"Preparation of the Workshops" and "Participants' Understanding of HDI Design Guidelines in [Victorelli *et al*., 2019]. Guidelines described in: [Victorelli and Reis, 2020]	4.2
WS2	Guidelines and Interaction Categories Understanding	"Explanation of Interaction Categories"	Interaction categories [Yi *et al*., 2007]	4.2
WS3	Design Materialization	Low Fidelity Prototype Designed	Brainwriting [VanGundy, 1984] adapted for Data Interaction Design	4.3.1
WS4	Design Materialization	Low Fidelity Prototype Designed	Storyboarding [Greenberg *et al*., 2011, 2012] adapted for Data Interaction Design	4.3.2
WS4	Design Materialization	Low Fidelity Prototype Designed	Braindraw [Muller *et al*., 1997] adapted for Data Interaction Design	4.3.3
WS5	Design Materialization	Navigable Prototype Constructed	Supporting Tools such as: Figma, Marvel, InVision and Axure.	4.3.4
WS6	Evaluation	HDI Design Guidelines Usage Evaluation	Questionnaire	5.1
WS7	Evaluation	User Experience Evaluation	One general question	5.2

practices and techniques that supported the workshops.

We sought a subject that would motivate the participants to define the design problem addressed in the study. The desire to have an experience abroad emerged from the researchers' conversations with the participants in preparation for the workshops. The underlying design problem selected for the study was to support the user's decision to choose a new country to live in.

A common challenge for young people who graduate studies and want to live abroad is selecting a new country. This decision involves many aspects of young people's lives. Moving to another country is a challenge that excites young people like most participants. In Brazil, according to a survey[2], forty-three percent of the adult population expressed a desire to leave the country. Sixty-two percent of young people aged between 16 and 24 would move to another country if they could. There are 19 million young people who would leave Brazil.

It is not easy to muster courage and undo the bonds. Many doubts go through the mind of people who want to migrate. How to choose the country? What to take into account? What are the factors that impact the lives of individuals who move abroad? Will I get a job? What could I count on if I faced any difficulties? How do people live in different countries? How do the government and citizens understand and treat the individuals who move there? What are the requirements for applying for a residence visa? Choosing a new country requires time, insight, and analysis.

Individuals who will make this decision need to know themselves well. They analyze their relationship with the characteristics of the countries of origin and destination. Different types of data visualization regarding the quality of life in countries, labor markets, and academic opportunities can help them analyze this information. An interactive Website can be a tool to clarify doubts about each country's main characteristics and support decision-making about moving.

In our study, we invited the participants to design information visualizations and interactions to support users' decisions to choose a new country. Although all participants were students, there was a significant diversity of profiles and perspectives on the subject. When choosing a country to live in, some prioritized a place where they could earn money quickly; others wanted a place with better quality of life; or where they could feel that their work would make a "difference" in the social context. Some of them did not consider moving to another country at the time. They also differed on the best way to obtain information and various other aspects. When asked where they would obtain information to support this decision, most mentioned the Internet and references from people living abroad. Some said they would feel safer consulting a specialized travel agent, and others would prefer to consult the embassies of the countries in which they were interested.

The socio-technical needs influenced the design of the artifacts. The environment may favor important factors of participatory design standpoint concerning workplaces and the introduction of new technology [Bjögvinsson *et al.*, 2012]. Our study ensured that those affected by design should have a say in the design process. The prevailing situation during the design process was controversy rather than consensus around the emerging object. The study favored the prediction of use before actual use.

We aimed to understand if and how the applied process and participatory practices could help inexperienced designers to create IV. At this stage, we were interested in the qualitative aspects. We decided not to use a control group to compare the results. It was impossible to ensure that all groups were composed of members with equivalent profiles because the participants had diverse skills, knowledge, and previous experience. Then, maintaining a group that did not have access to the defined practices and recommendations would not serve as a basis for comparing the design produced by groups that followed the process and those that did not. We understand that maintaining a control group would result in more disadvantages by depriving some students of the experience than real gains regarding the study's validity. Section 4 details the results of the HDI development process. The evaluation is presented in Section 5.

4 Results

We present the results obtained in the first three phases of the proposed process. Subsection 4.1 presents problem clarification activities. Subsection 4.2 describes the activities presented for facilitating the participants' understanding before design activities. Subsection 4.3 presents the low-fidelity prototype design and the construction of the navigable prototypes.

4.1 Results of the problem clarification

The clarification activities started with presenting the design problem to the participants. They discussed and explored the issue by themselves. To this end, the participants considered Socially Aware Design (SAD) [Baranauskas *et al.*, 2009; Baranauskas, 2014]. SAD supports the understanding of the organization, the solution under design, and the context in which the solution will be introduced. This approach seeks to effectively address the socio-technical needs of a particular group or organization. In SAD, design activities involve all types of stakeholders to fill in artifacts collaboratively. The artifacts facilitate the expression of ideas and deliberation about design solutions.

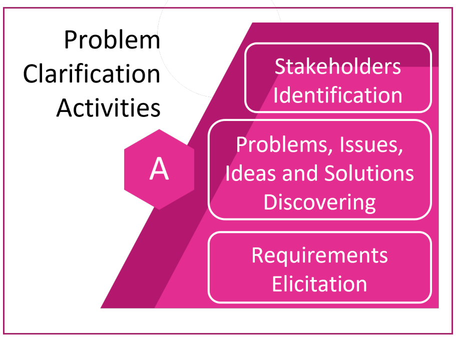

Figure 2. Activities for the clarification phase of the HDI Design Process.

[2]`https://www1.folha.uol.com.br/cotidiano/2018/06/se-pudessem-62-dos-jovens-brasileiros-iriam-embora-do-pais.shtml` Datafolha, May 2018

Figure 2 presents the main activities in the clarification phase. Various artifacts were used to mediate the communication and facilitate creative and collaborative design engagement. As support material for the activities, the participants received printed sheets of paper with figures to fill out for each artifact. The participants filled in SAD artifacts covering the main concerns and interests of the stakeholders on the proposed problem, as follows:

1. Stakeholder Identification Diagram (SID) [Liu, 2008] helps to identify the people interested or affected by the solution. Several stakeholders involved in the design problem were identified, including young people interested in migration, migration agencies, Brazilians living in other countries, and embassies.
2. The Evaluation Frame (EF) [Baranauskas *et al.*, 2005] supports coordinating problems and the initial search for solutions. It informs about specific problems and issues of stakeholders and ideas or solutions they envisage. For embassies, for example, issues regarding changes in immigration laws were pointed out. Possible solutions include in-depth knowledge of the country's laws. The product owner, another type of stakeholder, has the problem of creating a monetizing strategy for the solution. Interviewing potential customers to understand how much they would be willing to spend on this product can solve this problem.
3. Semiotic Framework (SF) [Stamper, 1973] supports identifying and organizing requirements according to six different communication levels. The first three levels can be related to technological issues (physical, empirical, and syntactic), and the other levels concern the aspects of human information functions (semantic, pragmatic, and social world). For the physical level, for example, participants identified cloud-based systems. For the social layer, they stated that it was essential to help people choose another country, considering cultural aspects and beliefs.

The artifacts are filled in an integrated way; the information captured in one artifact can influence the filling of the others. For instance, a group identified expatriates, people who already live in another country, as a stakeholder. Identifying this type of stakeholder may have helped to consider requirements or functionality related to them. This group's solution enabled expatriates to report their experiences and review information from their country.

4.2 Results of guidelines and interaction categories understanding activities

In a previous study about the HDI process, specialists learned the guidelines as required by the subject covered in each workshop [Victorelli *et al.*, 2020b]. They understood the guidelines during the design and evaluation activities. In this study, we involved inexperienced designers. Participants needed to know and understand the guidelines before starting the design. Therefore, the guidelines were previously selected and introduced to the participants. Figure 3 presents the activities conducted in the phase of understanding guidelines and interaction categories.

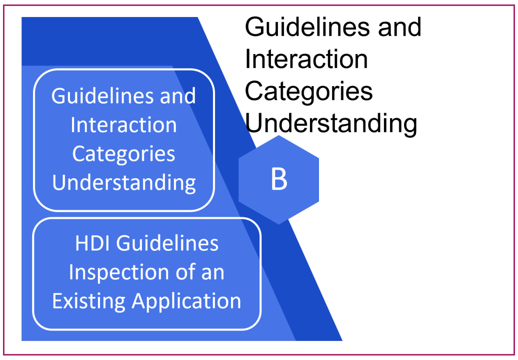

Figure 3. Activities in the phase of understanding guidelines and the interaction categories.

The understanding phase aims to ensure the comprehension of the HDI design guidelines and interaction categories. To this end, we tailored the activities that guarantee understanding of the guidelines for the scenario under study. We prepared the support material and conducted the understanding by the stakeholders following the steps proposed for "Preparation of the Workshops" and "Participants' Understanding of HDI Design Guidelines" in a previous study [Victorelli *et al.*, 2019]. We included items to facilitate the assimilation of the interaction categories in practices.

We introduced the data interaction categories (see Subsection 2.2) and the HDI design guidelines (see Subsection 2.3) to the participants in an integrated way. We explained each guideline and interaction category with examples of applications. Different contexts familiar to the participants, such as renting property, were used. Simplified examples that involved interactions similar to those that would be used in the following steps were chosen. We explored the design guidelines and the interaction categories in the same examples so they could better understand the relationship between them.

We prepared some practical tasks to be performed on two particular websites highlighting points that users should observe. The participants explored by themselves the interactions on the website while performing the predefined tasks. They identified interaction categories and HDI design guidelines involved. Then, the participants are gathered to discuss their understanding of the guidelines and interaction categories.

First, a real estate website was used to execute the prepared tasks. Participants should choose a property to rent in a specific city area. This website enabled users, for example, to pan the map to see the properties on the streets near other views. Other visualizations were updated when moving the map view, showing photos and data of the properties of the new area. Thus, while performing an interaction of the category "Explore" they could observe the guidelines "consistency between coordinated visualizations", and "immediately provide visual feedback".

We investigated the participants' first impressions of how the guidelines were followed in developing the real estate website. We asked participants about the importance of the guidelines. This exercise aimed to force participants to think more deeply about applying the guidelines.

They selected the most relevant recommendations from the HDI design guidelines set according to their view. Participants listed the guidelines in order of relevance to them. For each selected guideline, they explained in their own words how it could support users and gave an example of the guideline application in any context or a counterexample. They sketched information visualizations and interactions to materialize the example. We encouraged them to mention the categories of interaction explored for each example.

We consolidated the results and established a ranking of the most relevant HDI design guidelines according to the participants' perceptions. The participants chose the most relevant design guidelines related to *reinforcement of a clear conceptual model*. In contrast, they considered the guideline on the *use of smooth animated transitions* between visualization states less critical.

To reinforce their understanding of the guidelines, the participants also explored and interacted with an existing website with IV entitled "What's the Happiest Country in the World?". The United Nations Sustainable Development Solutions Network annually releases the Happiness Report, which seeks to analyze the happiness of citizens from over 160 countries[3]. The countries' Happiness Index is a combination of six measured variables: gross domestic product per capita, healthy life expectancy, social support, perception of corruption, freedom to make life choices, and generosity.

This application facilitates the investigation of the satisfaction level among several countries' inhabitants. We proposed comparing the happiness index of some countries of their choice. While executing this task, participants verified the application of HDI design guidelines in visualizations based on a happiness index.

The groups' participants understood the data about each country and observed the clarity of information, how information was exposed, and how data were interrelated.

For example, an insightful way to analyze the data set was to observe the correlation between different variables that constitute the happiness index. Figure 4 shows a scatter plot with correlation data between gross domestic product per capita (GDP per capita) and healthy life expectancy for countries (the color of each point is based on the happiness score). It was possible to visually observe that, in general, the higher a country's GDP per capita, the higher its life expectancy.

Figure 4. Correlation between GDP per capita and Healthy Life Expectancy (January 2021)

While executing the task with the website, the participants performed a procedure similar to the usability heuristics evaluation [Nielsen, 1994b]. They assessed whether the website design respected each HDI design guidelines and the categories of interaction supported. They should check which categories of interaction they could perform. An example of interaction from the "Reconfigure" category was the ability to navigate between different visualizations using the tabs at the top of the page, as shown in Figure 4. This allowed the user to switch from a map visualization to rank, correlation, or history visualizations.

The groups reported their evaluation of the application of each guideline in a free text.

They stated whether each guideline was identified and where they observed its application on the website. The groups were encouraged to provide an assessment of the degree of application of each guideline throughout the website. No scale has been defined for this assessment. The inspection procedure performed by the participants provided descriptive answers about the application of the guidelines.

To better understand the results of this activity, we need to have an overview of the assessment made by the groups. We performed a thematic analysis establishing codes for classifying qualitative evaluations provided. We analyzed the answers to identify the participants' comments on each guideline to assign a code to each response. We gave one of the following codes to each comment: 1) the group did not analyze the guideline; 2) the guideline was analyzed by the group but not applied on the website; 3) the guideline was analyzed by the group and applied on the website.

In general, most groups could adequately recognize the application of the guidelines on the website. The evaluations for each guideline were similar across the groups, with minor discrepancies in a few cases. Some groups identified potential points of application of specific guidelines. They identified guidelines that were not used, but could have been applied. Spontaneously, they wrote suggestions on how to apply them.

Overall, the groups' evaluations noted applications of guidelines related to *immediate feedback* and the *clear conceptual model*. The missing guidelines in the participants' perception were related to *smooth transitions* and *semantically enriched interactions*. The groups could correctly observe the application or the absence of the guidelines they considered most important in this activity.

4.3 Results of the design materialization

The goal of the design materialization phase is to produce a navigable prototype. The participants proposed design alternatives in low and high-fidelity prototypes for data visualizations concerning the design problem at this step. To this end, they considered issues and ideas of solutions obtained as results of the clarification phase (see Subsection 4.1).

Figure 5 presents the main activities of this phase. Participatory and prototyping practices were adapted with a focus on data. The HDI design guidelines and categories of interaction were used to guide the participants in the design materialization activities.

The design practices were organized to guide the participants in the proposal, materialization, and refining solutions

[3] https://s3.amazonaws.com/happiness-report/2016/HR-V1_web.pdf

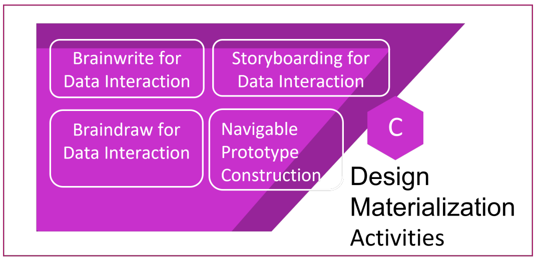

Figure 5. Activities conducted in the design materialization phase of the HDI Process.

for the design problem. We enhanced the participatory practices Storyboarding, BrainWriting, and BrainDraw (see Subsection 2.1) to facilitate the conception of prototypes focusing on data interaction design using the HDI design guidelines (see Subsection 2.3) and interaction categories (see Subsection 2.2).

4.3.1 Brainwriting for Data Interaction Design

Brainwriting activity produced a textual description of an interaction scenario. Participants described how users would interact with visualizations to select a new country. The goal was to tell the analysis that would be performed to support the decision-making on choosing a country to live in.

Brainwriting is a speedy practice to capture the participants' first ideas.

Our BrainWriting for Data Interaction Design proposal combined the Brainwriting practice with the taxonomy for interaction categories. The taxonomy of Yi *et al.* [2007]. Established verbs to describe high-level operations in IV applications [Yi *et al.*, 2007]. The operations enabled the discussion and conception of the interaction involved in an analysis scenario. Participants should describe an interaction scenario using verbs representing interaction categories whenever possible.

Participants started remembering the interaction categories. Each participant proposed a short written description of an interaction scenario supporting the choice of a new country to live in. They indicated the steps the user should take in writing a report of the interaction's intentions.

Then, the user's intention in each step of the scenario was classified by choosing one verb related to the interaction categories, such as "Select", "Explore", and "Filter".

However, if they could not remember or identify which verb to use, they should go ahead and write down their ideas in the best possible way. In these cases, the verbs of interaction categories could be introduced in the next step. In this step, capturing users' ideas quickly is the most relevant goal.

After a pre-defined time, everyone exchanged their piece of paper with the person next to them. In each turn, the participants read the interaction scenario received and complemented the proposal of interactions based on their ideas. This was repeated several times until the participants received their scenarios back. Then, the group discussed the scenarios and consolidated them into one.

The following excerpt exemplifies one interaction scenario described with verbs related to interaction categories by one of the groups. "The user will be able to **select** the country they prefer and be will be guided to the country description page. Alternatively, on the home page, the user can **explore** the survey information (happiness index, generosity, social support, etc.) in the form of a single map on the home interface, which can be **filtered**. The interface will be updated according to the filtered information. The user can click on the **selected** country and access its description page. In addition, the user will be able to **configure** the map display."

4.3.2 Storyboarding for Data Interaction Design

Having the written consolidated interaction scenario, the groups materialized and detailed it with storyboarding. This activity visually represented the interaction scenario. Our Storyboarding for Data Interaction Design enables connecting transitions with interaction categories and HDI design guidelines. The artifact produced shows how the prototype would support step by step the choice of a new country to live in.

To this end, the groups prepared an annotated and indexed state transition storyboarding [Greenberg *et al.*, 2011, 2012]. They generated a sequence of transitions representing the steps of the interaction scenario proposed to select the place they wanted to live. For each transition, the participants reflected on the data and the moments when the transition would begin and end. Thinking about data from the early stages of design helped to identify the applicable categories of interaction and design guidelines. In this step, they could include some relevant aspects of data visualizations, data manipulation, controls, mechanisms, and the context in which the interaction occurs. The group could use additional sketches to include these details.

Figure 6 shows the template proposed to the participants to produce the adapted storyboard. They identified the interactions that triggered transitions from one state to another using representative verbs regarding the interaction categories. In each interaction, they could indicate the possibility of using HDI design guidelines if they could anticipate their application. They wrote the guidelines applicable in each transition of the storyboarding. Figure 7 illustrates an example of storyboarding generated during the workshops.

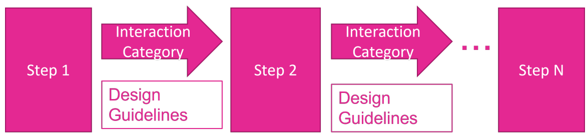

Figure 6. The template for storyboarding with spaces to identify interaction categories and design guidelines.

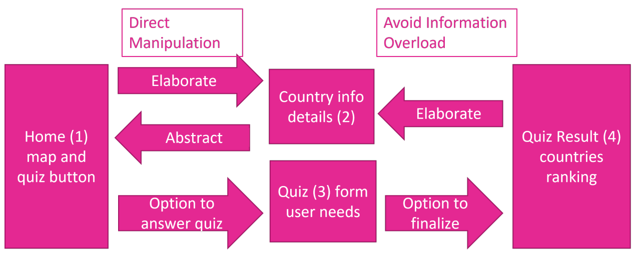

Figure 7. An annotated and indexed storyboard with adopted design guidelines and interaction categories representing the transitions between states.

4.3.3 Braindraw for Data Interaction Design

Braindraw is a technique for graphic brainstorming in cycles. It is helpful in quickly populating an interface design space focusing on a particular interface proposal. Our Braindraw for Data Interaction Design adds elements to study the user's data interaction appropriately, as the original Braindraw was not initially designed for it.

Braindraw for Data Interaction Design enables detailing what changes occur between data states and representations when users navigate from one interface to another. Using the adapted BrainDraw the participants could design each transition considering the HDI guidelines and interaction categories involved. To focus on understanding the dynamics of specific transitions, the groups should choose the most critical state transitions from the storyboard to detail using BrainDraw.

In the BrainDraw activity, the participants drew the interfaces and the IV on a blank sheet folded in half and opened again. Figure 8 shows our proposal for the areas of the sheet and guidance on how to fill them out.

In the left half sheet, the participant delineated the interface and visualization where users trigger the interaction. They should represent the elements involved in transitioning from one screen to another. In the right half, they drew how the transition ends, detailing the resulting information visualization. They were instructed to consider some recommendations:

- Highlight the data and context that matters for the interaction's start and end.
- Mark data, controls, or other mechanisms users select to perform the transition.
- Include elements that evidence the transition. Show if users interact directly with the data; how they made the selection; how they triggered the transition; and other relevant details.
- After the time indicated by the activity coordinator, pass the drawing to the next participant.
- Repeat the process until each participant has received their drawing back. If participants deem it appropriate, the cycle can be repeated.

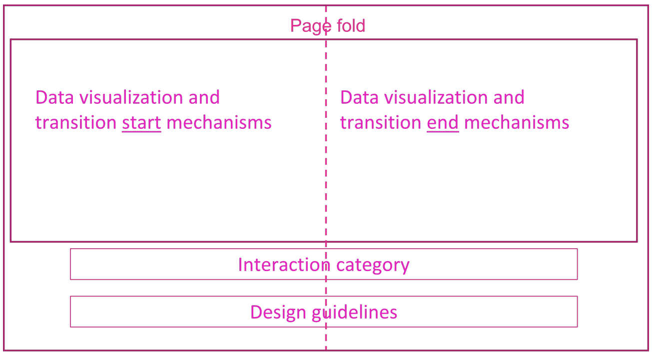

Figure 8. Template for BrainDraw page with areas to draw the transition start and end, and identify interaction categories and design guidelines.

The participants should write the verb that characterized the users' intention in the transition in the paper fold region. Optionally, they could indicate the HDI design guidelines that were or should be applied in the design of that transition. They could use as many guidelines as they considered relevant to each transition.

They had two minutes to draw the interaction individually in the first round. After that period, the participants passed on their drawing to their right-hand colleagues. Upon receiving a drawing, the next participant continued the process by filling in as much information as possible. After each participant received their initial design back, they gathered to discuss the generated alternative designs. They consolidated the ideas into a new draw that sometimes included elements from different proposals.

Figure 9 illustrates the result of a BrainDraw session performed by one of the groups. In the illustrated transition, coordinated visualizations show a map and a ranking of the countries according to the pre-defined Happiness Index. Users can change the importance of each variable that determines the ranking according to their preferences. When users change their preferences, the map and the ranking must be presented in different configurations.

The group stated that the interaction category involved was Reconfigure. The guideline applied was "Consistency between coordinated visualizations". The map visualizations and the ranking must be consistent with the users' preferences and with one another. According to the group, other potentially applied guidelines were "Immediately provide visual feedback on the interaction" and "Use smooth animated transitions between visualizations states". These guidelines guarantee that the user can observe the results of the changes in preferences immediately on the map and in the ranking. And users could perceive the relations between information in both presentations with the animated transition.

4.3.4 Navigable prototype construction

The static low-fidelity prototypes were transformed into high-fidelity interactive prototypes to refine the design. The prototypes aimed to support the most critical interactions in the scenario under study. The navigable prototypes helped represent how the human-data interaction would occur. The focus was on detailing the transition between visualizations.

Our goal was that the participants could understand how to apply the HDI design guidelines in human manipulation, analysis, and construction of meaning of data. They chose from the designed interactions – detailed in previous activities (see Sections 4.3.1, 4.3.2 and 4.3.3) – those that would be addressed in the high-fidelity prototype. The participants traced the interaction scenario steps that would contribute to the investigation of user interaction with the data.

The groups should consider all the HDI design guidelines that benefit the solution and the importance of each one in the context. They decided which guidelines would be effectively used (applied to the high-fidelity prototype), considering the time and resources they had. They had to explain the reasons for not using the applicable guidelines. Finally, they built a high-fidelity interactive prototype.

Supporting Tools. In transforming a low-fidelity prototype into a high-fidelity interactive prototype, participants were allowed to use any available prototyping tool. The recommendations were that the chosen prototyping tool should

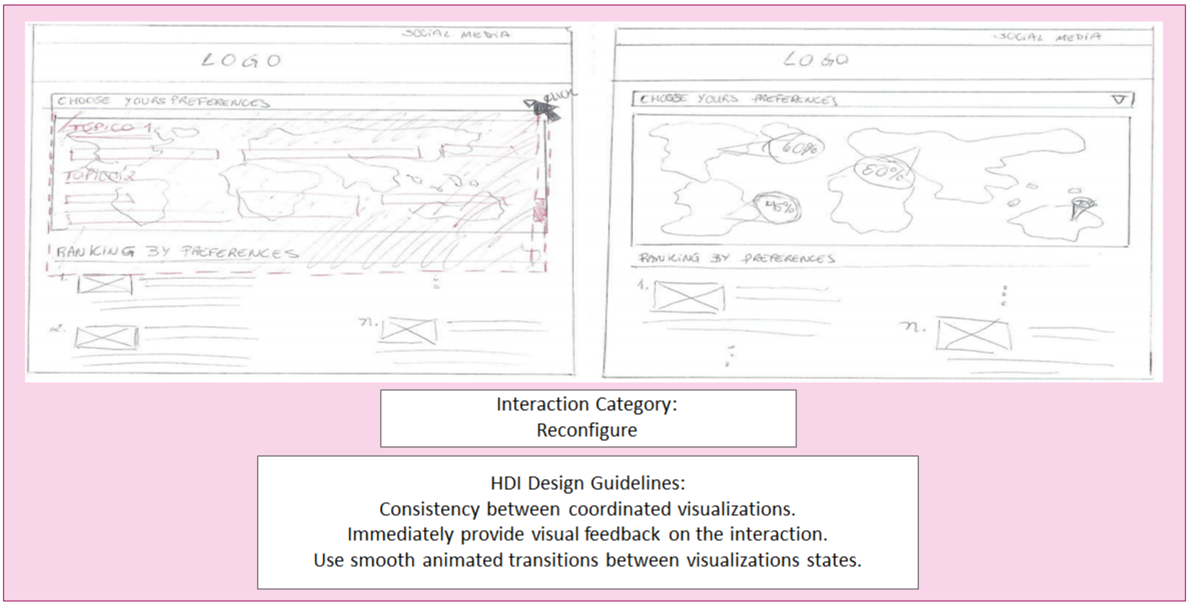

Figure 9. Sample drawing resulting from the BrainDraw activity adapted with two drawing areas and space for notes on the category of interaction and HDI design guidelines involved.

enable exploring the various interaction categories involved in the scenario and enable demonstrating the application of the HDI design guidelines. Preferably, the high-fidelity interactive prototype should be presented in Html files. In general, files of this type are generated automatically by prototyping tools.

The groups chose the prototyping tool they considered most appropriate. Most of the groups used tools such as Figma [4], Marvel [5], InVision [6] and Axure [7]. However, some groups adopted simpler alternatives, for example, using PowerPoint slides connected by links.

Sixteen groups built navigable prototypes detailing transitions to enable evaluating data interaction.

Figure 10 shows one prototype in which the "direct manipulation" guideline was applied to the "select" interaction category. Users selected one country on the map to obtain more information about it.

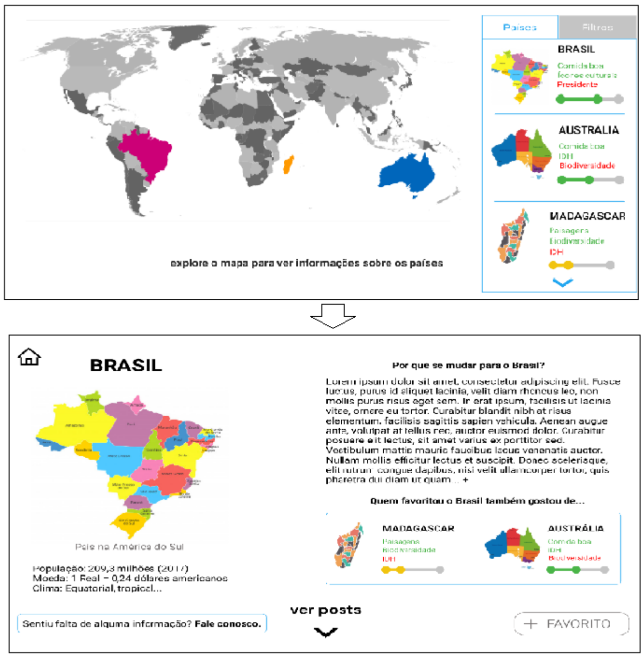

Figure 10. The transition between visualizations started with the interaction of the category "Select" to mark a country on the map. The "Maximize direct manipulation with data" and "Minimize information overload" guidelines were applied.

5 Evaluation

We conducted three different evaluations to assess our proposal. We evaluated the process and the quality of the product generated by the execution of the design process, which was materialized in the prototypes. In the first step, the prototypes were inspected to verify if the guidelines were used (see Subsection 5.1). The user experience in the interaction with the constructed prototypes was also evaluated (see Subsection 5.2). Additionally, we assessed the process conducted to generate the products asking participants about the usefulness of the process and guidelines (see Subsection 5.3).

[4]https://www.figma.com/
[5]https://marvelapp.com/
[6]https://www.invisionapp.com/
[7]https://www.axure.com/

5.1 HDI Design Guidelines Usage Evaluation

The goal of the first evaluation was to understand whether the teams really used the guidelines. The use of the guidelines was not mandatory and the designers could use only the ones they wanted or considered relevant for the scenario they planned. They could not use any guidelines if they did not consider them relevant. Therefore, we need to know if the guidelines were applied.

The prototypes were inspected to determine how much the HDI design guidelines were followed in constructing the prototypes. The inspector analyzed various interaction elements concerning the HDI design guidelines.

The prototypes were distributed to the evaluators in random order, with the restriction being that the group members could not evaluate the prototype developed by the group itself. Therefore, each participant analyzed the design solution materialized in an interactive prototype built by another group. The identity of the group that created the prototype being evaluated was hidden for the evaluators. All 52 participants inspected one of the 16 prototypes to verify the level of application of the guidelines. On average, 3 to 4 inspectors evaluated each prototype.

A form registered the analysis of HDI design guidelines usage. According to the inspector's judgment, each guideline received a classification with a scale from 0 to 5. Grade 0 indicated that the guideline was not used in the prototype; 5 referred to an adequate application of the guideline in all relevant points; the intermediate values on the scale represent partial use.

The inspectors were also instructed to justify the classification of each guideline in the prototype in a free-text form. Optionally, they could give suggestions for improving the application of each guideline. At the end of the form, the inspector could make suggestions for improving data interaction in a generic way, even if it were not related to the application of the guidelines.

Table 2 summarizes the results showing the number of prototypes that had the application of guidelines evaluated in a given range of grades. Almost all prototypes had grades greater than two and less than four. According to the evaluation scale used, these results indicate that the guidelines were applied in constructing the prototypes but not in all points where it would be possible to apply them. Only one of the sixteen prototypes was graded outside these ranges.

Table 2. Summary of the results of the inspection of application of guidelines indicating the number of prototypes evaluated in a given range of grades.

Average Grade	Number of Prototypes
$4 < grade < 5$	0
$3 < grade < 4$	8
$2 < grade < 3$	7
$1 < grade < 2$	1

We deepened the analysis, checking the extent to which each guideline was applied in the prototypes according to the participants' answers. Table 3 details each guideline, the average score received, and the standard deviation. The average score considered all assessments conducted by all participants/inspectors in all prototypes.

The guideline better evaluated was "*DG 5.1. Give Information Context*" - related to ensuring that users have the necessary information to know where they are and how to go or navigate where they want to go. Some inspectors considered that filters by countries and annotations about previous choices represented good ways to contextualize the user. The inspectors also highlighted that due to the simplicity of the application, it would be easy for users to know where they are and how to go where they want.

The following guideline better evaluated was "*DG 1.1. Self Evidence in Coordinated Views of Data*". This is a recommendation about making relation between multiple visualizations apparent to users. Many inspectors mentioned that users could always have a clear idea of the state of the visualization.

The worst rated guideline was "*DG 6.3 Refinement and training of models through user feedback*" - related to providing semantic interaction to capture a user's knowledge for refining models. Many inspectors understood that this guideline was not applied due to the complexity of its implementation compared to the simplicity of the constructed prototype. They gave suggestions for the evolution of the prototype using this guideline. Inspectors suggested that the application learn and behave according to user preferences for countries, hotels, etc.

We investigated whether the guidelines considered most important at the beginning of the study were the most used in designing prototypes. Comparing the results of Table 3 about guidelines usage and results about guidelines considered most relevant (see Section 4.2), we understood that the guidelines considered most relevant were not always the most used, as the following examples show:

- Design guidelines considered most relevant (see Section 4.2) were related to reinforcing a clear conceptual model. This assessment seems to be aligned with the fact that this group of guidelines has been widely applied in prototypes (see Table 3).
- The smooth animated transitions between visualizations were the least relevant in the participants' opinion (see Section 4.2). Although not considered relevant, it had a meaningful application in prototypes (see Table 3). This may be due to some tools' ease for implementing these guidelines.
- Guidelines related to semantic enrichment, although considered important in the results of initial activities (see Section 4.2), were little used in prototypes (see Table 3). We hypothesize that the participants were not entirely familiar with the concept of semantic interaction. The lack of experience working with semantic interaction in design made it harder for them to notice that concept in other existing applications. This made it difficult to apply that guideline in their projects. Additionally, the difficulty in implementing solutions to use these guidelines may have inhibited their exploration.

We also analyzed the variation between grades assigned by the participants. The standard deviation shown in Table 3

Table 3. Average Grade for the Application of each Guideline

Guideline	Average Grade	St. Deviation
DG 1. Reinforce a clear conceptual model.	—	—
DG 1.1. Self Evidence in Coordinated Views	4.07	1.21
DG 1.2. Consistency between coordinated visualizations	3.47	1.74
DG 1.3. Reversible Operations in visualizations	3.83	1.55
DG 2. Use smooth animated transitions between visualizations states.	3.02	1.76
DG 3. Immediately provide visual feedback on the interaction	3.38	1.79
DG 4: Maximize direct manipulation with data	3.34	1.66
DG 5. Minimize information overload	—	—
DG 5.1. Give information context	4.15	1.04
DG 5.2. Avoid requiring memorization	3.34	1.87
DG 6. Semantically enrich the interaction	—	—
DG 6.1. Semantically enrich search interaction	2.26	2.09
DG 6.2. Enriched feedback from humans incorporated into the system	1.21	1.82
DG 6.3. Refinement and training of models through user feedback	0.75	1.43

shows the most significant discrepancies, as in "*DG 6.1. Semantically enrich search interaction*". Initially, we suspected the differences could be due to a lack of understanding of the guideline, or the difficulty of recognizing the guideline application in the prototype.

We further investigated the justifications for the grades for each guideline. We observed that most of the inspectors adequately recognized the application of the guideline in the prototypes. However, although the inspectors read the proposed interaction scenario for the prototype, they did not know precisely what each part of the prototype intended to show. This may have generated a different understanding of the functionality of the same prototype.

We looked even deeper into the details of the grades received by each prototype. We investigated some very different grades for the same guideline in each prototype. Justifications for some divergent given grades clarified that some inspectors considered features that they thought the prototype intended to show. Meanwhile, other inspectors considered only what was implemented in the prototype. The grades assigned to guidelines application were well justified with consistent arguments, even if they presented a significant variation.

5.2 User Experience Evaluation

In the subsequent evaluation, our goal was to further understand users perceptions and responses that resulted from using the information visualization prototypes built in this study. We evaluated the experience that the participants had during the interaction with the prototypes developed.

For user experience evaluation, we chose six of the sixteen prototypes built. The criterion for selecting the six prototypes was the prototype classification regarding guidelines usage. We selected two prototypes with best, two with worst, and two with intermediate classification regarding guidelines application.

Forty-eight people participated in this assessment. Each participant evaluated the experience with two different prototypes. The prototypes were assigned to evaluators in random order, but assuring the assigned prototype was different from the ones they had built or evaluated in the first step (see Subsection 5.1). The developers' names of the evaluated prototype were hidden for the evaluators.

User experience is subjective, context-dependent, and changes over time. It includes the emotions and physical and psychological responses that occur before, during, or after product usage [ISO, 2018]. Users' experience with an interactive product involves several aspects, including the way it feels in their hands, how well they understand how it works, how they feel about it while they are using it, how well it serves their purposes, and how well the product fits into the entire context [Alben, 1996]. In short, the experience should be pleasant and useful for the user.

The participants should not position themselves as designers in this evaluation. They interacted with prototypes from the end-users perspective, executing an interaction scenario that prototype designers proposed in the Brainwriting for Data Interaction Design activity (see Subsection 4.3.1).

For experience evaluation, we asked one general question about the participant's perception with the question: "In general, what was your experience with the prototype?". Users answered by rating their experience on a scale from 0 to 10. We calculated the general experience of each prototype by the average score obtained in the answers to this question.

As a result, most prototypes' user experience was evaluated above the average scores. On a scale from 0 to 10, four prototypes scored above 6. The other two prototypes scored between 4 and 6.

Finally, we considered the hypothesis of a relation between the guideline's degree of use (application) and the user experience using the prototype. Figure 11 shows a scatter plot with the relation between the average grades for HDI design guidelines usage and the average grades for general experience perceived for each prototype. For guidelines usage, we considered the average grade obtained for each prototype taking into account the usage evaluation for all guidelines (see section 5.1).

We used too few prototypes to claim that this relation follows a linear pattern based on this graph. Therefore, the results require further investigation to verify if the more intensive the use of HDI design guidelines, the better the user experience tends to be.

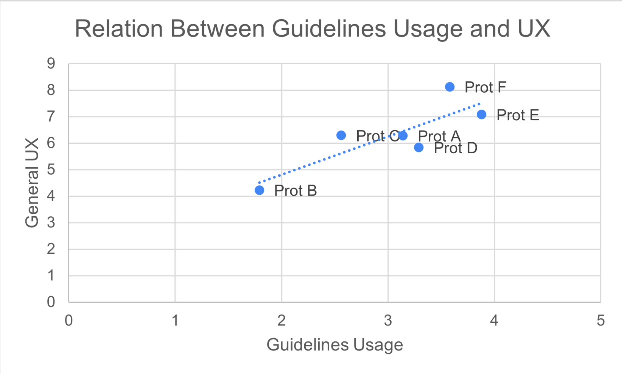

Figure 11. Relation between the average grade obtained in the HDI Design Guidelines Usage Evaluation and the general UX perceived by the users per prototype.

5.3 Evaluation of Process Practices and Guidelines

Finally, the participants were invited to evaluate the process, guidelines, and practices. The objective was to understand if the participants found the activities and guidelines easy to understand. It was also important to verify if the recommendations facilitated the design, were useful, and enabled everyone to participate. Thirty students who participated in the design activities assessed the process, guidelines, and practices. Responses to the assessment protocols were anonymous.

The participants assessed the guidelines and practices through an online questionnaire so we could understand how the participants perceived the different methods used, The participants expressed the level of agreement in ten sentences (four about the guidelines and six about the practices) and answered one open question. The sentences about guidelines are presented in Table 4, and the sentences regarding practices are shown in Table 5.

We used a Likert scale from 1 to 5 in which the respondents specified their appraisal of a specific aspect. For each sentence, the participant should choose one of the following options: "I totally agree" (N1 - weight 5- 100%), "I agree" (N2 - weight 4- 75%), "I neither agree nor disagree" (N3 - weight 3 - 50%), "I disagree" (N4 - weight 2 - 25%), and "I totally disagree" (N5 weight 1 - 0%). Based on these answers, a degree of agreement was calculated using the formula:

$$\text{Agreement} = \text{N1}*100 + \text{N2}*75 + \text{N3}*50 + \text{N4}*25 + \text{N5}*0)/\text{SUM(N1:N5)}*100$$

Figure 12 presents the data in two visualizations. The bars represent the absolute number of answers each sentence received from the participants. After the bar, we show the calculated degree of agreement, represented by a percentage.

All aspects had similar assessments. The guidelines were evaluated with intermediate scores. The best-evaluated aspect was item P2 - "opportunity to contribute to the design for all group members". The lowest grade was assigned to Item P6 - "BainDraw activity with two screens". The most general

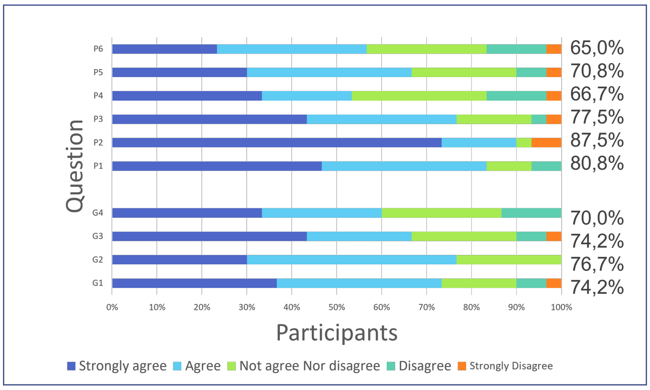

Figure 12. Questionnire answers for user evaluation of guidelines and practices.

items on participatory practices, such as items P1, P2, and P3 of Table 5, were the best evaluated. Nevertheless, items on specific participatory practices, such as P4, P5, and P6 of the Table 5, had a good assessment but slightly lower than more generic items.

6 Discussion

We proposed a design process to support inexperienced designers in conceiving IV applications in non-complex domains. Our contribution seeks to help design software tools that facilitate user interaction with data. The proposed design practices involve specific aspects of data-driven application design and consider data from a design perspective. The proposal has particular elements of HDI and information visualization.

The focus on HDI enabled a prior selection of guidelines. The design guidelines selected are specific to data interaction [Victorelli and Reis, 2020]. Interaction categories describe data-related actions to the data in IV systems [Yi *et al.*, 2007]. The verbs associated with data interaction categories drive the choice of interactions in practices in adapted Braindraw [Muller *et al.*, 1997], Storyboard [Greenberg *et al.*, 2012], and Brainwriting [VanGundy, 1984]. Participatory practices for prototyping acquired additional elements and recommendations to support the design of specific aspects of information visualizations.

The particularities demanded by the focus on inexperienced designers designing data interaction brought other implications for the proposed process. We introduced the predefined set of HDI design guidelines [Victorelli and Reis, 2020] before starting the design process. We anticipated introducing guidelines regarding the sequence of activities proposed in Victorelli *et al.* [2020b]. This order of tasks enabled the designers, even with little experience, to expand their knowledge of alternatives and act with a broader view of possible solutions.

One limitation of the work was inherent to the context in which it was carried out. It was desirable to involve a control group with participants not informed as to the set of guidelines, the process, and its practices. However, that was not possible, as this study was carried out in the context of a course for undergraduate students and had educational objectives. Leaving some students without the opportunity to learn the design process was undesirable. On the other hand,

Table 4. User Evaluation of Guidelines.

Item	Sentence
G1	I understood the HDI design guidelines.
G2	The design guidelines were used.
G3	All participants were able to argue about design guidelines.
G4	The guidelines helped drive interaction design.

Table 5. User Evaluation of Process Practices.

Item	Sentence
P1	The participatory practices suggested in the activities helped achieve the task's objectives.
P2	All group members had the opportunity to contribute to the design activities.
P3	The activities enabled the reconciliation of different points of view.
P4	The BrainWrite with verbs representing interaction categories helped create an analysis scenario.
P5	The Storyboard helped clarify the steps of the scenario.
P6	The BrainDraw with two screens on each sheet facilitate the appearance of new solutions for interaction design.

because the group of students was large, it was possible to involve more than fifty participants as designers, which is usually unfeasible.

The initial website exploration in the same context as the design problem may have inhibited the students' creativity. Probably, the use of this website may have influenced the design solutions. The participants' goals were to design a new solution to the problem of choosing a country to live in. We did not expect a redesign of an existing application. However, most prototypes generated had a home page with a map similar to the evaluated website. To avoid bias in the solution, the participants should explore websites that involve the guidelines being studied but that deal with an unrelated theme in future experiments.

Other limitations can be overcome in the next studies. It is feasible to improve the process to consider the selection of the data sources phase. And finally, it is also possible to conduct more detailed user experience evaluations with a validated tool, even if it is not dedicated to information visualization systems.

Despite their limited experience as designers, we found that the students understood the HDI design guidelines and interaction categories. Based on our workshop observations and results, we observed that the participants mastered these subjects. The participants could discuss the design guidelines and the interaction categories using appropriate terms, meanings, and application forms. When working on the design activities, the guidelines and interaction categories became part of their vocabulary.

Additionally, the participants adequately evaluated the guidelines on existing websites and prototypes. They also gave many relevant suggestions when inspecting the guidelines' application in prototypes other students built. We interpreted the excellent quality of evaluations and justifications the participants provided as another indication that they reasonably understood the guidelines and interaction categories presented.

Above all, the participants used the guidelines in the solutions designed. The reasonable grades assigned for guidelines usage in the prototypes (see Table 3) may indicate that the HDI design guidelines were helpful for designing them. The participants generally used the recommendations in the prototypes constructed at points that were appropriate and directly related to the guidelines. They were not limited to the obvious applications, which enable the emergence of ideas for innovative solution. For example, one of the groups developed a quiz to trace user interests and present personalized recommendations and data considering the quiz results.

From a different perspective, the participants' guideline assessment can represent a relevant contribution to the evolution of the guideline repository proposed by Elmqvist *et al*. [2011]. Our study included several guidelines from that repository. The repository author asked for contributions from people other than the creators themselves. In our study, the participants' assessment highlights some strengths and weaknesses of the guidelines in the repository.

Another positive aspect was the feasibility and usefulness of the proposed practices. The participatory approach facilitated the design of interactions in the information visualization application for use in the common-sense domains by inexperienced designers according to the level of agreement for P1 to P6 in Figure 12). According to these results, we have more than 80% agreements that all group members had the opportunity to contribute to the design activities, and that the suggested participatory practices helped achieve the objectives of the design activities. The results also show more than 75% agreement regarding the possibility of reconciling different points of view of several participants.

We observed that inexperienced designers were inspired by users' intentions listed in the interactions categories [Yi *et al*., 2007]. The practices of Storyboarding [Greenberg *et al*., 2012], BrainDraw [Muller *et al*., 1997], and Brainwrite [VanGundy, 1984] combined with the interactions categories [Yi *et al*., 2007] seem to have facilitated designing the application and helped structure the design activities. We materialized a practical way to conduct design by adapting these practices to the context of interaction with visualizations and incorporating the categories of Yi *et al*. [2007]. The adapted techniques made it easier for inexperienced designers to identify what type of interaction they could use in their design.

The usefulness of specific participatory practices, such as BrainWriting and BrainDraw, had a good evaluation but was slightly lower than the other questionnaire items (see P4 and P6 in Figure 12). There were variations in how the participants conducted these activities, although the practices were simple, and their step-by-step procedures were very detailed. The variations may indicate that the participants need more explanations about the activities and their objectives. We will refine the practice description to deal with the detected deviations. We intend to include an oral explanation and discussion of the practices before the execution.

Several groups significantly advanced the design solution when they performed the BrainDraw activity (see Subsection 4.3.3). Thanks to this practice, the groups managed to deepen the analysis of the interaction dynamics in the solution and went far beyond drawing the elements of each screen. It is worth further investigating what aspects triggered the sped-up progress at this stage. This deepened understanding may help find a way to start this sped-up advance early in the process and lead to improvements in the "Understanding" phase (see Subsection 4.2).

We observed that design support tools were crucial in making participatory practices feasible. The participants were allowed to choose the tools they would use. They preferred to use paper during the workshops. When the participants could not complete the activities during the workshop, they needed a tool that supported the design done remotely in a collaborative manner. Most groups chose tools that helped remote activities carried out by several designers simultaneously. The immediate updating of information between the various group members seems to have been considered more important than other advanced features offered by some design tools. We understand this is one of the most relevant requirements for prototyping tools that support participatory design practices carried out remotely.

The user experience evaluation (see Section 5.2) sought to understand relevant aspects of the product quality generated by the proposed process. The participants' assessment seems to indicate that the products generated by the process (the prototypes) provide a good experience. Figure 11 showed an apparent correlation between guidelines application and general experience perceived. In this graph, the more significant application of the guidelines corresponds to the prototypes with a better overall experience perceived by the user. We plan to study instruments further to evaluate the experience with HDI applications in future work.

The evaluations carried out in this study provided prospects for new activities that can help to refine our proposal. Some methods are proposed in the literature to assess user experience applicable to software applications [Hassenzahl and Tractinsky, 2006; Minge *et al.*, 2017]. However, they do not focus on the dynamic aspects of data interactions. In subsequent studies, we will analyze existing evaluation instruments and propose new criteria for HDI-related user experience.

Considering data from a design perspective is still an under-explored research topic. Existing efforts in related research must be added to enable progress in this area. We intend to study ways to harmonize our results with other initiatives that approach the subject from different perspectives [Seidelin *et al.*, 2020; Muller *et al.*, 2019; Feinberg, 2017]. Adding the results of studies focused on selecting data sources to our proposal can provide new ideas about the method and the activities needed in each design step [Feinberg, 2017]. We consider it relevant to evolve our approach to have practices to deal with the complexity inherent in selecting data sources. We understand that improving our proposal for data interaction design with co-design practices is possible [Seidelin *et al.*, 2020]. Combining these approaches may improve the current data practices, help address potential challenges, and obtain more significant benefits from exploiting large volumes of data.

7 Conclusion

Inexperienced designers can provide new undiased ideas for information visualization solutions. However, designers with little experience may find it difficult to participate in such design process without support. They lack sufficient knowledge of design guidelines, and participatory practices are not focused on developing data-driven applications. This article proposed a design process to guide inexperienced designers in creating information visualization applications. We used a set of HDI design guidelines and interaction categories as input and combined them with participatory practices defined to consider the context of data interaction. We found that the proposal is feasible to be used by inexperienced designers.

The participants exhibited facility in using the proposed guidelines and practices and were comfortable discussing their ideas with arguments based on the guidelines. They effectively used the recommendations in developing prototypes and inspected prototypes using them.

The results indicate the feasibility of applying our proposal in information visualization development projects in common-sense domains.

Declarations

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Authors' Contributions

EV and JR contributed to the conception of this research approach, planned the experiments, and conducted the workshops. EV analyzed the results and is the writer of this manuscript. JR reviewed the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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