Validation and Refinement of Usability Heuristics for Interactive Web Maps

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Abstract: The usability of interactive web mapping systems is crucial for a wide range of applications, extending from urban planning to personal navigation. This study, grounded in the context of Human-Computer Interaction (HCI), specifically aims to enhance the usability of interactive web maps. The goal is to provide designers and developers with improved guidelines that not only elevate the user experience but also effectively address the unique challenges of these interfaces, promoting more efficient navigation. Our methodology is distinguished by the development of new usability heuristics, derived from a detailed analysis of the specificities of interactive web mapping systems. The study proposes the introduction of a set of 12 usability heuristics, carefully adapted for these systems. The preliminary results are promising, outlining a set of heuristics that have the potential to be significant in the design and implementation of interactive web maps. The contribution of this study is substantial, offering new perspectives for the continuous improvement of usability heuristics and emphasizing the need for specific approaches for different digital interaction contexts. Thus, this work not only advances the theoretical field of HCI but also provides crucial practical guidelines for the future development of interactive web mapping systems, meeting the current demands and expectations of users.

1 INTRODUCTION

The User Interface (UI) serves as the gateway through which the user interacts with the system. This interaction underpins the overall user experience, which may determine the effectiveness, efficiency, and satisfaction during product use. A well-designed user interface allows users to navigate and operate the system in a planned manner, significantly contributing to a positive experience. Therefore, UI design is not just about aesthetics; it is an essential component that connects the user to the system, facilitating a harmonious and efficient interaction.

To ensure the efficiency of an interface design in the Human-Computer Interaction (HCI) field, quality of use criteria such as usability, communicability, user experience, and accessibility are essential (Barbosa et al., 2021). Among these, usability emerges as a fundamental criterion for evaluating the effectiveness of this interaction. According to Nielsen, usability is defined by the ease with which the interface can be learned and used, as well as the satisfaction provided by the system's efficient operation (Nielsen, 1994). To achieve this objective, principles known as usability heuristics are employed, which guide designers and developers in creating and evaluating interface designs.

Since their formulation in the 1990s, Nielsen's heuristics have been a milestone in the field of usability (Nielsen, 1994). Composed of 10 widely recognized principles, these heuristics are used to comprehensively identify usability problems in interfaces. However, despite providing a solid foundation, these heuristics do not fully cover the nuances and specific requirements associated with new devices and emerging systems, such as web-based interactive map visualization systems (Griffin et al., 2017)(Roth et al., 2017). This scenario highlights the need to adapt or develop new heuristics that consider the unique characteristics of these modern technologies (Jiménez et al., 2012).

The development of specialized usability heuristics is vital for significantly improving the user experience, particularly in areas where interactions are intri-

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cately complex, and demands are extremely specific. In this context, this research proposes a new set of usability heuristics meticulously adapted for interactive maps on the web. Our goal is to provide designers and developers with an enhanced set of guidelines that can be applied to enrich the user experience in interacting with these maps. This new list of heuristics aims to address interactive maps' peculiarities and unique challenges, ensuring more efficient and effective navigation.

2 BACKGROUND

In the field of HCI, usability heuristics play a crucial role in the system evaluation process. They are used as guidelines to identify potential usability problems. Among the evaluation methods used in HCI, which Barbosa et al. (2021) categorizes into three groups: investigation, inspection, and observation, usability heuristics are specifically employed during the inspection method, particularly in heuristic evaluation. This approach involves a detailed analysis of interfaces to detect and resolve issues, thereby optimizing the user experience. This technique involves a thorough analysis of interfaces to identify and solve problems, significantly contributing to the enhancement of the user experience. Heuristic evaluation, a methodology introduced by Nielsen and Molich (1990), is recognized as a highly effective inspection method, characterized by its detailed analysis of products or interfaces in search of usability issues. This approach is valued for its agility, cost-effectiveness, and efficiency. During heuristic evaluation, specialized evaluators inspect a system's interface, using a set of usability heuristics as a reference for identifying problems, thereby ensuring a rigorous and comprehensive assessment.

Nielsen's heuristics, widely recognized in the field of usability, consist of ten fundamental principles, each accompanied by a name and a detailed description (Nielsen, 1994):

Visibility of System Status (1). The design should always keep users informed about what is happening within a reasonable timeframe.

Match Between the System and the Real World (2). The design should speak the users' language. Use words, phrases, and concepts familiar to the user, rather than internal jargon. Follow real-world conventions, making information appear in a natural and logical order.

User Control and Freedom. Users Often Perform Actions by Mistake (3). They need a clearly marked "emergency exit" to leave an unwanted action without having to go through a lengthy process.

Consistency and Standards (4). Users should not have to wonder if words, situations, or actions mean the same thing. Follow platform and industry conventions.

Error Prevention (5). Eliminate operation errors through confirmation conditions and presentation before proposing a confirmation action.

Recognition Rather than Recall (6). Minimize the user's memory load by making elements, actions, and options visible. The user should not have to remember information from one part of the interface to another. Information needed to use the design should be visible or easily retrievable when needed.

Flexibility and Efficiency (7). Shortcuts, hidden from novice users, can speed up interaction for the experienced user, so that the design can cater to both inexperienced and experienced users. Allow users to customize frequent actions.

Aesthetic and Minimalist Design (8). Interfaces should not contain irrelevant or rarely needed information. Each extra unit of information in an interface competes with relevant information units and diminishes their relative visibility.

Help Users Recognize, Diagnose, and Recover From Errors (9). Error messages should be expressed in plain language (no error codes), precisely indicate the problem, and constructively suggest a solution.

Help and Documentation (10). It's best if the system does not need any additional explanation. However, it may be necessary to provide documentation to help users understand how to complete their tasks.

However, despite the proven effectiveness of these general heuristics, they may not be fully suitable to address the specific challenges found in new applications and devices. This gap has motivated the development of new sets of heuristics tailored to specific domains to meet the unique demands of these modern applications, as mobile maps (Kuparinen et al., 2013), virtual worlds (Rusu et al., 2011), interactive digital television (Solano et al., 2011), visualization systems (Victorelli and Reis, 2020), and extended reality applications (Vi et al., 2019),

With the aim of identifying new sets of usability heuristics, Jimenez et al. (2016) conducted a literature review and identified nine articles proposing new sets. However, it is important to note that despite the introduction of these new sets, they were not created using a specific methodology designed for this purpose. Instead, the majority adopted an approach that combined Nielsen's heuristics with domain-specific characteristics, while others were developed based on expert opinions. This varied approach to creating heuristic sets highlights the lack of a standard in this research area and the importance of adapting heuristics to meet the specific needs of different application domains.

To fill these gaps, Quiñones and Rusu (2019) proposed a new methodology for the development of domain-specific usability heuristics. This methodology consists of eight stages, whose data inputs are:

- Exploration: collection of information about the application, gathering usability attributes, and survey of a set of heuristics and/or other relevant elements.
- Descriptive: Analyze data that are obtained in different experiments to collect additional information that has not been identified in the previous stage
- Description: classification of selected information and resources about the application, selection of usability attributes, selection of a set of heuristics and/or other relevant elements.
- Correlation: correlation of corresponding characteristics, attributes, and existing heuristics, definition of categories.
- Selection: process of adjusting and refining information for the creation of each heuristic.
- Specification: description of the heuristics of the new set.
- Validation: verification of the performance of the new set.
- Refinement: descriptive document of the proposed new set.

It provides a structured protocol to guide the process of creating usability heuristics, ensuring their relevance and effectiveness in specific domain contexts. This approach has proven versatile in developing sets of heuristics for various applications, such as Progressive Web Applications (PWA) (Anuar and Othman, 2022) and Mobile Health Applications (UGmHA) (Nasr et al., 2023).

In the context of interactive web maps, Marquez et al. (2021b) identified the need to develop a specific set of heuristics aimed at enhancing usability in this area. To this end, they adopted the methodology proposed by Quiñones and Rusu (2019) to formulate a new set of domain-specific usability heuristics. After completing the stages of exploration (1), description (3), correlation (4), selection (5), and specification (6), the authors introduced a set consisting of 10 specific heuristics for Interactive Web Mapping (IWM) applications.

To validate this new set, Marquez et al. (2021a) carried out the validation stage (7) of the methodology by Quiñones and Rusu (2019), which involves three types of evaluation: expert analysis, heuristic evaluation, and user testing. Initially, an expert analysis was conducted, including a detailed evaluation of each heuristic, focusing on clarity, ease of use, and the need for additional checklists, to ensure that they effectively addressed the key usability aspects relevant to IWM. The completeness of the heuristic set was also assessed to ensure that it covered all critical elements affecting the user experience in interactive web map applications. As a result of this process, Marquez et al. (2021a) presented version 2 of the heuristic set, incorporating refinements based on expert feedback, aiming to further enhance its applicability and effectiveness in the context of IWM. Subsequently, a heuristic evaluation was conducted, the outcomes of which led to the development of version 3 of the heuristic set, detailed in this article.

3 RESEARCH METHOD

Continuing the quest for improvements, a new validation phase was conducted, heuristic evaluation, resulting in the third version of the set of 12 usability heuristics designed for IWM Applications. This iteration represents an ongoing effort to refine and expand usability heuristics, ensuring that they more precisely meet the demands of users in this specific context.

3.1 Data Collection

The heuristic evaluation was conducted with the purpose of assessing the effectiveness of the proposed heuristics in identifying usability issues. For this purpose, both the specific set for IWM applications (Marquez et al., 2021a) and Nielsen's set (Nielsen, 1994) were employed. The evaluation took place on the CulturaEduca [1] platform, an innovative platform developed by Instituto Lidas in collaboration with the Special Secretariat of Culture (SECULT/Brazil). This platform provides a specialized tool for visualizing geographic data and integrating essential information in the fields of education and culture.

The evaluation involved the participation of eight volunteers, comprising six males and two females.

[1] Link: https://culturaeduca.cc/

The volunteers included graduate students and professionals in the field of Computer Science, all of whom had no prior experience using the platform. This study received approval from the Ethics and Research Committee of the Federal University of São Paulo (CAAE: 52578921.4.0000.5505), and all participants agreed to the Informed Consent Form (ICF) presented at the beginning of the heuristic evaluation process.

The evaluation procedure was divided into three distinct stages:

- In the first stage, we introduced the study and presented an explanatory video lasting twelve minutes detailing the theme and the nature of the evaluation.
- In the second stage, participants filled out a form providing information about their previous experiences in usability and geographic information visualization, characterizing the profile of the volunteers.
- Finally, in the third stage, participants conducted the heuristic evaluation, identifying usability problems on the platform during a 40-minute period. We established this duration to balance the depth and breadth of the evaluation with the well-being and attention of the participants, based on previous experience. In this period, 10 minutes are dedicated to familiarizing with the interface, and another 10 minutes are allocated for specific tasks to obtain targeted insights on usability aspects. The remaining 20 minutes are reserved for free exploration, allowing for a more natural and spontaneous interaction with the system. The heuristic evaluation involved performing three exploration activities:
  - Initially, participants conducted a search for layers.
  - Next, they performed a search for filters.
  - Lastly, they had the remaining time to conduct free exploration and collect usability problems.

The participants were randomly divided into two groups: Group A was responsible for conducting the evaluation using the proposed set of usability heuristics for IWM (Marquez et al., 2021a), and Group B used Nielsen's usability heuristics (Nielsen, 1994).

3.2 Analysis

In total, 56 usability problems were identified, 32 identified by Group A and 24 by Group B. To assess the performance of each set of heuristics, the five criteria described in the methodology by Quiñones and Rusu (2019) were applied:

- Criteria 1 - Numbers of Correct and Incorrect Associations of Usability Problems in Relation to Heuristics:

  The identified usability problems are analyzed and classified as correct or incorrect in relation to the heuristics they were associated with. The effectiveness of Correct Associations (CA) and Incorrect Associations (IA) was evaluated using equations 1 and 2.

$$CA = \left(\frac{\sum_{n-1}^{T} CAHn}{TP} \right) \times 100 \quad (1)$$

$$IA = \left(\frac{\sum_{n-1}^{T} IAHn}{TP} \right) \times 100 \quad (2)$$

  In this equation:

  CA: Correct associations;

  IA: Incorrect associations;

  T: Total number of heuristics in the set;

  CAHn: Number of correct associations of problems in "n" heuristics;

  IAHn: Number of incorrect associations of problems in "n" heuristics;

  TP: Total usability problems identified.

  To be considered as having good performance, the experimental set should have $CA(A) > CA(B)$ and $IA(A) < IA(B)$.

- Criteria 2 - Number of usability problems identified:

  Usability problems were divided into three groups:
  - P1 - Problems identified by both sets.
  - P2 - Problems identified only by the experimental set (A).
  - P3 - Problems identified only by the control group (B).

  The experimental set is considered to have good performance if P1 and/or P2 are greater than P3.

- Criteria 3 - Number of usability problems identified as specific:

  To assess the Effectiveness of Usability problems considered Specific (ESS), the selection criterion adopted was problems directly related to the visualization of geographic data. The efficacy of the number of specific problems was calculated using the equation 3:

$$ESS = \left(\frac{NSP}{TP} \right) \times 100 \quad (3)$$

  In this equation:

ESS: Effectiveness;

NSP: Number of usability problems identified as specific;

TP: Total usability problems identified.

To be considered as having good performance in this criterion, it is necessary for ESS(A) to be greater than ESS(B).

- Criteria 4 - Number of usability problems identified that qualify as most severe:

  Usability issues were assessed and categorized according to their severity using Nielsen's severity scale (Nielsen, 1993) (Table 1). The Effectiveness (ESV) of the set was determined by dividing the number of usability problems with a severity rating greater than 2 by the total number of usability problems (Equation 4).

$$ESV = \left(\frac{NPV}{TP}\right) \times 100 \quad (4)$$

In this equation:

ESV: Effectiveness;

NPV: Number of specific usability problems identified that qualify as severity greater than 2;

TP: Total usability problems identified.

Similarly to the previously mentioned criteria, the performance of the experimental set (A) is considered good when ESV(A) is greater than ESV(B).

Table 1: Severity of usability problems.

Value	Severity	Description
0	No problem	Not considered a usability problem.
1	Cosmetic problem	No immediate need for a solution, only if there is extra time available
2	Minor problem	Fixing this problem is desirable, but it receives low priority
3	Major problem	Fixing this problem is desirable, but it receives low priority
4	Catastrophic problem	Important to fix, receives high priority

- Criteria 5 - Number of usability problems identified that qualify as most critical:

  Based on the number of usability problems obtained in the severity analysis, we were able to calculate the frequency (Equation 5) of the identified problems. Subsequently, we identified the corresponding frequency value in Table 2 and calculated the criticality by adding this value to the severity of the problems:

$$Frequency = \left(\frac{gravity}{TP}\right) \times 100 \quad (5)$$

In this equation:

Frequency: Frequency of incidence;

Severity:Number of usability problems found in the severity analysis;

TP: Identified usability problems.

Table 2: Value associated with the frequency of usability problems for determining criticality.

Frequency	Gravity
<1	0
1 - 10	1
11-50	2
51 - 90	3
>90	4

3.3 Results

The Table 3 presents the results of experimental group A and control group B for each of the criteria mentioned earlier.

Table 3: Values achieved for the five performance criteria.

Criteria	Group A	Group B
Percentage of correct associations (CA)	84,4 %	83,3%
Percentage of incorrect associations (IA)	15,6%	16,7%
Number of usability problems identified	P1 = 16 P2 = 22 P3 = 18	
Efficacy in terms of the number of specific usability problems identified (ESS)	59,4%	62,5%
Efficacy in terms of the number of usability problems that qualify as more severe (ESV)	84,4%	54,2%
Efficacy in terms of the number of usability problems that qualify as most critical (ESC)	84,4%	54,2%

Based on the results, it becomes evident that the differences in performance between Group A and Group B raise interesting questions about the effectiveness and specificity of usability heuristics in the context of interactive web maps. The ability of Group A to identify a greater number of usability problems suggests that the new heuristics created may have value in addressing a wider range of issues. This highlights the potential of these new heuristics to positively contribute to usability assessments in this domain.

On the other hand, Group B's superior performance in criterion 3, related to specific usability problems, indicates that there may be room for improvements in the heuristics associated with this criterion. This finding emphasizes the importance of refining and adapting heuristics to effectively address domain-specific challenges.

To provide a qualitative overview, we delved into the nature of the usability issues identified by each group. For instance, the findings from Group A may encompass a diverse range of issues spanning navigation, information layout, and user interaction, reflecting the comprehensive applicability of the new heuristics. In contrast, the problems identified by Group B, are more specialized, indicating the need for further refinement of the heuristics that focus on specific usability challenges.

While the differences are statistically detectable, their magnitude is small and should be considered in the appropriate context. Moreover, we acknowledge that these subtle variations might not be robust enough to directly influence design decisions or recommended practices without a deeper analysis of the specific contextual nuances of use. This understanding is crucial to ensure that our conclusions are both accurate and relevant. Based on the findings, we were able to make significant adjustments to the proposed heuristics to address the identified issues, refining our contribution to the usability field.

4 USABILITY HEURISTICS FOR INTERACTIVE WEB MAPS

After refining the heuristics, we identified commonalities and patterns that emerged in their application. These insights have allowed for an organized grouping of the heuristics based on their shared attributes. By categorizing them into cohesive groups, we enhance the clarity and ease of application, thereby increasing their efficacy in assessing the usability of interactive web map systems. In this evolved framework, the usability heuristics are strategically divided into three targeted groups: map verification heuristics, information verification heuristics, and system verification heuristics (Figure 1). Each group is meticulously tailored to address the distinctive elements of interactive web map systems. Every heuristic within these groups is defined with precision, assigned a unique identifier, and described with a lucid definition, serving as an extensive toolkit for the evaluation and improvement of interactive web map usability.

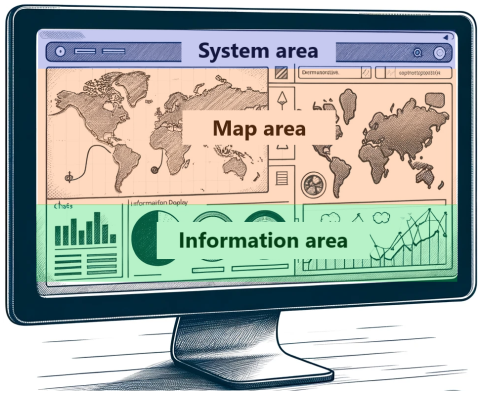

Figure 1: Representation of the three usability heuristics groups for interactive web maps. Image created by the author.

4.1 Map Verification Heuristics

In the Map Verification Heuristics group, the heuristics are specifically focused on the map area, meaning they should be applied to assess the regions where one or more maps are represented. The Figure 2 presents examples of two usability problems identified by the usability heuristics for interactive web maps.

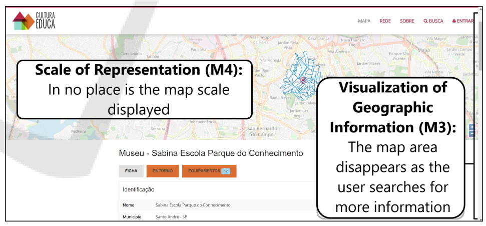

Figure 2: Examples of usability problems identified by the map verification heuristic group. Image created by the author.

Representation of Geographic Data (M1). The information displayed on the map, such as symbols, labels, or toponyms, should be visible regardless of the scale adopted.

Map Manipulation Tools (M2). The map manipulation tools should be functional, understandable, and easily accessible.

Visualization of Geographic Information (M3). The map layout should remain visible throughout its use.

Scale of Representation (M4). The user should be informed about the scale at which the map is being represented.

Cartographic Conventions (M5). The adopted symbols should comply with cartographic standards and be presented in a visible and well-defined manner.

4.2 Information Verification Heuristics

Concentrated on the presentation and organization of information within the system, this set of heuristics aims to ensure that data, both geographic and non-geographic, is displayed in a logical, understandable, and accessible manner. The Figure 4 presents an example of a usability problem found with a heuristic from the information verification group.

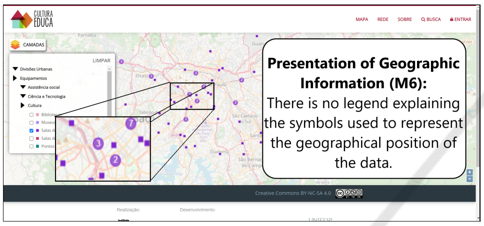

Figure 3: Examples of usability problems identified by the information verification heuristic group. Image created by the author.

Presentation of Geographic Information (M6). The search results related to a position in geographical space should be organized and standardized in their descriptions.

Presentation of Non-Geographic Information (M7). The presentation of non-geographic information should not overlap the entire map area.

Search Mechanisms (M8). The search mechanisms should be prominently featured in the interface.

Export of Geographic Information (M9). Provide a function that allows for the export of the map and the researched geographic data.

4.3 System Verification Heuristics

This focuses on the overall usability of the system and the user's interaction experience with the interface. This group of heuristics addresses cross-device compatibility and the overall ease of use of the platform. The Figure 4 presents an examples of usability flaws identified by the system verification heuristic group.

Ease of Learning (M10). The interface should facilitate understanding of the control devices and how to use them.

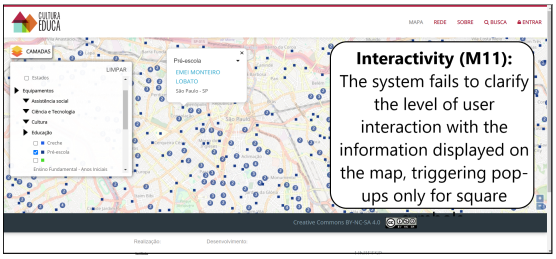

Figure 4: Examples of usability problems identified by the system verification heuristic group. Image created by the author.

Interactivity (M11). The level of interactivity allowed with the map should be clear to the user.

Compatibility with Different Devices and Browsers (M12). The interface should adapt to different screen sizes and offer the same effectiveness regardless of the device or browser used.

5 CONCLUSION

This study originated from the need to develop specific usability heuristics to meet the unique demands of interactive web maps, recognizing the gap in general usability heuristics. We focused our efforts on creating a set of heuristics specially tailored for this domain. The development of this set followed an established protocol, based on a robust and proven methodology. This systematic process not only ensured the comprehensiveness and relevance of the heuristics but also ensured that they were meticulously adapted to address the complexities and specific challenges found in interactive web map systems.

The development and refinement of version 3 of usability heuristics for interactive web maps represent a significant milestone in the refinement process. The first version underwent a rigorous validation phase involving experts in usability and cartography, which was essential to ensure the accuracy and effectiveness of the heuristics in the practical context of IWM systems. The adoption of an interdisciplinary approach involving experts in both Computer Science and Cartography has proven to be extremely valuable, significantly expanding the scope and relevance of the heuristics. This collaborative effort has the potential to further advance the field of usability evaluation in the context of interactive web maps.

As presented in this article, the second version of the heuristics was subsequently applied in the heuristic evaluation of a geographic information visualization system, providing valuable insights for the development of version 3. The results demonstrated superior performance of the proposed set of heuristics compared to the already established set. However, the difference in the values found was not significant, highlighting the importance of heuristics adaptation. This ongoing cycle of development, testing, and refinement underscores the evolving nature of heuristics and their ability to adapt to changes and advancements in the field of interactive web maps.

This is an ongoing research, and our plans for future work include several important steps. Firstly, we plan to conduct a new expert analysis, followed by another heuristic evaluation. Both analyses aim to ensure the validity and comprehensiveness of the developed usability heuristics. Additionally, we intend to perform usability tests with real users, ensuring that all tests receive equal attention and emphasis. To achieve this, we will form an interdisciplinary team of participants, involving professionals from the fields of Computer Science and Cartography, to ensure a comprehensive and representative evaluation. These tests will allow for the practical validation of the heuristics and the identification of potential improvements. Based on the results of these tests, we plan to iterate on the heuristics, refining and adapting them as needed. Furthermore, we will continue to collaborate with experts from different disciplines to further enrich our approach and promote advancements in usability evaluation in the context of interactive web maps.

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