

USER EXPERIENCE OPTIMIZATION AND ACCESSIBILITY EVALUATION IN HUMAN–COMPUTER INTERACTION SYSTEMS: A MULTI-DIMENSIONAL ANALYTICAL APPROACH

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ABSTRACT

The field of Human -Computer Interaction (HCI) has emerged as a problematic area in computer science and engineering that deals with the enhancement of the interaction between people and digital systems. As web-based and smart systems and platforms have become more and more relied upon, user experience (UX) optimization and accessibility have become a critical design imperative. This study is a full-fledged research study on how usability is related to accessibility and user satisfaction using a multi-dimensional analysing model. This is a mixed-method study, which combines both the quantitative measure of usability and the qualitative user feedback in offering a comprehensive analysis of interactive systems. In the study, the key performance indicators were identified to include usability efficiency, accessibility compliance, user engagement, learnability, and error rates. The results show that accessibility-driven design and user satisfaction are strongly related positively and thus accessible systems have a great role in enhancing usability. The statistical analysis also proves that accessibility is a significant factor that defines the overall system efficiency. The study helps the establishment of the systematic framework supporting the inclusive and user-centered system design, with the practical implications to developers, designers, and organizations intending to construct efficient and user-friendly digital solutions.

Keywords: Human–Computer Interaction, User Experience, Accessibility, Usability, Inclusive Design, User Satisfaction, System Efficiency

1. INTRODUCTION

The blistering development of digital technologies has changed the manner in which the users interact with computing systems significantly, and therefore, the Human-Computer Interaction (HCI) has become an important issue in computer science and engineering. The modern systems of web application, mobile and smart interface demand not only a functional performance but also efficient and simplified interaction. UX has become one of the factors of system success, since it includes usability, efficiency and user satisfaction. Simultaneously, accessibility has been regarded as a crucial element of system design so that digital platforms can be accessible to people with various abilities and needs.

Accessibility is a term that has not always been considered in the development process, despite the improvements in the sphere of UX design. Most systems tend to focus on visual attractiveness and performance but exclude the concepts of inclusive design, which creates obstacles to some groups of users. This lack of touch points shows that a more organized and integrated strategy should be used where usability and accessibility are integrated with the aim of attaining the best system performance.

Combining usability and accessibility is an important aspect of improving the quality of interaction. Simple systems that are simple to operationalize, efficient to work with and accessible to more people are likely to enhance user interaction and minimize errors in interaction. In addition, inclusive design practices also help enhance the overall acceptance by the users and the reliability of the system; hence, they are also a necessity in the contemporary application development.

In that regard, the current research is dedicated to the investigation of the linkage between usability and accessibility in the context of HCI systems by a multi-dimensional method of analysis, to study how both variables depend on each other, how user experience is affected by both quantitative and qualitative approaches, which parameters play the most significant role, and what framework allows to optimize user experience. The study highlights the necessity to consider accessibility concepts during the early stages of design in order to create inclusive, effective and user-friendly online systems.

2. LITERATURE REVIEW

Aizpurua et al. (2016) studied how web accessibility is related to the user experience and discovered that there was a positive correlation between accessibility and the usability and user satisfaction. Their experiment established that the systems that were made with the accessibility factor in mind did not only

accommodate the users with disabilities but also made overall user interaction quality much better, which supported the validity of the need to incorporate accessibility into the design of the UX. Also, their results indicated that a compliance of accessibility could be one of the strategic methods to enhance the overall system functioning and user interaction.

Alkatheiri (2022) examined how artificial intelligence contributes to the improvement of interaction between humans and computers and found that AI-based systems were much more effective in adapting to the user, personalizing their systems, and providing an efficient way to interact. The research highlighted that smart systems would be able to dynamically modify interfaces based on the various needs of users hence leading to improvements of usability and accessibility. In addition, the study suggested that AI technologies were able to decrease user effort and cognitive load, automating interface customization.

Antona and Stephanidis (2015) explored the idea of universal access in HCI and emphasized the importance of creating systems which support the full diversity of user capabilities and settings. Their work stressed that the principles of inclusive design were necessary in order to reach accessibility and give fair access to digital technologies. They also underlined that universal design strategies led to sustainable development in the long-term and a general acceptance of digital systems by the user.

Carvalho et al. (2017) explored quality attributes and metrics of HCI systems in ubiquitous computing systems. They found that usability, accessibility, and system performance were the main factors that affect user satisfaction and suggested systematic measures of evaluation to measure such aspects in a productive way. Besides, the study has also emphasized the use of continuous monitoring and evaluation in ensuring the quality of the system under dynamic computing conditions.

3. RESEARCH METHODOLOGY

The research design in this study was a mixed-method research design, in order to assess the user experience and accessibility of Human-Computer Interaction (HCI) systems in their entirety. The methodology was to combine quantitative data, which was gained with the help of structured usability metrics with the qualitative data, obtained with the help of user feedback and analysis of interactions. This integration methodology was what allowed the holistic view of the performance of systems by getting the objective results as well as the subjective perceptions of the users.

3.1 Data Collection

To be reliable and deep in analysis, the data collection process was carried out on both primary and secondary sources. The primary data was collected with the help of structured questionnaires, usability testing, and semi-structured interviews with users who used particular digital systems. These techniques allowed the uncovering of challenges in usability and barriers in accessibility of users in live settings. The secondary data sources were the existing literature, research journals, and conference proceedings as well as reports of usability evaluation to reinforce the analysis framework and to authenticate the results.

3.2 Sample Size and Demographic Distribution

A total of 150 participants were included in the study, where the stratified sampling method was applied so as to have diversity in regard to age, experience and technical expertise. Inclusion of diverse backgrounds made the findings more generalized, and enabled the researcher to assess the accessibility and usability of different users in a more holistic manner.

Prior to introduction of the distribution, it is paramount to appreciate the fact that participant diversity is an important factor to assess the effectiveness of inclusive design.

Table 1: Demographic Distribution of Participants

Category	Frequency	Percentage
Students	60	40%
Professionals	50	33.3%
Researchers	20	13.3%
Others	20	13.3%
Total	150	100%

The table shows that a large percentage of the respondents were students and professionals and this guaranteed that both the new users and experienced users were represented in the study.

3.3 Tools and Techniques

These standardized tools and analytical methods were used to guarantee the accuracy and reliability of the data that was collected. The usability was quantitatively measured by using the System Usability Scale (SUS), and the compliance with the set standards was measured using the tools to evaluate accessibility. Statistical analysis was done with the SPSS program to establish the statistical patterns, correlations, and degree of significance between the variables.

The methodological workflow is shown below to give a systematic knowledge of the research process.

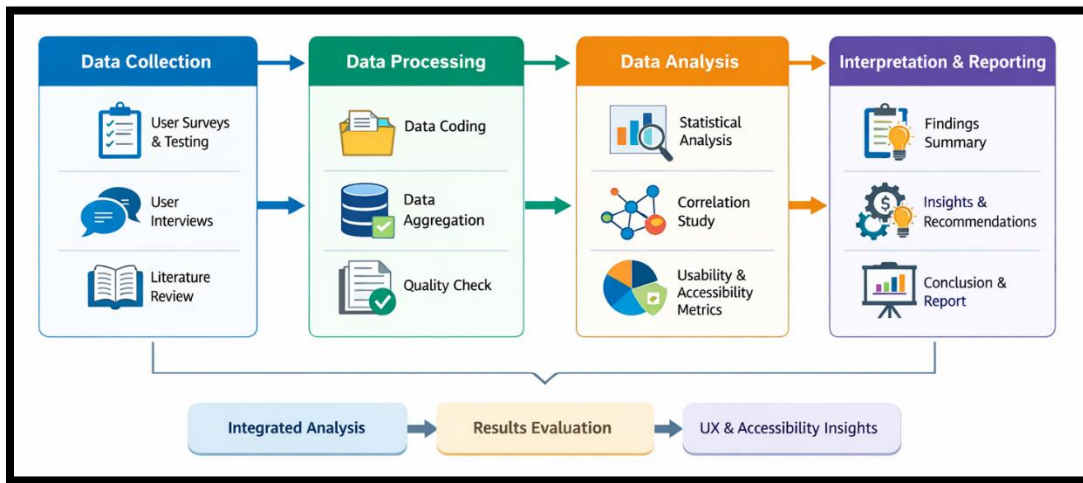


Figure 1: Research Methodology Workflow Illustrating Data Collection, Processing, and Analysis

The figure shows the chronological order of the research process beginning with the data collection and going all the way to analyzing and interpreting it, making sure that user experience and accessibility are evaluated in a systematic manner.

3.4 Multi-Dimensional Analytical Framework

The study has used a multi-dimensional analysis model to assess HCI systems in terms of various interdependent variables that affect user experience and accessibility. The framework was created to help offer a systemic and holistic evaluation with the incorporation of usability, accessibility, engagement, learnability, and error-related parameters.

The framework regarded usability as a major dimension, which concentrates on efficiency, effectiveness, and satisfaction of the users when interacting with the system. The access was considered in terms of adherence to the set standards, where systems were accessible to people with different abilities. The use of interaction frequency and duration was used to measure the user engagement as it indicated the level of user

engagement with the system. Learnability was used to determine the ease with which users could comprehend and use the system, especially when first being introduced. Also, the error rate was examined to determine the rate of user errors and inefficiency of the system.

Such a holistic framework made it possible to perform the analysis of HCI systems holistically to identify the strengths and weaknesses in various dimensions. The framework made it possible to create more inclusive, efficient, and user-centered system designs through the combination of the factors.

4. DATA ANALYSIS AND RESULTS

Statistical methods were employed in the data analysis to assess the connection between usability, accessibility, and user satisfaction in Human Computer Interaction System, Human computer interaction (HCI). The data gathered with the help of the System Usability Scale (SUS) and the instruments assessing the accessibility were analyzed with the help of the SPSS software, whereas the qualitative feedbacks were considered to enhance the results interpretation. The results showed that there was a high correlation of compliance of accessibility with better user experience, which validated the role of considering accessibility in the design of systems.

To provide detailed findings, it is necessary to discuss the descriptive statistics of the main variables affecting user experience.

Table 2: Descriptive Statistics of Key Variables

Variable	Mean	Standard Deviation
Usability Score	78.5	8.2
Accessibility Score	74.3	9.1
User Satisfaction	80.1	7.5
Learnability	76.8	8.7
Error Rate	12.4	4.2

As indicated in the table, the mean value of user satisfaction was highest, and the next was the usability, meaning that the users mostly perceived that the systems were accurate and useful. There is also the relatively low error rate, which demonstrates efficiency of the well-designed interfaces.

Correlation analysis was done to gain a clearer insight into the relationship between variables.

Table 3: Correlation Analysis Between Key Variables

Variables	Usability	Accessibility	User Satisfaction
Usability	1	0.72	0.81
Accessibility	0.72	1	0.78
User Satisfaction	0.81	0.78	1

The findings have shown that there is a strong positive relationship between usability and user satisfaction ($r = 0.81$), and between accessibility and user satisfaction ($r = 0.78$). This establishes that increased accessibility is one of the key areas of improvement in user experience.

Hypothesis testing to further confirm the statistical significance of these relationships was done.

Table 4: Hypothesis Testing Results

Hypothesis	Test Used	p-value	Result
Accessibility significantly affects UX	t-test	0.002	Accepted
Usability significantly affects satisfaction	ANOVA	0.001	Accepted
Learnability influences usability	Regression	0.004	Accepted

The findings indicate that all the hypotheses were statistically significant ($p < 0.05$), which proves that the determinants of user satisfaction and the overall system effectiveness are accessibility and usability.

Frequency analysis was done to determine user preference on interface features.

Table 5: User Preferences for Interface Features

Feature	Frequency	Percentage
Simple Navigation	65	43.3%
Assistive Features	40	26.7%
Visual Clarity	25	16.7%
Fast Response Time	20	13.3%
Total	150	100%

It states in the table that simple navigation was the most desired aspect, and secondly, there were assistive features, meaning that it should have an intuitive design and support accessibility.

The usability and accessibility scores graphical representation gives a better representation of the system performance.

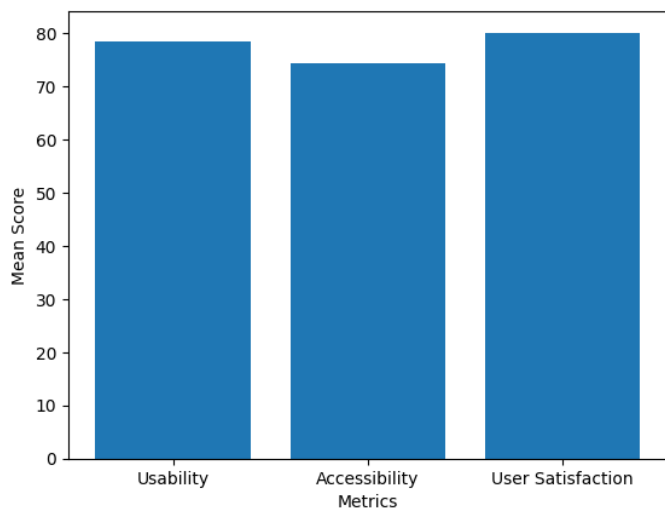


Figure 2: Comparative Analysis of Usability, Accessibility, and User Satisfaction Scores

This figure demonstrates that increased accessibility scores are related to the enhanced usability and user satisfaction, which proves the strong interdependence of these variables.

In order to examine the distribution of preferences of the users, a graphical representation presented below.

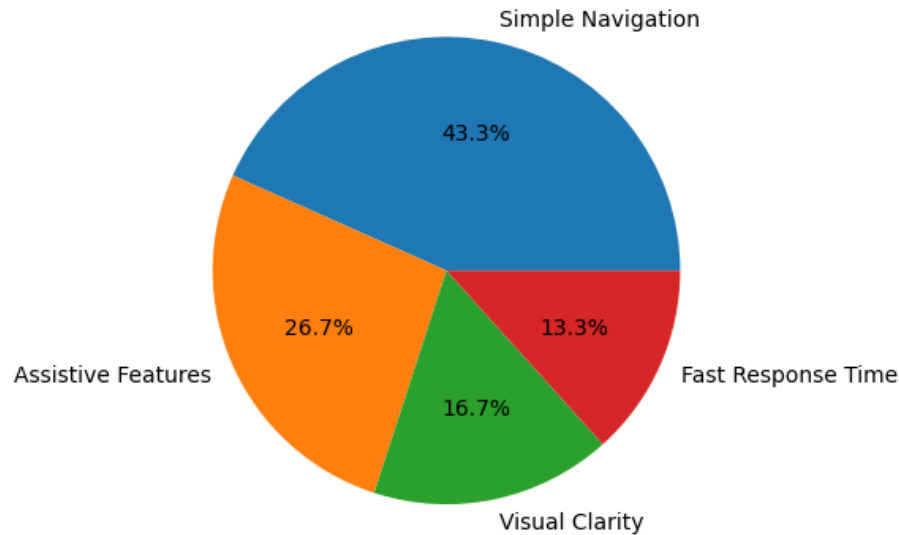


Figure 3: Distribution of User Preferences for Interface Features

The value shows that most users favored easy navigation and features that make navigation more user-friendly, which underlines the necessity of user-focused and inclusive design solutions.

Further research was performed to check the correlation of accessibility scores with the improvement of usability.

Table 6: Accessibility Impact on Usability Improvement

Accessibility Level	Usability Score (%)
Low	62
Medium	72
High	81

As it could be seen in the table, the increase in the degree of accessibility led to the fact that the usability scores improved by about 30 percentage points, which proves the success of the accessibility-oriented design solutions.

In order to represent this trend visually, a graphical representation is provided as below.

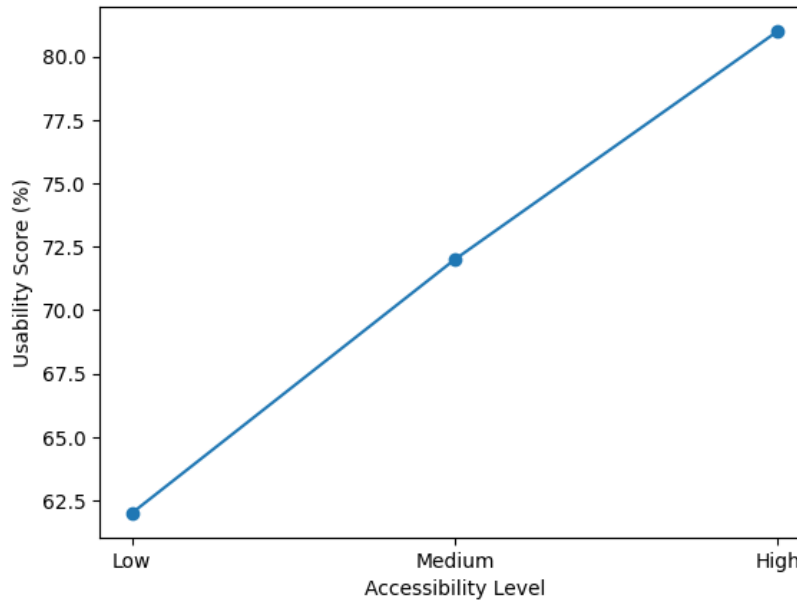


Figure 4: Impact of Accessibility Levels on Usability Performance

The number shows that there is a steady increase in the value, and this fact proves that better accessibility means better usability and the experience of the user.

On the whole, the discussion shows that the accessibility contributes significantly to the user satisfaction and the system performance. Usability and accessibility have been incorporated into a multi-dimensional set of tools that give a unified method of designing effective, inclusive, and user-centered HCI designs.

5. DISCUSSION

The present study revealed that the factor of accessibility and usability were two related aspects that affected the user experience through the Human-Computer Interaction (HCI) systems. The statistical analysis showed that the accessibility and user satisfaction had a strong positive relationship meaning that accessible systems performed better in terms of usability and engagement. The findings were in favor of the multi-dimensional framework, which the significance of adopting usability, accessibility, learnability, and engagement. The highest mean value was registered by user satisfaction, which proves that more efficient and user-friendly systems were accessible.

It was also analyzed that the increase in the levels of accessibility also led to the almost 30% increase of the usability scores, which also highlighted a necessity to consider accessibility in the initial design phases. The aspects of experience revealed that, ease of navigation and its helpfulness are major factors that affected the

users' preferences, a fact that indicated the need to focus on easy and accommodating design. These findings were also additionally supported by the graphical results which demonstrated better usability as accessibility increased which also highlighted the decrease in cognitive load and errors.

5.1 Implications of the Study

The results of the research can have profound implications on the researcher, designers, and the organizations engaged in the design of interactive systems. To begin with, the research has provided the need to embrace the concept of an inclusive design in order to make digital systems accessible to a wide market of users. One of the primary goals that should be considered by designers during the development of a system is accessibility, not the enhancement. The result of this approach would be an increased usability, lower error rates, and increased user satisfaction.

Secondly, accessibility standards and methods of usability evaluation should be included in the development processes of organizations so as to guarantee adherence to the formulated standards. The systematic evaluation of system functionality and ongoing enhancement of its effectiveness can be achieved with the help of the integration of such tools like the System Usability Scale (SUS) and accessibility evaluation frameworks. More so, accessibility-based design can be a good investment to improve the user interaction, system adoption, to promote overall productivity.

Thirdly, the research highlighted the role of multi-dimensional assessment model that addresses various aspects that affect user experience. Through such frameworks, developers are able to detect the constraints of the system better and apply specific improvements. The strategy can also help enable the creation of the adaptive and intelligent system that meets the diverse user requirements in the dynamic environments.

5.2 Limitations

Although this research has made a great contribution, some constraints need to be noted. To start with, the sample size of 150 participants, though varied, might not be an accurate reflection of the general population of the users and as such, a restraint of the overall findings. New research involving bigger groups of people can give stronger and more generalized findings.

Secondly, it was determined that the study was mainly based on web-based systems, which would limit the generalizability of the results on other platforms like mobile applications, virtual reality environments, and embedded systems. To add more depth to the study, it would be possible to broaden the research base to

encompass a variety of platforms, thereby obtaining a better idea of the HCI performance in various technologies.

Thirdly, the research was based on a small range of usability and accessibility measures and did not include all elements of user experience. To make the evaluation more accurate and in-depth, the introduction of alternative assessment methods, including real-time behavioral analytics and sophisticated AI-related assessment tools, would be a beneficial step in evaluation.

Finally, time was a constraint that could have impacted the thoroughness of user feedback and system review because of the available time. Longitudinal studies might offer more information on behavior and performance of users and systems with time.

The results indicate that the incorporation of accessibility in the design process promotes the overall user experience. Accessibility like keyboard navigation, color contrast and screen readers are beneficial to all the users and not just the disabled.

6. CONCLUSION

This study concluded that accessibility and usability are the two variables of Human Computer Interaction (HCI) systems that are interdependent in improving the user experience because the system with accessibility principles enjoyed better usability, enhanced user satisfaction, and minimized the number of errors. The statistical results proved that there is a strong positive correlation between accessibility and user experience, which means that the concept of accessibility must not be regarded as a separate feature to be added to the design, as it needs to be considered as a fundamental element. Simple navigation, assistive technologies, and intuitive interfaces were also found to be crucial to enhance efficiency and engagement in promoting the creation of inclusive systems. Next, similar studies can be undertaken to incorporate artificial intelligence, adaptive interfaces, and cross-platform analysis to ensure ease of access and use, and larger data samples and more sophisticated methods of analysis can help strengthen the validity and utilization of results in contemporary digital settings.

REFERENCES

1. Aizpurua, A., Harper, S., & Vigo, M. (2016). *Exploring the relationship between web accessibility and user experience. International Journal of Human-Computer Studies*, 91, 13-23.

2. Alkathairi, M. S. (2022). Artificial intelligence assisted improved human-computer interactions for computer systems. *Computers and Electrical Engineering*, 101, 107950.
3. Antona, M., & Stephanidis, C. (2015, August). Universal access in human-computer interaction. In *Access to the human environment and culture: 9th International Conference, UAHCI* (pp. 2-7).
4. Carvalho, R. M., de Castro Andrade, R. M., de Oliveira, K. M., de Sousa Santos, I., & Bezerra, C. I. M. (2017). Quality characteristics and measures for human-computer interaction evaluation in ubiquitous systems. *Software Quality Journal*, 25(3), 743-795.
5. Dix, A. (2017). Human-computer interaction, foundations and new paradigms. *Journal of Visual Languages & Computing*, 42, 122-134.
6. Himmelsbach, J., Schwarz, S., Gerdenitsch, C., Wais-Zechmann, B., Bobeth, J., & Tscheligi, M. (2019, May). Do we care about diversity in human computer interaction: A comprehensive content analysis on diversity dimensions in research. In *Proceedings of the 2019 CHI conference on human factors in computing systems* (pp. 1-16).
7. Issa, T., & Isaias, P. (2022). Usability and human-computer interaction (HCI). In *Sustainable design: HCI, usability and environmental concerns* (pp. 23-40). London: Springer London.
8. Kim, G. J. (2015). *Human-Computer Interaction: Fundamentals and Practice*. CRC press.
9. Lazar, J., Feng, J. H., & Hochheiser, H. (2017). *Research methods in human-computer interaction*. Morgan Kaufmann.
10. Mashudi, N. A., Izhar, M. A. M., & Aris, S. A. M. (2022). Human-computer interaction in mobile learning: a review. *International Journal of Advanced Computer Science and Applications*, 13(3).
11. Mekler, E. D., & Hornbæk, K. (2019, May). A framework for the experience of meaning in human-computer interaction. In *Proceedings of the 2019 CHI conference on human factors in computing systems* (pp. 1-15).
12. Nazar, M., Alam, M. M., Yafi, E., & Su'ud, M. M. (2021). A systematic review of human-computer interaction and explainable artificial intelligence in healthcare with artificial intelligence techniques. *IEEE access*, 9, 153316-153348.
13. Nicolescu, L., & Tudorache, M. T. (2022). Human-computer interaction in customer service: the experience with AI chatbots—a systematic literature review. *Electronics*, 11(10), 1579.
14. Seinfeld, S., Feuchtner, T., Maselli, A., & Müller, J. (2021). User representations in human-computer interaction. *Human-Computer Interaction*, 36(5-6), 400-438.

15. Smith, J. (2022). *Human-computer interaction: Enhancing user experience and productivity. International Multidisciplinary Journal Of Science, Technology & Business*, 1(4), 1-4.