

## Construction of a virtual usability laboratory for conducting user tests during remote attendance

*Construcción de un laboratorio virtual de usabilidad para la conducción de test con usuarios durante la presencialidad remota*

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**Resumen:** Uno de los retos educativos que surgieron debido a la pandemia del COVID-19 fue la adaptación a la virtualidad de cursos teórico-prácticos o prácticos. En este contexto, el curso de Interacción Humano Computador (HCI) del Programa de Ingeniería de Sistemas de la Universidad de Cartagena tuvo que abordar el desafío de desarrollar la temática de test con usuarios, que implica la realización de pruebas con usuarios finales en un entorno controlado o laboratorio de usabilidad. Este artículo presenta como contribución el diseño e implementación de un laboratorio académico virtual de usabilidad para llevar a cabo test con usuarios. El laboratorio propuesto fue construido y evaluado a partir de las prácticas realizadas por los estudiantes de la asignatura HCI mencionada. Este laboratorio tiene como objetivo servir de referencia para la realización de pruebas de usabilidad tanto en el ámbito académico como en el corporativo.

**Palabras clave:** Laboratorio de usabilidad, pruebas de usabilidad, test con usuarios, usabilidad.

**Abstract:** One of the educational challenges arising from the COVID-19 pandemic was the adaptation of theoretical-practical or practical courses to virtual formats. In this context, the Human-Computer Interaction (HCI) course in the Systems Engineering Program at the University of Cartagena faced the challenge of developing user testing, involving conducting tests with end-users in a controlled environment or usability laboratory. This article contributes by presenting the design and implementation of a virtual academic usability laboratory for conducting user tests. The proposed laboratory was built and evaluated based on practices undertaken by students in the aforementioned HCI course. This laboratory aims to serve as a reference for conducting usability tests in both academic and business settings

**Keywords:** Usability laboratory, usability tests, user test, usability.

## 1. INTRODUCTION

Taking into account the growth in the number of cloud applications and app stores, one of the key aspects to promote the competitiveness of companies in the software field and end-user productivity is usability, and therefore, user-centered design [1]–[4]. According to Jakob Nielsen, considered the father of usability, it can be defined as a software quality attribute aimed at evaluating the ease of use of interactive system interfaces and is defined by five main components: ease of learning, efficiency, ease of recall, error management, and satisfaction [5], [6].

Similarly, in accordance with ISO 9241-11, usability can be defined in terms of the effectiveness, efficiency, and satisfaction with which an interactive system allows specific users to achieve specific objectives in a particular usage context [7]–[10]. It is important to appreciate that usability is defined by 3 attributes according to ISO 9241-11: effectiveness, efficiency and satisfaction. Effectiveness refers to the user's achievement of goals within the interactive system; efficiency relates to resource optimization, where the most important resource for the user during interaction is time; finally, the satisfaction attribute, according to the standard, is associated with the presence of positive attitudes during the use of the software product [11]–[14].

One of the ways to assess the usability of a software product is through the use of user tests, in which a group of evaluators or test coordinators monitors and observes the behavior of a group of users as they perform a series of tasks in a specific software, within a controlled environment or usability laboratory [14]–[18]. Taking into account the attributes considered by the ISO 9241-11 standard, a usability lab should enable the acquisition of metrics associated with each of these attributes [19].

The topic of software evaluation methods based on user tests is part of the content of the elective course Human-Computer Interaction (HCI) of the Systems Engineering Program of the University of Cartagena. This theme is developed both theoretically and practically with the aim of providing students with different methods to assess interactive applications from a usability perspective, ultimately improving the quality of the final product. The theoretical aspect addresses the stages

that make up a user test, the structure of instruments used in the tests, and the calculation of metrics associated with different attributes of the standard. On the practical side, test instruments are designed, various tests are conducted with real users on interactive software applications from different application contexts, in a controlled environment adapted as a usability lab, and finally, the calculation of effectiveness and efficiency percentages, as well as the satisfaction level, is performed.

The COVID-19 pandemic forced educational institutions to adapt their academic processes, including classes, meetings and academic events, among others [20]–[23]. Regarding classes during the lockdown period, one of the challenges faced by universities was the development of theoretical or theoretical-practical courses, sometimes requiring the suspension of such courses or emphasizing theoretical content through the presentation of practical videos developed by the instructor or providing students with various online resources [24]–[26]. In this sense, for the particular case of the HCI course of the Systems Engineering Program mentioned above, it was necessary to adapt the practices corresponding to the subject of user tests methods to the dynamics of the so-called remote attendance, providing an infrastructure based on virtual tools for the development of user tests with similar advantages to the tests performed in person.

Based on the above, this article proposes as a contribution the construction of a prototype of a virtual usability laboratory, which was built and configured in the HCI course of the Faculty of Engineering of the University of Cartagena, in order to promote the development of the practices of the course in question, within the specific subject of user tests. For this research, four methodological phases were defined as follows: P1. Characterization of user tests, P2. Identification of techniques and technologies for the implementation of the virtual academic laboratory, P3. Design and implementation of the virtual laboratory using the selected tools, and P4. Case study in which a usability test was conducted on a commercial portal using the implemented usability laboratory. The proposed lab intends to be extrapolated and refined at both academic and business levels for conducting various user test approaches, enhancing software quality in interactive applications evaluated through the lab. In this regard, the lab becomes a viable

alternative to address infrastructure deficiencies in laboratories at universities and companies.

The remainder of the article is organized as follows: Section 2 presents a set of related works that were considered in the development of this research; Section 3 describes the different methodological phases considered to achieve the proposed objectives; Section 4 presents the obtained results, including the characterization of user tests, the design and implementation of the virtual usability lab prototype, and finally, a case study to verify the relevance of the research; finally, Section 5 provides conclusions and future work derived from this research.

## 2. RELATED WORKS

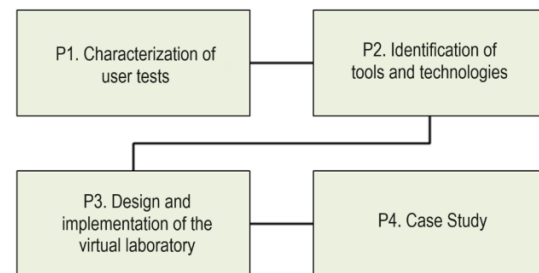
Different contributions have been made regarding the development of practical activities both in an educational context and in other scenarios. For example, in [27], a review is conducted on various simulation tools for teaching and learning robotics, aiming to identify possibilities that best suit the characteristics of classes in the context of the pandemic. In [28], an experimentation scenario is proposed based on LabVIEW and Multisim tools for the development of different virtual laboratories in the field of engineering. In [29], the development of a virtual reality-based simulator is presented to train practitioners and nurses involved in testing and treating patients affected by the COVID-19 pandemic. In [30], a review is presented demonstrating the use of E-learning platforms, virtual case sessions with experts, and telemedicine tools for practical sessions in the training of cardiology fellows. In [25], it is shown that for academic activities in various dentistry faculties across several Asian countries, virtual sessions were developed using teleconferencing tools, and physical labs were organized, which experienced a high dropout rate. Therefore, they propose leveraging the construction of virtual reality-based systems in the future.

On the other hand, in [26], it is demonstrated how educational video tutorials, prioritizing content generated through the Loom tool, were utilized for practical activities in the Melbourne Veterinary School. Similarly, in [24], it is described how virtual sessions supported by a learning management system (Blackboard) were employed for practical classes in the pharmacy program at the University of Saudi Arabia. Additionally, multimedia content was generated by university professors to support the development of practical activities. Finally, in

[20], a strategy based on ICT is proposed for the adaptation and organization of virtual events during the pandemic, validated through the implementation of a virtual fair in the Chemical Engineering program at the University of Cartagena. The works presented in this section highlight the need for tools, ICT-based scenarios, and virtual laboratories to support the development of practical activities in the context of remote attendance.

## 3. METHODOLOGY

Four methodological phases were defined for the development of this work: P1. Characterization of the structure of the user tests, P2. Identification of tools and technologies for the implementation of the laboratory, P3. design and implementation of the virtual usability laboratory and P4. Case study (see Figure 1).



*Fig. 1. Methodology Considered.  
 Source: own elaboration*

In Phase 1, the various stages comprising usability tests with end-users, or user tests, were identified to determine the necessary instruments and technological requirements for obtaining the effectiveness, efficiency, and satisfaction attributes defined in ISO 9241-11. In phase 2, technologies and tools were explored and identified for the construction of the virtual academic usability laboratory, as well as the completion of the different stages of the tests. In Phase 3, a prototype of the virtual usability lab was designed and implemented for the development of user tests in accordance with the ISO 9241-11 standard. Finally, in phase 4, several usability tests on commercial web applications were developed by students of the HCI elective of the Systems Engineering Program, from which a case study was chosen and is presented in this article.

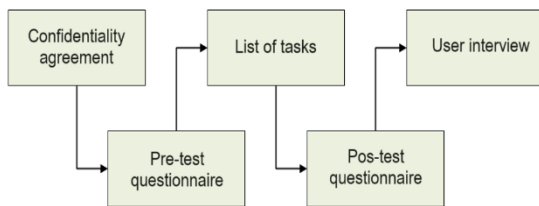
## 4. RESULTS

In this section, the results obtained from this research are presented. Firstly, the structure of

conventional user tests is described, followed by an illustration of the design and implementation of the laboratory. Finally, a case study is presented to verify the relevance of the implemented usability laboratory.

#### 4.1. Characterization of user tests

One of the most effective means to evaluate the usability of a software product is through the use of user tests, which correspond to usability tests focused on observing the interaction tasks of a group of users with a specific software, conducted in a controlled environment or usability laboratory [14]–[16], [31], [32]. A user test consists of 5 sequential stages [33], as presented in Figure 2.



**Fig. 2.** Stages of a usability test.  
*Source:* own elaboration

In the confidentiality agreement, users participating in the test are informed about the scope of the test, and it is explained that the results will only be used for academic purposes. The pre-test questionnaire aims to obtain the user's profile and their experience with tools similar to the one being evaluated in the test. In the task list, users perform a set of tasks within the software under evaluation, which have been defined by the observers or coordinators of the test in advance. Subsequently, the post-test questionnaire is completed, which includes both quantitative and qualitative questions seeking to inquire. The first type of questions aims to investigate aspects of the evaluated software, such as graphic interface, navigation, ease of learning, ease of use, satisfaction in use, among others, using the Likert scale. Meanwhile, the second type of qualitative questions seeks to obtain possible recommendations from the user to improve the usability and functionality of the evaluated software. Finally, and optionally, coordinators can conduct an interview with the user to obtain detailed information about specific aspects observed during the test. The aforementioned test stages are conducted in the context of a usability laboratory, which conventionally has two isolated rooms (for the user and for the coordinators), so that from the coordinators' room, they can monitor the tasks that the user performs in specific software.

Considering that the proposal presented in this article aims to provide the virtual infrastructure for the development of user tests in accordance with ISO 9241-11, it is necessary to consider the different metrics associated with the effectiveness, efficiency, and satisfaction attributes of the standard [34]. Thus, based on the observations made by the test coordinators regarding the tasks and subtasks of the test, the percentages of effectiveness, efficiency, and the satisfaction level are calculated. These metrics are then used to determine the overall usability level of the evaluated software. The percentage of effectiveness per task can be determined using Equation (1), which relates the number of subtasks performed by the user to the subtasks defined for each task.

$$\% \text{ Effectiveness} = \frac{\text{number of subtasks performed} \times 100}{\text{number of defined subtasks}} \quad (1)$$

On the other hand, the efficiency percentage per task can be determined based on what is presented in equation (2), in which the estimated time for each task is related to the time spent by the user in the execution of the specific task.

$$\% \text{ Efficiency} = \frac{\text{Estimated time per task} \times 100}{\text{Time spent per task}} \quad (2)$$

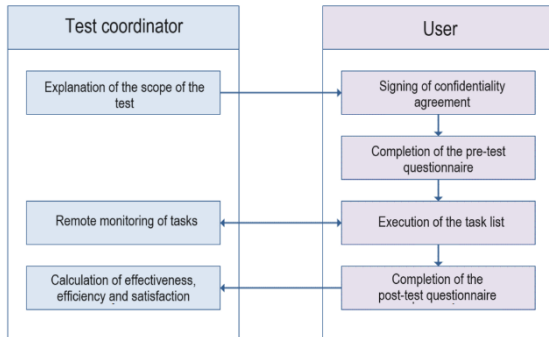
Finally, in the case of satisfaction, the average rating given by end-users in the post-test questionnaire questions related to user perception or satisfaction is calculated, as presented in equation (3). Since in equation (3), the satisfaction level obtained falls within the range of 0 to 5, it must be multiplied by 20 to scale the level within the range of 0 to 100.

$$\text{Satisfaction Level} = \frac{\text{sum of the ratings to the questions}}{\text{number of questions}} \quad (3)$$

#### 4.2. Design and implementation of the usability laboratory

Building upon the user tests characterization conducted in section 4.1, Figure 3 initially presents the operations that both the user and the test coordinator must carry out during a conventional user test to be conducted within the virtual usability laboratory to be implemented. Accordingly, the test coordinator initially explains the scope of the test to the user, who proceeds to sign the confidentiality agreement, complete the pre-test questionnaire, perform the list of tasks defined beforehand by the test coordinator(s), and finally complete the post-test questionnaire. While the user executes the task list, the coordinator remotely monitors how the user performs different tasks, the gestures and expressions made during the interaction with the

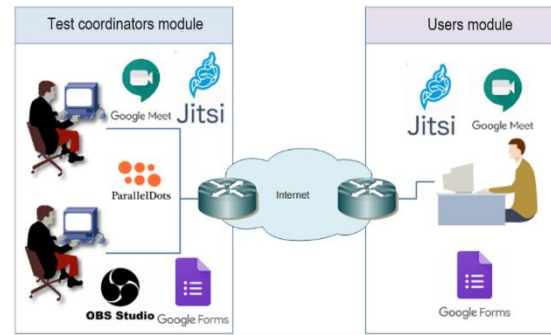
application, which can serve as an indicator of user satisfaction. Additionally, once the test is completed, the coordinator is responsible for calculating effectiveness, efficiency, and satisfaction based on the data collected during the user test.



**Fig. 3.** Operations carried out by the user and the test coordinator.

Source: own elaboration

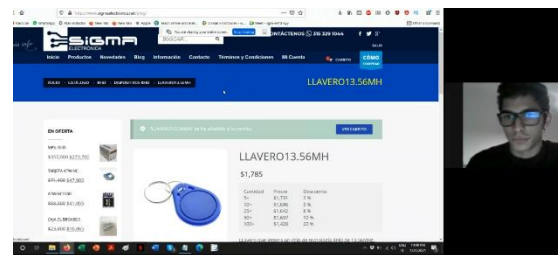
Considering the operations to be carried out by both the user and the test coordinator, a set of tools was selected to establish the infrastructure of the virtual laboratory, enabling the execution of various operations described in Figure 3. Figure 4 illustrates the proposed virtual laboratory infrastructure, taking into account the selected tools and the two modules or rooms (coordinator module and user module). First, for creating the instruments to be used in the user test (confidentiality agreement, pre-test questionnaire, task list, and post-test questionnaire), the tool provided by Google Forms was selected. This tool allows the creation of forms and multiple-choice questionnaires, as well as questionnaires based on open-ended questions. To remotely monitor the tasks performed by the user within the laboratory, Google Meet and Jitsi were selected. These tools enable one or more coordinators to silently monitor the interactions between the user and the evaluated software while sharing the screen with the coordinators. Similarly, for recording both the user's interactions and their gestures and facial expressions, the open-source tool OBS Studio was chosen. This tool allows the coordinator's equipment to capture remote interactions of the user. Captures of user gestures and facial expressions during the test can be used to obtain indicators of satisfaction, considering the emotional heuristics provided by [35]. Finally, to process the qualitative questions from the post-test questionnaire and obtain indicators of satisfaction, it is possible to leverage the advantages provided by the Paralleldots tool to determine the polarity of open-ended questions defined in the test.



**Fig. 4.** Proposed virtual usability lab. Source: own elaboration

### 4.3. Case study

Utilizing the infrastructure of the established virtual laboratory, within the HCI course of the Faculty of Engineering, 6 working groups were formed within the mentioned course. Each of these groups was tasked with evaluating commercial websites in Colombia, involving at least 5 users external to the course. This evaluation took into consideration Nielsen's recommendations, stating that with 5 user participants in a test, at least 70% of the usability issues of an interactive system can be identified [36]. Consequently, this section presents the results of one of the tests conducted by a formed group on the Sigma Electronics website, which is engaged in selling and distributing electronic products for academic and business purposes. As mentioned earlier, a total of 5 users participated in the test, ranging in age from 22 to 52 years (see Figure 5).



**Fig. 5.** Case study test. Source: own elaboration

With regard to the tasks performed by the 5 users in the test within the virtual laboratory infrastructure, Table 1 describes each of the tasks defined by the test coordinators. Likewise, Table 1 presents the number of subtasks associated with each test task and the estimated time by the coordinators for its completion.



**Table 1:** List of tasks performed by users

Tasks	Description of tasks	Number of subtasks	Estimated time (sec)
<b>Task 1</b>	Register on the Sigma Electronics website using a test email provided by the coordinators.	2	180
<b>Task 2</b>	Interact with the shopping cart on the website by searching for three products available in the store.	3	180
<b>Task 3</b>	Access the blog section and make a comment on one of the blog articles.	2	180

After conducting the remote monitoring of the test and collecting the completed subtasks for each user, the results for the efficiency percentage for each task, by user and overall, are presented in Table 2. The calculation is performed using Equation 1.

**Table 2:** Effectiveness calculation from case study results

User	% Effective ness T1	% Effective ness T2	% Effective ness T3	% Total Effective ness
<b>1</b>	100	66.67	100	88.89
<b>2</b>	100	100	100	100
<b>3</b>	100	100	100	100
<b>4</b>	100	100	50	83.33
<b>5</b>	100	100	100	100
<b>Average</b>	100	93.33	90	94.44

The effectiveness of each task in the test is notably high, as 100% of the users were able to complete the first task without difficulties, while 80% of the users successfully carried out tasks 1 and 2. Small difficulties were encountered by 20% of the users in product search (prioritizing the product code over its name) and in identifying items within the blog section of the portal. Consequently, the consolidated effectiveness of the web portal is 94.44% of users. Similarly, based on the collected times for each user, Table 3 presents the results obtained for the efficiency percentage per task, per user, and overall using Equation 2.

**Table 3:** Efficiency calculation from the results of the case study list of tasks performed by users

User	% Efficiency T1	% Efficiency T2	% Efficiency T3	% Total Efficiency
<b>1</b>	96.77	69.23	61.54	75.85
<b>2</b>	315.79	150.00	118.81	194.87
<b>3</b>	52.17	125.87	109.09	95.71
<b>4</b>	50.00	150.00	66.67	88.89
<b>5</b>	272.73	45.80	46.69	121.74
<b>Average</b>	157.49	108.18	80.56	115.41

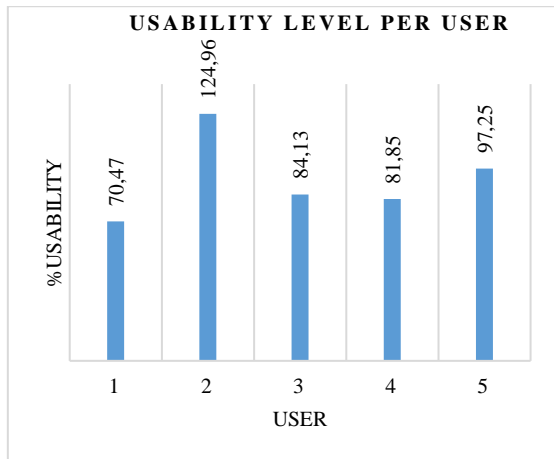
In Table 3, it can be observed that, although the efficiency of tasks 1 and 2 exceeds 100% (the average time spent by users is less than the time estimated by the coordinators), in the case of task 1, 60% of users completed the task in a time longer than established, while for task 2, 40% of users took longer than defined by the coordinators. Regarding task 3, which has a percentage below 100%, it can be noted that 60% of users took more time to complete the task than defined by the coordinators. Similarly, considering the effectiveness values from Table 2, it can be concluded that the efficiency values for tasks 1 and 2 can be explained by the difficulties encountered by some users in product search and identification of items in the Blog section of the portal (calculated using Equation 1 for efficiency). In conclusion, by consolidating the efficiency results of users, the total efficiency percentage of the portal is 115.41%. On the other hand, regarding the satisfaction attribute, 6 of the quantitative questions from the post-test questionnaire were taken into account, which inquired about the perception and satisfaction with different aspects of the site. Thus, in Table 4, the results of the satisfaction level per user and overall are presented using Equation 3 for calculation.

**Table 4:** Calculation of the level of satisfaction from the results of the case study

User	P1	P3	P4	P5	P6	P7	Sat. Level
<b>1</b>	3	2	2	2	2	3	2.33
<b>2</b>	3	4	4	4	5	4	4
<b>3</b>	3	3	4	4	1	2	2.83
<b>4</b>	3	3	4	4	4	4	3.67
<b>5</b>	3	4	4	4	2	4	3.50
	3	3.2	3.6	3.6	2.8	3.4	3.27
<b>% Sat</b>	60	64	72	72	56	68	65.33

Based on user responses to post-test questions related to satisfaction, it is possible to observe that the satisfaction level ranges between 3 and 3.6, corresponding to a satisfaction percentage between 60% and 72%, respectively. Thus, the consolidated satisfaction level in using the portal was 3.27, with a satisfaction percentage of 65.33%, which can be explained by the fact that, although the portal allows

searching for products in the store, the search engine has been implemented using the product code, making it difficult to easily find a product. Similarly, as mentioned earlier, users encountered difficulty locating items in the Blog section of the portal, which could influence the satisfaction rating. Considering the results obtained in Tables 2, 3, and 4, Figure 6 shows the usability percentage calculated for each user, taking into account the percentages of effectiveness, efficiency, and satisfaction.



According to the consolidated usability percentage for each of the test users, it can be observed that the usability percentage ranges from 70.47% (user 1) to 124.96% (user 4), resulting in a total usability percentage of 91.73%. Although the usability level of the evaluated web portal is high, it is important for improving the site's usability to focus on search functionalities and ease of access to items in the Blog section.

In discussing the results, it is important to highlight that the main contribution of this article was the design and construction of a virtual academic laboratory for the development of the different phases that comprise a user test. This represents a significant improvement in logistical efficiency and the utilization of internet infrastructure and its tools compared to usability tests conducted in non-virtual laboratories, such as those used in [19], [33] to validate the usability of different applications. Virtual laboratories offer greater flexibility by eliminating the need for physical travel and space constraints, facilitating the participation of users from various geographical locations [37]. Additionally, these laboratories can integrate with various software tools that automate and streamline the data collection and analysis process, increasing the overall efficiency of the evaluation process.

Furthermore, it is worth noting that the proposed virtual academic laboratory enables the collection of necessary inputs for calculating metrics associated with usability attributes: effectiveness, efficiency, and satisfaction. Thus, through the calculation of these attributes, it is possible to determine the usability level of an evaluated application and identify areas for improvement based on the various data collected during the remote test. Remote tests, like conventional usability laboratories, provide the same functional capabilities [38], allowing for a comprehensive and detailed evaluation of application usability. However, virtual laboratories significantly optimize logistical and development costs of the tests, as they do not require specialized physical facilities or the physical presence of participants, which reduces associated expenses and increases the accessibility and reach of usability evaluations.

## 5. CONCLUSIONS

Based on the need to have a virtual controlled scenario for the development of user tests within the HCI course of the Systems Engineering Program of the University of Cartagena, this article proposed as a main contribution the construction of an academic virtual laboratory for the development of user tests within the framework of the remote presence raised by the COVID-19, taking into account the ISO 9241-11 standard.

The proposed virtual usability lab brought together a set of tools that enable the generation of different instruments associated with the stages of user tests, as well as the remote monitoring of tasks performed by users in the test and the recording of sessions conducted by each user. This allows obtaining essential inputs in the calculation of usability attributes. The proposed approach aims to serve as a reference for the extrapolation of the infrastructure within similar or related courses in the field of software testing.

The case study presented in this article demonstrated that the infrastructure of the proposed virtual laboratory allows for the assessment of the ISO 9241-11 usability attributes (effectiveness, efficiency, and satisfaction). Therefore, it is suitable for conducting user tests in both academic and corporate contexts, contributing to the improvement of software product quality.

As a future task arising from the current proposal, the intention is to adapt the proposed infrastructure to the context of mobile and augmented reality applications, enabling the development of user tests in these types of applications.

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