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DIGITAL HUMAN-CENTERED INTERFACE DESIGN FOR A SHORT LEARNING CURVE ON CRITICAL TELEMETRY SYSTEMS

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Abstract

Critical telemetry systems in analog astronaut missions allow communication between astronauts and a Mission Control Center (MCC). These systems require digital interfaces to allow individuals to perform quick and timely actions or reactions to any situation that might arise during Extravehicular Activities (EVA) and/or regular Mission Activities. This document describes the design, validation and implementation of a digital interface that was tested by analog astronauts and validated on the critical telemetry system Astro Casco (an Andes Aerospace product), taking the name of Astro Casco Receiver Interface (ACRXI). Thus, using a methodology that is based on User Experience (UX) principles, we understood and enhanced Human-Computer Interaction through a validation meeting, and a usability heuristics evaluation. This interface (ACRXI) minimizes the learning curve for reading data in telemetry systems, so their users have an effective and efficient way to observe, understand and interpret the data received during EVAs.

Keywords: User Interface Design (UI Design), User Experience Design (UX Design), Product Design, Extravehicular Activities (EVA), Analog Space Mission, Astro Casco.

1. Introduction

1.1 Astro Casco

Astro Casco is a communication system for telemetry transmission/reception, originally thought for analog space missions. This system [1] is integrated by two main devices and one optional device:

(1) Astro Casco Data Processor and Transmitter (ACPTX): It is attached to the simulated spacesuit of an analog astronaut. The ACPTX is in charge of gathering the data from relevant connected sensors, packing that data into digital packets, and transmitting them

wirelessly, thus reporting ambient temperature, ambient pressure and ambient humidity. Optionally, an external heart rate chest strap can be paired to allow for heart rate reading of the astronaut in real time.

(2) Astro Casco Receiver (ACRX): located and set up at the MCC, the ACRX is in charge of receiving and handling the data generated by the ACPTX(s). This includes: reception, unpacking, logging and visualization of the data in the MCC/base.

(3) Astro Casco Repeater (ACR) optional device: located in strategic points on the field to be explored by the astronauts during EVAs. The ACR is in charge of extending the system coverage for the astronauts up to 2 km.

In this document, we focus on the second device, the ACRX, specifically on the digital interface that allows users (astronauts that are in the MCC) to visualize and understand all the data that is being received, which is the result of the EVAs that are happening in real time, outside of the MCC. Design, evaluation, validation, usage.

For a better understanding of our work on ACRX, the structure of this document is organized as follows: Design, Evaluation, Validation, Use.

1.2 User Interface Design (UI Design) and User Experience Design (UX Design)

A user interface can be defined as the set of integrated components that allows a user to interact with that system. These components can be buttons, cards, text fields, navigation bars, labels, breadcrumbs, tooltips, loaders, among many others. The design operations for User Interfaces (UI) are known as User Interface Design.

Every UI must be designed considering the principles of User Experience (UX) to guarantee a high level of usability and that the digital product resulting from the the design process is equitable, useful, easy to use, and enjoyable. These parameters must be evaluated and validated by professionals, focus groups, and optionally by potential users. These parameters must be evaluated and validated by professionals, focus groups, and optionally by potential users. Only after this evaluation and validation process can we say that the product has (1) a good interface design and (2) a good user experience.

In this document, we will describe not just the design process, but also the validation and validation process of the ACRXI, and how this UI is a solid and robust part of the integrated system Astro Casco.

2. Design

2.1 UX Design Overview

Fig. 1. Wireframe designed as a prototype before the User Interface Design.

2.2 UX Design

In order to have a final product that is validated as good, we followed the UX Principles stated by the authors Jakob Nielsen and Donald Norman in several books and reports on UX Guidelines [2]. Based on these principles, we began to shape the design of a wireframe that considers the key elements to guarantee good usability later. These key elements are:

a) Structure: Every single component of the UI was placed over a white background previously and strategically divided with a vertical grid (a 12-column grid for horizontal screens and a 4-column grid for vertical screens), using both Adobe Xd and Figma software. The grid was designed from the beginning to provide structure, order, and correct separation to every component of the UI. The values with which the grid was constructed are described in table 1.

Table 1. Grid Structure in pixels for a responsive 1080 x 1920 px resolution

Number of columns	Mid width	Column width	Border width
12	16 px*	122 px	140 px

* px = Pixels

b) Color: For the background of the interface, the white value was selected as a neutral space. To separate and organize the information, some shades of gray were also used, according to the corporate color palette of the Andes Aerospace company.

For other components, colors were selected that, according to color theory and psychology, allude to positive (green), caution (orange), and danger (red). In all three cases, background, structure, and components, all the selected colors have a contrast ratio that is in accordance with the UX Guidelines for Accessibility described by Nielsen & Norman [3].

Table 2. Contrast ratio of the selected colors for ACRXI against a white background.

Color name	HEX code	Contrast ratio over white background
Green	#B5D062	1:7:1 WCAG 2.1*
Orange	#F2AD3E	1:9:1 WCAG 2.1
Red	#DC5656	3:8:1 WCAG 2.1
Gray	#C1C5C8	1:7:1 WCAG 2.1
Black	#2D2A26	14:3:1 WCAG 2.1

* Web Content Accessibility Guidelines

c) Typeface: The selected typeface was Helvetica. The selection criteria were (1) the legibility and (2) readability that it provides in titles and short paragraphs, considering that legibility corresponds to the measure of how

distinguishable individual characters and words are to the eye of the reader, while readability corresponds to the measure of how easy it is to read the text overall. The legibility and readability of Helvetica are seamlessly described in an article that studied those features on Arial [4], which has a 95% match with Helvetica. These features were also validated by a focus group, as described later in this document.

Technical specifications of the fonts used are described in the table below.

Table 3. Configurations for Helvetica font used in five text types within the ACRXI.

Text type	Weight	Size	Character spacing	Line spacing
Main title	Medium	50 px	-50 px	—
Card title	Medium	30 px	-50 px	—
Card paragraph	Medium	14 px	-50 px	18 px*
Parameter title	Medium	13 px	-50 px	—
Parameter value	Medium	13 px	-50 px	—
Events	Medium	10 px	-50 px	—

* px = Pixels

2.3 UI Design Overview

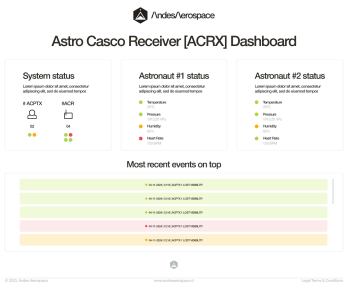

Fig. 2. Final User Interface Design for ACRX.

2.4 UI Design

After establishing the UX design bases, we proceeded to visually design the components and graphic/visual resources of the UI. The selection criteria for key components for the UI was to simplify and minimize the process of reading and understanding the data received by the ACRX.

Thus, the five key components selected were:

1. Cards: They provide responsiveness and adaptability characteristics to the interface, while grouping and separating content to shorten data reading and understanding times.

2. Icons: Two different icons were designed, one to symbolize the number of ACPTX attached to astronauts that are transmitting information and another to symbolize the number of ACRs on the field that are extending the transmission lengths of the system.
   The icons are accompanied by a number indicating the number of devices and by elliptical labels indicating the status of those devices.

3. Labels: The labels indicate the status of a device or the nature of an event.

   (a) Device Status: These labels were designed in elliptical shapes for the ON-OFF indicators of the ACPTX and ACRX devices, as well as for the variation indicators of environmental and biometric data. These elliptical labels are located separately from the text, to function as "lights" that are always on but vary in color, depending on the parameters that are altered or remain stable: Green for ON, Orange for Caution, and Red for OFF.

   (b) Nature of an event: On the other hand, the labels that highlight the events that are received by the ACRX —and that are displayed at the bottom of the screen— were designed in a rectangular shape to give enough space to the content and have the visual aspect of an information container. Green for Positive, Orange for Caution, and Red for Negative/Danger.

4. List: Key component to put the most recent events at the beginning —top— of the list and the oldest ones at the end of the list —bottom—, distinguishing through colors those that are positive, cautionary and negative. Thus, the List

component provides users with a temporal context. The list is shown at the bottom of the UI.

5. Slide bar: It enables efficient navigation within the List component and to visualize the events quickly. Users can jump to a particular point in time without having to scroll through the timeline. The slide bar design has the common and widely used visual aspect of a rounded and gray rectangle in a vertical orientation.

3. ACRXI Evaluation

ACRXI has two main objectives for the users:

1. To observe data: For the fulfillment of this purpose, ACRXI is constantly —and in real-time— displaying the data [5] received. This UI was built and designed based on UX Principles such as

   (a) Accessibility, using colors and contrast ratios that allow the user to correctly observe the information displayed. We also use a readable and clean typeface.

   (b) User centricity, while it is crucial to give the users at MCC just the necessary elements and data that they can handle and focus on.

   (c) User control. We also consider that the UI must fit in a short screen resolution height when it is displayed on a desktop computer. Thus, users at MCC can feel that they have all the parameters in view.

2. ACRXI was planned to provide users the ability to not just observe, but understand data rapidly, so they can focus on what is really important: to take action and having enough time to react to an unexpected event if necessary. Thus, in order to understand data, ACRXI was designed based on UX Principles such as:

   (a) Consistency: All the data on ACRXI looks and also feels simple and easy to understand. We achieve this, by giving the UI a consistent visual style based on a universal color key system, so the users can associate green with a positive state, orange with caution, and red with something dangerous.

   (b) Hierarchy, through the sizing and spacing of different texts. We assign Headings a bigger size, and then we reduce the size of the following Sub-headings until we reach paragraphs and key parameters. We also separated the content into cards that organize the information of the astronauts that are being monitored specifically, and the events that are being received as a whole system.

   (c) Context. We set up a minimalist context for the ACRXI, so the users can easily and quickly navigate through the screen and find the data they need. Every component was also thought to be responsive, making the ACRXI a system that can be displayed in desktop, tablet, and mobile contexts, without losing coherence and data organization.

In every possible manner, these six UX Principles were widely respected and followed as stated below in this document after a Heuristic Evaluation of the ACRXI.

3.1 Heuristic Evaluation

The two main objectives of ACRXI —to observe and to understand data— were validated in two different instances. The second instance will be fully explained in System Validation later in this document.

In the first instance, we proved and tested out the User Experience and functionality of the ACRXI. This session was conducted by an Electronic Engineer, an expert in Informatics Sciences, and a Product Designer, an expert in both User Experience Design and User Interface Design.

At the moment of the session, the Heuristic Evaluation methodology was used, which consisted of a series of questions about the proper use and compliance of UX Principles of an interface —in this case— in a controlled environment and simulation session. Just as

stated by Moran and Gordon [6] from Nielsen Norman Group, “Heuristic evaluations are useful for identifying glaring problems in an interface. That interface can be just about anything that users will interact with —including prototypes, physical products, games, virtual reality, or voice interfaces.”

Each response that contributes to the positive development of the user's activities with the UI corresponds to one point on an 18-point scale. Each response that is considered negative, does not add any point to the evaluation. To determine the evaluation was successful, the result should be over 15 points. In the event that the result shows a score equal to or less than 14 points, the UI must be redesigned in depth, questioning all the evaluation responses, even those that were considered positive.

Furthermore, each aspect that gives a response that is not completely satisfactory to meet the objectives of the ACRXI must be improved for an optimized version in a second iteration of the system.

Below, we present the series of 18 questions that were considered in the evaluation session and their corresponding answers.

3.1.1 Visibility of System Status

A UI design should always keep users informed about what is happening.

- Does the design clearly communicate its state?
  Yes. Since the user runs the system for the first time, the UI reacts showing within less than 3 seconds all the data that is being received from the ACPTX.

- Is the feedback presented quickly after user actions?
  Yes, because the user just needs to browse (look-scroll-look), and the data is always being displayed on the screen.

3.1.2 Match Between System and the Real World

The design should speak the users' language.

- Will users be familiar with the terminology used in the design?
  Yes, since every word and term used in the UI and data are widely utilized on analog space missions. The functioning of the system is also explained in a user manual.

- Do the design’s controls follow real-world conventions?
  Yes. The user only needs to know how to look and navigate through the system just as they would with any everyday website.

3.1.3 User Control and Freedom

Users often perform actions by mistake.

- Does the design allow users to go back to a step in the process?
  No. It is not necessary, because the user does not need to execute any action or enter an input that must be corrected. The user only has to look and navigate the system.

- Are exit links easily discoverable?
  No. They are not necessary. The user only needs to close the web browser window that they are using to view the User Interface.

- Can users easily cancel an action?
  No. The user should not cancel actions, since they do not need to execute one either.

- Is Undo and Redo supported?
  No. The user should not Undo/Redo actions, since they do not need to execute any action either.

3.1.4 Consistency and Standards

Users should not have to wonder whether different words, situations, actions or elements mean something they do not know from previous experiences.

- Does the design follow industry conventions?
  Yes. The UI was designed following a visual style known as Flat Minimal UI Design.

- Are visual treatments used consistently throughout the design?
  Yes. All UI Design elements used respect the same style throughout the system.

3.1.5 Error Prevention

Good error messages are important, but the best designs carefully prevent problems from occurring in the first place.

- Does the design prevent slips by using helpful constraints?
  No. It is not necessary, as users only need to look and navigate through the system, without having to perform any actions or enter inputs.
- Does the design warn users before they perform risky actions?
  No. It is not necessary, as users only need to look and navigate through the system, without having to perform any actions or enter inputs.

3.1.6 Recognition Rather Than Recall

Minimizing the user's memory load by making elements, actions, and options visible.

- Does the design keep important information visible, so that users do not have to memorize it?
  Yes. All the information that is needed to measure the parameters of the environment and the health of the astronauts in EVAs is always visible on the screen as long as the ACPTXs are working correctly. In case any of the ACPTXs are not working correctly, that is also reported in the UI with a red visual label.

- Does the design offer help in-context?
  No. The design does not offer help in context by now. In a second iteration of the system, it is proposed to use Tooltips as UI components to improve the user experience and the understanding of the data displayed on the screen.

3.1.7 Flexibility and Efficiency of Use

Shortcuts —hidden from novice users— may speed up the interaction.

- Does the design provide accelerators like keyboard shortcuts and touch gestures?
  No. The inclusion of shortcuts in this first version of the Astro Casco System was determined to be unnecessary, since users do not need to take any action or enter any input, just observe and navigate the UI.

- Is content and functionality personalized or customized for individual users?
  Yes. The system includes customization of the UI in the number of ACPTXs and ACRs that have been acquired by the client and, therefore, connected to the Astro Casco System. This customization is evident visually under the ACPTX and ACR icons with a number and also with colored ellipses that indicate the status of the devices according to the quantity reported in the number above.

3.1.8 Aesthetic and Minimalist Design

Interfaces should not contain information that is irrelevant or rarely needed.

- Is the visual design and content focused on the essentials?

  Yes. All the information shown on the UI corresponds to the data that the ACPTXs are capable of collecting both from the environment and the health of the astronauts on EVAs.

- Have all distracting, unnecessary elements been removed?
  Yes. The only information on the screen that does not correspond to data collected by the ACPTXs are: the title of the system to provide context and the corporate identity of the company that developed the system.

The final score of the evaluation was 18/18, because all the answers point towards a correct application of UX principles and a positive development of usability. This score allows the ACRXI to be considered correct and

ready to be validated by users, without the need to make any design-related corrections.

4. ACRXI Validation

After the Heuristic Evaluation of the ACRXI, we set up a validation meeting known as a Focus Group Session, with a batch integrated by nine people of different professional interests, education levels, genders, ages, and technology adoption levels.

The Focus Group method was selected to get validation of the ACRXI because of the quantity of data that can be collected from individuals with different backgrounds on a single occasion [7].

As stated by the Social Psychologist Andrea Rivera Icarte, Co-Author of this document, "A group of participants was selected with different profiles in terms of variables such as age, gender, nationality, profession and level of technological adoption, the latter being the most prominent differentiating factor [due to the session context that is known to be for the ACRX validation]. The selection criteria were broad with the objective of promoting the emergence of a diversity of perceptions and experiences within the dynamics of the focus group."

4.1 Focus Group Session

The nine individuals selected were all together at a single occasion that lasted two hours, proactively offering proper feedback on the ACRXI User Experience, based on a series of questions made to them by a moderator. Each person had their own seat and access to the same screen and at the same time as the rest of the focus group participants.

For the session, we had the support of the Electronic Engineer Nicolás Sepúlveda V., who was in charge of the system simulation and who made variations of the data shown on the screen for all participants. These temporary modifications of the data were in accordance with the requests that the moderator requested every few minutes.
A list of nineteen questions was directed towards the participants to respond slowly according to what was observed on the screen. The participants recorded their answers and then shared them at the end of the session for the moderator's consideration and later Validation Results analysis for this document.
The questions ranged from basic associations related to color, to observing, to measuring delay times in executing a particular action or in finding some information on the screen. The questions were formulated verbally (in spanish) and repeated twice to avoid errors.

4.2 Validation results

After registering their answers, participants delivered their results to the moderator for the Validation Results analysis.

Since displaying each of the 152 responses from the participants in this document would make the reading too long, we have selected the most important points from the entire pool of results and averaged them to be able to work based on UX metrics.

Below we will present the average response to each question and then proceed to present the metrics that shed definitive light on the usability of the ACRXI.

(1) How many colors can you distinguish in the entire interface?
Answer in numbers.
A: 5.

(2) What do you associate the color green with?
A: Something positive or good.

(3) What do you associate the color red with?
A: Something bad or wrong.

(4) What do you associate the color orange with?
A: Something to be warned of.

(5) Can you identify which one is the astronaut icon?
How many seconds did it take you to find it?
A: 3 to 6 seconds.

(6) Can you identify which one is the Receiver icon?
How many seconds did it take you to find it?

A: 3 to 4 seconds.

(7) Was the amount of information on the screen enough to find the elements that the moderator asked of you?
A: Yes.

(8) Please, find the Astronaut 1's card.
How many seconds does it take you to find it?
A: 2 to 3 seconds.

(9) Please, find the Astronaut 2's card.
How many seconds does it take you to find it?
A: 1 to 2 seconds.

(10) Please, find the recent events list.
How many seconds did it take you to find it?
A: 1 to 2 seconds.

(11) Please, find the ambient temperature of astronaut 1.
How many seconds did it take you to find it?
A: 1 to 2 seconds.
(12) Please, find the heart rate of astronaut 2.
How many seconds did it take you to find it?
A: 1 to 2 seconds.

(13) Please, find the Atmospheric Pressure of astronaut 1.
How many seconds did it take you to find it?
A: 1 to 2 seconds.

(14) Please, find the Atmospheric Pressure of astronaut 1.
How many seconds did it take you to find it?
A: 1 to 2 seconds.

(15) How many times did you think that you had found what you were looking for and in reality, it was something else?
A: No participant made a mistake in finding an element.

(16) Were there times when you felt like you were taking too long to complete a task?
A: One participant stated that he thought he was taking too long to find the Receiver icon.
(17) Does not apply.

(18) From 1 to 10, (1 being very difficult and 10 being very easy), how much would you say that ACRXI is easy to use?
A: Every participant stated that they scored the ACRX usability as 10.

(19) After this experience, would you feel qualified to monitor the environmental and health conditions of an astronaut using the ACRXI?
A: Every participant stated that they feel qualified to monitor the environmental and health conditions of an astronaut using the ACRXI.

4.3 Usability Metrics

We analyzed the results in order to obtain measurable data, thus, with a final review of the processed results we can define if the usability ACRXI is high or low and if the learning curve of this UI is as short as it needs to be. For having those positive conclusions, we separated the metrics into three types: Efficiency metrics (results integrity over the effort of users), Effectiveness metrics (the accuracy of users in achieving objectives), and User satisfaction metrics (how users feel and perceive the system).

4.3.1 Effectiveness metrics

Two different effectiveness metrics were selected:

1. First try attempt ratio (FTR): It looks towards the fact that whether each user completed their tasks on the first attempt or not.

$$FTR = \frac{T}{A - X}$$

Being “T”, the number of tasks given. “A”, the number of attempts of all the users to complete a task (this number must always be equal to “T”); and “X”, the number of attempts with no task completion.

For having a good FTR, the result should be 1, meaning that every task was completed with no error. The more negative the result, the FTR is

considered "low." That is, users make too many mistakes with the given tasks.

Considering that we gave our participants 9 tasks and that everyone completed the tasks at the first attempt with no error, the FTR of the ACRXI during the Focus Group is

FTR = 9 / 9 - 0
FTR = 1

2. Number of persistent or repetition errors (NPE): It looks towards the fact that whether each user made errors or persistent errors during the test.

$$NPE = \frac{e}{T}$$

Being "e" the number of errors made by the users, and "T" the number of tasks given during the session. The result must be 0 for a robust UX of the ACRXI. The more the number increases above zero, the worse the usability level is.

Considering that we gave our participants 9 tasks, and that we found 0 errors, the NPE of the ACRXI during the Focus Group is:

NPE = 0 / 9
NPE = 0

4.3.2 Efficiency metrics

Two different efficiency metrics were selected:

1. Average time on task (AVT): The average time that users take to complete a task.

$$AVT = \frac{t}{TT}$$

Being "t", the average time taken to complete one task, and "TT", the total time to complete all tasks.

To measure AVT, we selected three of the tasks considered most complex for users.
(a) To identify the Astronaut Icon in the ACRXI (4.5 seconds average).
(b) To identify the Receive Icon in the ACRXI (3.5 seconds average).
(c) To find the Astronaut 1's card in the ACRXI (2.5 seconds).

The total time to complete all tasks will be considered as the sum of (a), (b) and (c) tasks (10.5 s total). This decision was taken due to the excellent results of the Focus Group Session.

(a) AVT = 4.5 s / 10.5 s
(a) AVT = 0.42 s

(b) AVT = 3.5 s / 10.5 s
(b) AVT = 0.33 s

(c) AVT = 2.5 s / 10.5 s
(c) AVT = 0.23 s

2. Total time for tasks completion (TTC): The average time that the users, altogether, used to complete all the tasks given.

$$TTC = t_1 + t_2 + t_3 + t_4 \ldots$$

Each "t_x" represents the sum of the times of the average user for a task. Therefore we are adding the time totals for each task.

The TTC obtained was:

TTC = 2 s + 2 s + 2.44 s + 1.86 s + 1.13 s + 2.75 s + 2.17 s + 2.04 s + 1.58 s
TTC = 17.97 s

4.3.3 User satisfaction metrics

Only one User satisfaction metrics were selected:

1. User control percentage (UC%): Of the total number of users who tested the ACRXI, how many of them felt they had control over the system.

$$UC\% = \frac{100 * (total\ users\ -\ negative\ experiences)}{total\ users}$$

Every participant stated that they had a positive experience, and that they always felt in control of the UI. They even stated that they could easily monitor the health parameters of an astronaut if they use the ACRXI. Considering this, and that we enlisted 8 participants, we obtained the following results:

UC% = 100 * (9 - 0) / 9
UC% = 100%

5. Conclusions

ACRXI is a User Interface that was evaluated through simulation and heuristics by design and engineering professionals.

Subsequently, the UI was validated in a focus group where participants of different ages and with different contexts and study history, technological adoption, etc., claimed to have mastered and controlled the UI 100%.

Furthermore, the participants in this validation felt that they had a good experience and completed all the tasks that were asked of them in a very short time. This, is despite none of them being related to the space or astronomical industry, nor to engineering studies.

We have to highlight that even, no participant read a manual or used a wizard to learn previously about the Astro Casco Receiver Interface.

The surprising results at task completion times showed that on average, a user with no prior knowledge —in the first contact with the UI and without any of the contexts mentioned in the previous paragraphs— takes 18 seconds to learn enough to master the entire ACRXI.

We attribute the success of rapid learning to the organization of the content, the result of having strictly followed the universal principles of UX. Furthermore, a positive phenomenon of incremental understanding of the UI occurs, when users perceive that since there is a coherent visual language, it is enough to learn to read a card to know where to find other elements on a second or third card.

Also, the selection of colors helps a lot so that ACRXI users can understand in a universal code what green, orange, and red correspond to. This way, they can quickly understand what they are seeing.

After users unconsciously understand the basis on which the UI is designed, they can, regardless of their educational background, sit in front of the ACRXI to read and understand the data displayed on the screen.

This represents an enormous advance in the field of user interface design, considering that the main objective of this document is to be able to demonstrate that ACRXI is an excellent option for astronauts on analog space missions to monitor other astronauts from the safety of an MCC. who are exposing their physical integrity in EVAs.

We believe that astronauts in an MCC will be able to quickly learn, even in less than a minute, to understand the ACRXI and the data displayed therein.

Without a doubt, designing this UI always thinking about the user as the center of the experience helps avoid errors when validating the ACRXI product. Despite this, it is always possible to perfect the systems and we believe that future incremental improvements to the system and ACRXI will be implemented so that even without questions or prior instructions that generate biases, the UI can be used without major problems by anyone.

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