Undergraduate Thesis

Beyond Perfection: About learning from errors, NAO, and the World of Virtual Reality

by

Dana Isabella Acosta Castillo

Supervisor: PhD. Mario Fernando Jiménez Hernández

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"Your entire life is a Virtual Reality because you are seeing it only the way it happens in your mind."

- Sadhguru.

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Through a series of instructions, collaborative human-robot interaction is sought to achieve the execution of a practical session in the field of robotics. In this sense, a program composed of a series of instructions related to a typical activity of a practical session in the area of digital electronic systems was proposed. Specifically, a basic session on the management of embedded systems, where students of engineering and computer science will be participants.

Basic electronic elements and an embedded system were used to develop a practical session. These elements are usually found in a laboratory in the robotics field because they are part of the fundamental knowledge in such area. The practical session will be carried out through human-robot collaboration (HRC), were the set of instructions is a series of orders given by the NAO, which is a humanoid social robot, thus it is initially indicated to the participant where to locate the electronic elements within a robotics laboratory. Once the set of elements is available, the NAO provides instructions to implement a simple circuit for turning on an LED using an embedded system. In addition, during instructions, the NAO will intentionally give incorrect instructions to the participant without the participant being affected in any way by the said error.

In addition, the HRC was implemented in a virtual environment. Different tests were carried out in Virtual Reality (VR) environments because fewer resources are required for their development. In this way, we intend to corroborate the use of VR to develop HRC work tests that are normally carried out in the physical world. In this sense, the same laboratory environment used in the physical world was designed in a virtual environment and the NAO robot. In this way, the participant perceives that he is in a familiar environment. The aim for the participant was to develop a practical robotics session both in the physical world and VR, and to turn on the LED, even with the wrong instructions given by NAO. In both physical and VR cases, the NAO will give instructions for the development of the session. To assess compliance with this objective, a quantitative evaluation will be carried out using the Godspeed, RoSaS, and SUS questionnaires, which allows the evaluation of the perception associated with the performance of the NAO behavior. In addition, the NARS and BFI questionnaires were used to evaluate the participants' perceptions regarding their interaction with the NAO. The responses (numeric responses) will be classified on Likert scales, and from this information, it is possible to identify the effectiveness and acceptance of the NAO as a support tool for the proposed program.

65.22% of participants were able to carry out collaborative human-robot work during the practical session. These results support the feasibility and potential of social assistance robots in collaborative environments and highlight the importance of considering error perception and emotional responses in the design of robotic interactions and virtual reality environments.

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Dedication

This thesis is dedicated to Sizu my great friend.

To my sister Nataly, the woman who inspires me every day. I am grateful for her constant support and motivation.

To my mother, who taught me that we should never stop learning and that we can learn from everything, even from robots.

To my father, who has always supported me in my adventures and craziness, I thank you for being by my side every step of the way.

And finally, I want to dedicate this thesis to myself. From a young age, I developed a curiosity for knowledge, and over the years, I have always needed reasons to keep moving forward. This thesis is my reason to continue exploring and learning.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

HRI	Human Robot Interaction.
HRC	Human-Robot Collaboration.
VR	Virtual Reality.
RoSaS	Robotic Social Attribute Scale.
NARS	Negative Attitudes Towards Robots Scale.
SUS	System Usability Scale.

Chapter 1

Introduction

VR has made significant strides in recent years owing to technological advances. It has become a game-changer in various fields, including human-robot interaction (HRI).
In the HRI study, it was observed that the tests required considerable resources. In addition, the protocols that the test must follow are long and time-consuming. VR is being increasingly used for robot testing because it allows environments to be generated without using many resources. One such area is in the field of education, where VR technology is used to create immersive learning experiences for students. For example, virtual field trips can be created to allow students to explore historical sites, scientific phenomena, and other locations without leaving the classroom [8]. In addition, VR offers economic benefits and optimizes time, space, and resources [9]. Telepresence is a critical application of VR and HRI relationships, which allows users to control and interact with robots remotely. With the help of VR technology, users can feel as if they are physically present in a remote location, which can significantly enhance the quality and effectiveness of communication and interaction between humans and robots [10].
Many advances in robotics have involved human activity. Examples include Leonardo Da Vinci's robot (1495) [11], Unimate, the first commercial robot (1956) [12], PUMA robotic arm (1975) [13], Boston Dynamics and its animal-inspired robots (1992) [14], NAO robot for social assistance (2007) [5], robots from Amazon to optimize work and loads (2018) [15], and commonly used robots, such as automatic vacuum cleaners [16]. Owing to robotics, humanity has taken great steps towards the evolution of intelligent technologies, which have allowed for a simpler life [6]. Several operations involving robots require interaction or collaboration with humans.
Natural interaction between humans and robots is critical to ensure that the robot understands the human's intention and responds appropriately [17]. This is particularly important in collaborative tasks, where humans and robots need to work together to achieve a common goal. For example, in manufacturing, robots and humans often work together on tasks such as assembly, where the robot may need to hand a part to a human for installation [18].
To achieve natural interaction, it is necessary to understand how humans communicate and interact with each other. This information can be used to develop communication protocols and interfaces to enable effective communication between humans and robots.

Additionally, it is necessary to study how humans perceive and respond to robots, including their body language, facial expressions, and natural human things such as mistakes and learning to acknowledge them. This insight can be used to design robots to effectively convey information and respond to human cues [19].
In this sense, it is necessary to measure and study the link between humans and robots to obtain a natural interaction between humans and robotic devices [20].

Additionally, within the HRI can be found the Human-Robot Collaboration (HRC). This area is responsible for studying, analyzing, and improving the relationship between humans and robots, specifically working on a common task [21]. Furthermore, HRC has a component of social interaction, which is important for the development of robots that are cognitively and emotionally functional in intelligent environments [22]. However, the implementation of HRC is usually expensive, given the high prices of robots, sensors, and controlled spaces where they must normally be developed. Therefore, an alternative to lower costs and increase this type of study is the implementation of VR.
According to the literature, a VR experience is closer to real interactions with a real robot [23]. Similarly, tests or interactions in VR are more reliable and transferable to the skills of a real robot [23]. In this sense, the HRC test proposed in this study is based on the work published in [24], where the HRI was explored to measure the behavior of humans when a robot makes errors while the robot directs an activity. The proposed workshop involves a collaborative interaction between a human and NAO, that will guide the participant through the workshop instructions. The HRC will be executed in a virtual environment, with the same physical laboratory space and NAO robot designed in the virtual world. The goal of this HRC workshop is to validate the use of VR in conducting tests traditionally performed in the physical world and to provide an immersive learning experience for engineering and computer science students, in other words, we have two scenarios with the same test and objective.
The use of technology in various fields has become increasingly prevalent, and VR is one such technology that has shown promise in various applications. This study aims to evaluate whether VR-based testing is a viable alternative to physical testing in terms of efficiency, cost, and strategy optimization. Furthermore, the study sought to compare the outcomes and behaviors of participants in physical and virtual environments to shed light on the similarities and differences between these settings. Additionally, this study aims to determine whether the Pratfall effect works for both humans and robots and its implications for the development and use of robots in various settings that require empathy and social interaction.
In the context of this study, the proposed research assesses the effect and performance of NAO as an assistant monitor in a practical session with simple electronic assemblies. This study identifies human behavior to erroneous instructions given by the robot and determines whether this makes the robot more likable and easier to interact with. The aim is to develop a system that allows human-robot collaborative work for the execution of a practical session in the physical world and VR.
To gather the necessary data, we conducted two surveys using questionnaires from HRI (Human-Robot Interaction) and HRC (Human-Robot Collaboration) studies. Responses

were collected using Google Forms. This approach resulted in the creation of two distinct datasets—one for the physical group and one for the VR group. Each dataset encompassed the initial and final surveys, as well as supplementary participant information, such as names and gender. The inclusion of gender as part of the collected participant information was particularly significant. We incorporated this demographic variable because it aligned with our research objective of exploring potential gender-related influences on perceptions and responses within the context of our study.
Section 2 provides a comprehensive overview of the background, methods, materials, and practical sessions. In Section 3, we analyze the results and discussions for both the physical and VR parts individually, along with their comparison. We also emphasize the importance of errors in our analysis. Finally, in Chapter 4, we conclude and discuss future work that builds upon the findings of this study.

1.1 State of the Art

An important branch of robotics is HRI, which attempts to explore, analyze, and implement robots in several environments and observe how humans interact with these devices. HRI aims to develop robotic systems that can effectively communicate and collaborate with humans to achieve common goals. [25]
HRI involves the design and development of interfaces that enable effective communication and interaction between humans and robots. HRI also involves studying human behavior and cognition to understand how humans perceive and interact with robots. This includes studying how humans interpret robot movements, facial expressions, and body language and how they form mental models of the robot's behavior and capabilities. HRI has a significant potential to enhance productivity, safety, and efficiency by combining the strengths of humans and robots [26], [27].
An HRI Example is the study conducted by Kerstin Dautenhahn, who used artificial intelligence to measure different variables, such as movement, speed, speech, and environment, which is considered turn-on for HRI [5].
Another important study to highlight, thanks to the advancement of robotics and VR, is the "bici-positiva" [20]. This project aims to highlight the characteristics, usability, and user experience of a system that combines cognitive and physical therapy in a virtual environment for the rehabilitation of cognitive and motor deficiencies. On the other hand, a field that stands out in the human-robot relationship is Social Interaction Robotics (SRI). Significant progress has been made in this regard. One of the most outstanding is the study conducted on proxemics with different subjects [28]. This study is based on some metrics already found, which determine how close a human can approach another person. This distance depends on the type of relationship you have with the person you are approaching. A fascinating takeaway from this study is that it was also implemented for VR, and at the end, they compared the relationships between humans, robots, and robots in VR [10].
Human-Robot Interaction (HRI) is a field of research that focuses on studying the interaction and communication between humans and robots. The aim is to develop effective and

natural methods of communication that enable humans to interact with robots in a safe and intuitive manner. Within the area of HRI, the concept of Human-Robot Collaboration (HRC) plays a vital role in improving interactions between humans and robots. The HRC is responsible for exploring, analyzing, and enhancing the relationship between humans and robots when working together on a collaborative task. The ultimate goal is to achieve seamless collaboration between humans and robots, which can significantly improve the efficiency and effectiveness of various industrial and educational applications [29]. In HRC, humans and robots work together in various ways, such as sharing a workspace, performing complementary tasks, or collaborating on tasks. For example, in manufacturing, humans and robots often work together on tasks such as assembly, where the robot may handle heavy parts or perform repetitive tasks, whereas humans handle delicate parts or perform tasks that require fine motor skills [30]. To achieve an effective HRC, the design of robots should consider capabilities and human nature, such as their cognitive and physical abilities and psychology, to ensure effective collaboration.

Furthermore, The article "Effects of Robot Facial Characteristics and Gender in Persuasive Human-Robot Interaction" is crucial for our research because it sheds light on how a robot's facial characteristics and gender can impact persuasive interactions between humans and robots [31]. The study reveals that robots with attractive facial features and a perception of masculinity tend to be more persuasive than those with less attractive facial features and a perception of femininity. These findings suggest that robot design plays a significant role in their ability to persuade.
In our research, we plan to conduct a gender-based comparison in the sense of how genders perceive the robot based on the practical workshop and preconcepts. This could have valuable applications in creating persuasive robots tailored to various demographic groups.

Likewise, part of the HRC objective, in terms of social interaction, is important for developing robots that are cognitively and emotionally functional in intelligent environments [28]. Collaborative learning generally helps a group of people work and learn differently, coordinating actions to obtain the same shared objective [8].
The development of HRC-oriented protocols can be a challenging and expensive task, mainly due to the high cost of the necessary hardware, such as robots and sensors, and the controlled environment required for the experiments. Consequently, researchers are constantly searching for alternative ways to reduce costs while maintaining the quality of the results.[32].
One such solution is the use of VR technology, which has become increasingly popular in recent years owing to its ability to simulate complex scenarios in a cost-effective manner [33].
VR is a computer-generated simulation of a three-dimensional environment that can interact with a user through specialized hardware and software [34]. This technology uses advanced computer graphics, 3D modeling, and other techniques to create an immersive experience that simulates a realistic environment [35].
The headset is equipped with screens that display the images in stereoscopic 3D, which creates an illusion of depth and enables the user to feel as though they are inside the virtual

world.
To make the VR experience more engaging and realistic, VR systems come with handheld controllers or other devices that allow users to interact with the virtual environment using their gestures and movements. These controllers are equipped with sensors that track the user's movements and use this information to perform corresponding actions within the virtual world. With these controllers, users can perform various tasks such as manipulating objects, navigating through the environment, and interacting with other virtual entities.
VR has many applications in fields, such as entertainment, education, training, and therapy. In education and training, VR is used to simulate real-life scenarios and provide a safe and controlled learning environment. VR is used to treat conditions such as anxiety disorders [36], phobias, and post-traumatic stress disorder (PTSD) [37] by exposing patients to controlled virtual environments that help them overcome their fears and anxieties.
VR is hovering to revolutionize the way we learn and acquire knowledge. As a technology that simulates three-dimensional environments, VR provides an immersive and interactive learning experience. [38]
One of the primary advantages of VR in learning is the ability to create simulated environments that can be experienced in the real world with some changes, and we can even control it from the outside to enhance and improve the experience [38]. For instance, students can learn and manipulate electronic systems without the danger they can face in the physical world [39]. Additionally, VR enables participants to interact with virtual objects and situations, which promotes experiential learning, problem-solving, and teamwork skills [40]. Furthermore, VR provides a personalized learning experience, as participants can move at their own pace and receive individualized feedback. This personalized approach is particularly beneficial for participants with different learning styles and abilities, as it helps them better retain and apply knowledge [41] .
For HRI, a common thing to do is the Wizard of Oz (WoZ) [42, 43], which we applied in VR. In engineering, the term "Wizard of Oz" refers to a prototyping technique that involves creating a simulated version of a system or product that appears to be fully functional to its users, but is actually being controlled by a human operator behind the scenes [42]. This technique is often used in the early stages of product development to test user interactions and identify potential design flaws before significant resources are invested in building a fully functional prototype[44].
To implement the WoZ technique, a human operator (the "wizard") interacts with the user as if the system was fully automated. The user interface and other system components can be mocked using physical props, software simulations, or a combination of both [43]. The wizard observes the user's interactions with the system and responds accordingly using their knowledge of the intended system behavior to create the illusion of a fully automated system.
The WoZ technique has been used in a variety of engineering fields, including software development [45], robotics, and human-robot interaction [46]. For example in "Anthropomorphism in social robotics: empirical results on human–robot interaction in hybrid production workplaces" they used WoZ to analyze hybrid cooperation and team building in a controlled setting,[47]. It is particularly useful when creating a functional prototype is expensive, time-consuming or the final system design is still uncertain.
Another useful tool for evaluating HRI is questionnaires. In this regard, the Robotic Social

Attributes Scale (RoSAS) and the Godspeed questionnaire are commonly used to measure users' perceptions of a robot's social attributes [4], [1]. By using these questionnaires in combination with the WoZ prototype, engineers can gather valuable feedback on the effectiveness of HRI and identify design flaws to improve the end product [43].

In this way, the **(i) Robotic Social Attributes Scale (RoSAS)** is a survey that measures users' perceptions of a robot's social attributes and assesses social variables such as happiness, capability, responsiveness, competence, strange, and aggression [4]. It consists of 12 statements that describe different social attributes that a robot may possess, such as approachability, empathy, trustworthiness, and competence. [4][48][49]. In addition, the **(ii) Negative Attitude toward Robots Scale (NARS)**,[1], is "a tool that aims to measure the attitudes and emotions of people during the interaction with different kinds of robots." The NARS is composed of three subscales: negative attitudes toward situations of interaction with robots, negative attitudes toward the social influence of robots, and negative attitudes toward emotions in interaction with robots. [4]. Furthermore, **(iii) The Godspeed questionnaire** has been used in various HRI studies to evaluate users' perceptions of different types of robots and to investigate how these perceptions are influenced by factors such as the robot's appearance, behavior, and task performance [7].

Furthermore, the **(iv) System Usability Scale (SUS)** "is an instrument that allows evaluation of the usability of a prototype using parameters such as user experience, composed of 10 statements." [48]. For SUS, users are asked to rate their level of agreement or disagreement with each statement on a Likert scale from 1 to 5, where 1 represents "strongly disagree" and 5 represents "strongly agree." The ten statements were designed to measure two key aspects of usability: effectiveness (how well the system performs its intended functions) and efficiency (how quickly and easily users can perform tasks with the system) [50]. The SUS is a reliable and validated tool for measuring the usability of a system. The use of SUS has contributed to the development of user-friendly and efficient systems[2]. It has been widely used in various fields including human-computer interaction [51], product design [52], and user experience research [53]. The SUS scores can be used to compare the usability of different systems and identify areas for improvement [50].

Finally, to evaluate human extraversion, agreeableness, and, neuroticism, we used the **(v) Big Five Inventory (BFI) personality survey**, a psychological assessment tool designed to measure five broad dimensions of personality. It is based on the Five-Factor Model (FFM), which is one of the most widely accepted and researched theories on personality [54]. The five dimensions, also known as the "Big Five", are as follows.

- *Openness to experience*: This dimension measures a person's creativity, imagination, and willingness to try new things.
- *Conscientiousness*: This dimension measures a person's organization, dependability, and level of self-discipline.
- *Extraversion*: This dimension measures a person's sociability, assertiveness, and level of outgoingness.
- *Agreeableness:* This dimension measures a person's level of empathy, cooperation, and concern for others.

- *Neuroticism*: This dimension measures a person's emotional instability, anxiety, and negative affectivity.

The BFI survey consisted of 44 questions, with each question representing one of the five dimensions of personality. Participants were asked to rate the extent to which they agreed or disagreed with each statement using a 5-point scale. Once the survey is completed, scores are calculated for each of the five dimensions, providing a comprehensive understanding of an individual's personality traits. [55]
In this work, a study will be developed based on the work called "to err is a robot," which was used in [24] and was published in the journal Computers in Human Behavior in 2018. This study explores how humans react to errors made by social robots and how these errors affect users' perceptions of robots.
The authors of [24] conducted a study in which participants interacted with a social robot called Pepper that made deliberate errors during the interaction. Errors are designed to be either social or functional [56]. Social errors included the robot making inappropriate or irrelevant comments, whereas functional errors included the robot failing to correctly identify objects.
The authors suggested that understanding how humans perceive and react to errors made by social robots is important for developing and designing future robots. They also highlight the need for social robots to be designed with the capacity to learn from their mistakes and correct their behavior to maintain users' trust and engagement.
The primary objective of our study is to investigate the effects of using VR technology in human-robot interaction (HRI) experiments. Specifically, we aim to evaluate NAO's effectiveness as a teaching assistant even when programmed to make errors during practical sessions. Our analysis will focus on assessing whether participants' engagement and learning outcomes, such as turning on the LED, are negatively impacted. Furthermore, we will collect feedback from participants to gauge their perceptions of the robot's reliability and effectiveness. By utilizing VR technology, we aim to create a more realistic and immersive learning environment that better replicates real-world scenarios. Ultimately, the findings from this study could have significant implications for the development of educational robots and the use of VR in HRI research.

1.2 Objectives

General objective

1. To develop a system that allows the realization of a human-robot collaborative work for the execution of a practical session in the physical world and VR.

Specific objectives

1. To design a practical session with its respective instruction guide, which must be given by NAO robot.

2. To implement the practical session in the physical and VR world, taking into account that through the interaction of NAO with the participant, the development of the practical session is achieved.

3. To identify the effect of a social assistance robot on the human-robot collaborative work carried out during the development of the practical session.

4. To evaluate the perception of the participants regarding the interaction with NAO during the development of the collaborative work proposed for the execution of the practical session.

Chapter 2

Errors

"Perhaps the history of the errors of mankind, all things considered, is more valuable and interesting than that of their discoveries. Truth is uniform and narrow; it constantly exists and does not seem to require so much active energy as a passive aptitude of the soul in order to encounter it. However, error is endlessly diversified; it has no reality but is the pure and simple creation of the mind that invents it. In this field, the soul has room enough to expand herself, to display all her boundless faculties, and all her beautiful and interesting extravagances and absurdities."

- Benjamin Franklin

Errors are an inevitable part of the human experience and can have profound social implications [56]. In our daily lives, we often encounter errors made by ourselves and others, and judge and evaluate them in various ways [57, 58, 59]. However, defining what constitutes an error can be both complex and multifaceted. Is an error simply a mistake or does it involve a deliberate act of omission or commission? Is an error the same as a lie, and if so, is a lie the same as an error? These questions become even more complicated when the implications of errors in artificial intelligence and robotics are considered [56, 60].

As machines become more advanced and ubiquitous, the potential for errors increases [61]. However, the nature of errors in machines may differ from those made by humans, which raises new questions about how we perceive and evaluate these errors [62, 63]. Furthermore, our understanding of errors in humans and machines is deeply intertwined with broader social and cultural norms [64]. For example, certain professions may be more tolerant of errors than others, and errors made by people in positions of power may be viewed differently from those made by individuals with less authority [57]. In addition, biases and stereotypes may influence how we perceive and respond to errors made by different groups of people [59].

In this section, we explore the complexities of these errors and how they are perceived and evaluated by humans. We will examine the social and cultural factors that shape our attitudes towards errors as well as the implications of errors in artificial intelligence and robotics [56, 60]. Ultimately, by gaining a deeper understanding of the errors and our responses to them, we may be better equipped to navigate the complexities of a rapidly changing technological landscape [65, 66, 67].

2.0.1 Pratfall effect

The Pratfall Effect, initially proposed by social psychologist Elliot Aronson in 1966 [57], refers to a psychological phenomenon in which an individual's likability or attractiveness increases subsequent to the occurrence of a mistake or minor failure. This effect arises from the notion that individuals who display occasional errors or vulnerability tend to be perceived as more approachable and likable by others. The belief underlying this perception is that their mistakes render them more relatable and human, thereby eliciting a sense of empathy.

It is essential to note that the manifestation of the Pratfall Effect is subject to specific circumstances. For instance, if an individual's mistake is perceived as a substantial failure, it can diminish their likability or attractiveness [58]. Furthermore, the effect may not hold true when applied to individuals who are already regarded as highly competent or successful, as their mistakes may not significantly alter others' perceptions.

Practical applications of the Pratfall Effect extend across various domains including public speaking, marketing, and job interviews. For example, during a presentation, a speaker who commits a minor error may be viewed as being more likable and relatable by the audience. Similarly, a company that openly acknowledges its mistakes and exhibits vulnerability may be perceived as more trustworthy and authentic by customers. By strategically leveraging the Pratfall Effect, both individuals and organizations can enhance their interpersonal connections and cultivate heightened perceptions of authenticity [59].

2.0.2 Error: a Truth-for-now?

First, it is important to highlight the difference between lies and truth [58]. Throughout this text, the reader understands why this is relevant. We must bear in mind that lying and truth are intrinsically related because both are beliefs [58]. However, it is necessary to start from the fact that both lies and truth depend on objective facts, and reality, as an aspect of human life, is susceptible to distortion due to various factors [62].

Thus, we can affirm that truth constitutes the foundation of society [63]. Lying is defined as an act or statement intended to deceive or mislead another person into believing something false [67]. It is a deliberate and conscious form of communication that distorts truth [67]. However, let us turn our attention to truth and ask us a series of questions: What is it good for? What is the human interest in truth? Should we be constantly concerned with seeking truth?

To answer these questions, let us situate ourselves in Enlightenment, a period in which the search for truth through reason and empirical evidence is a central goal [60]. Enlightenment philosophers have encouraged critical and scientific thinking, and questioned traditional beliefs [68]. Their goal was to free humanity from ignorance and oppression through knowledge [60]. Truth is considered attainable through observation and scientific methods, although the limits of human knowledge and influence of subjectivity have been debated [64].

We can affirm that truth plays a fundamental role in humanity because it helps us live and survive as well as in predicting and understanding [58, 59]. A truth is achieved when a belief is justified and corresponds to reality [62]. We emphasize the importance of survival [62]. For example, without truth about a climate crisis, we would not be able to act as individuals or nations to prevent extreme risks [60]. Similarly, in the case of COVID-19, without truthful knowledge that vaccines save lives, we would not have been able to deal with the pandemic quickly and efficiently [60].

In general, truth is useful to us in the long run, is consistent, and plays a crucial role in trust [58]. When we are lied to, it betrays our trust in relationships and our trust in ourselves, because by believing those lies, we are betraying our senses and minds [67].

The incredible search for truth interests us because it not only helps us survive but is also constant and reliable [58]. Lying, on the other hand, is variable [66]. Humanity is not genetically prepared to live with uncertainty or unpredictable change [64].

The consistency of truth is useful for predicting, relieving distress, and maintaining an orderly and stable society [63]. It is important to note that part of the debate about truth lies in the fact that language creates reality, and the varied use of language can lead to different realities [65]. However, in this context, we do not address this aspect because we wish to focus on this debate in another direction.

With this said, let us analyze the different types of lying, focusing on contradictions [58, 66]. Contradiction is a form of lying that affects both sides [58]. It is based on the belief that we believe to be true, but that falls apart when confronted with facts, making it a lie [66]. For example, mathematically, when we prove by contradiction, we start from a false assumption and conclude that something does or does not occur [66]. However, many contradictions, despite being lies, are the products of human errors or mistakes [62]. For example, when we fight and defend our privacy, but for our ignorance or mistakes, we accept cookies and share social network details about what we do, think, and like [66].

Now, let us focus on new technologies that are gaining popularity, such as artificial intelligence (AI) and robots [69]. I ask the reader, What do you think when I mention the word "robot""? If the reader is familiar with the field of HRI, he or she will probably mention the importance of adapting society and the robots themselves to achieve harmonious coexistence in the future [69]. However, most people, influenced by movies, books, and entertainment, associate robots with qualities such as coldness, practicality, efficiency, and perfection [69].

This last word raises questions: how can we determine with certainty what perfection is? What is the ideal for perfection? Why do we want the machines to be perfect? [68].

Now, let us pose a specific problem we wish to address: What would happen if the robot we imagined above contradicted itself? How would we feel if we were lying with us? What would happen if the robot makes mistakes? Is lying and making mistakes exclusively in terms of human quality? [59].

Let us now discuss these mistakes. When we make a mistake, there are two possibilities: we are making the mistake without being aware of it or we know we are wrong [63]. When we recognize a mistake, different paths open, such as lying to make others believe that we have not made the mistake or accept it and moving on [62]. As with lies and truths, there are different types of errors, but here we focus on errors due to contradiction, lack of knowledge, or believing in something false [59].

Therefore, it is valid to ask how normal it is to make mistakes, and how many times [62]. If we review the literature, we find that making mistakes is normal and natural for humans

[63]. However, throughout history, the fact that mistakes are made has been questioned, and it is often said that mistakes are made until learning [62]. Despite this, just as we seek truth to improve the conditions and make predictions, we also seek to eliminate errors [64]. We have tried religion and science, but it is impossible to eradicate errors. For human beings, we know it is not possible, since that would lead us to absolute knowledge and to a perfect prediction that in religion (as mentioned by St. Augustine) is reflected by God [64]. This dilemma is present today with transhumanism and the yearning for eternal life, which translates into a search for perfection [64].
Unlike humans, we do not know if errors in machines can be eradicated, particularly amid the rise in artificial intelligence [60]. However, the purpose of this study was not to eliminate errors. This is to stop seeing robots as mere tools and to learn from them, understanding that errors are not negative [60].
Error, as stated in the cited reference, is presented to us as a "truth for now." It is a truth that has not yet been discovered; it is what is believed, and then, it may be contradicted. However, once this doubt is resolved, the truth will be known, which sustains humanity [59].

"What human beings are best at doing with mistakes is not recognizing them" [66]. Therefore, it is important to study mistakes and propose that, in the end, making mistakes is important, because it helps us learn and shows us that there is always something beyond. A prime example of the importance of errors is the Laplace curve, also known as a normal probability distribution [66]. Pierre-Simon Laplace, a French mathematician, and astronomer, studied the orbits of the planets [70]. He proposed the hypothesis that despite gravitational perturbations, the solar system is stable, and planetary orbits remain nearly unchanged over the long term. He developed a mathematical method called the osculating elements method to calculate the future orbits of planets. Although his approach was not completely accurate, it laid the foundation for future advances in celestial mechanics and theory of gravitation. Laplace won the mathematical race for his time as the only one to consider errors in his calculations. This is not the only mathematical analysis that exemplifies the value of errors in engineering and society [71].
Returning to the problem of attempting to eradicate mistakes, it is important to recognize that humans naturally make mistakes [66]. Although this may be uncomfortable, errors may occur. Although we strive for perfection, we know that it is impossible. We experience failures in the economic, political, and even educational systems. Our bodies also experience failures such as allergies or organ problems, and over time, these failures become more evident. Being creators of machines and artificial intelligence, why do we expect perfection from them? Why are we surprised when they fail or make mistakes? Why do we not learn from these mistakes or seek to improve both new technologies and ourselves as human beings? [68].

In the following sections, we explore the experiments conducted and their answers to these questions.

Chapter 3

Methods and Materials

In this section, we will examine the background that was used for the sessions both in the physical world and in the virtual reality world. We will explore the definitions used, the physical spaces where the sessions were held, and the materials and methods implemented. In addition, surveys and questionnaires were administered to the participants.

3.1 Equipment

NAO: This is a humanoid robot that incorporates two cameras, four microphones, nine tactile sensors, two ultrasonic sensors, eight pressure sensors, one accelerometer, and a gyroscope. It also has expression elements such as twenty-five RGB LEDs, a speech synthesizer, and two speakers. The NAO robot can be programmed through its software called "Choregraphe", which is compatible with Windows, Linux, and OS.

Figure 3.1: NAO Social Assistance Robot `https://www.erm-automatismes.com/p181-es-robot-humanoide-nao.html`.

Virtual Reality Glasses: The Oculus Rift S is a virtual reality headset that provides an immersive experience with a high-resolution display, responsive head tracking, and intuitive hand controllers. It includes a comfortable headset with built-in sensors for tracking head movements, two ergonomic controllers for interacting with virtual objects, and necessary cables for connecting to a computer. It offers a wide field of view, visual clarity, and the ability to project real-time visuals on a computer. Overall, Oculus Rift S delivers a comprehensive and engaging virtual reality experience for gaming, simulations, and interactive applications.

Electronic components: The practical session, was carried out in the School of Engineering, Science, and Technology laboratory. In this practical session, participants had to follow the instructions of NAO to successfully turn on an LED. In this sense, NAO provided step-by-step instructions that the participants had to follow to connect all electronic components to turn on an LED. The components used are listed in Table 3.1. It is important to highlight that Arduino was previously programmed using the respective code.

Figure 3.2: Oculus Rift s Virtual Reality Glasses https://hardzone.es/reportajes/comparativas/oculus-quest-oculus-rift-s/

Element	**Quantity**
Arduino	1
Arduino power source	1
Leds	1(red), 1(yellow), 1(green)
Resistence	1(220Ω)
Tweezers	1
Jumpers	1 set
Protoboard	1

Table 3.1: Electronic components

3.1.1 Questionnaries

Each participant completed a series of questionnaires before and after the practical sessions. Each question was answered using a Likert scale from 1 to 5, where 1 was 'strongly disagree' and 5 was 'strongly agree.' Based on Godspeed [7], RoSaS [72], SUS [2] and BFI [54] questionnaires, a series of questions were adapted to assess the acceptance of the use of NAO within the HRC, taking into account the intentional errors of the robot.
Before the session, the participants had to complete the Big Five Inventory (BFI) personality survey. This survey was conducted to check whether there was a correlation between the participant's personality and his or her answers from the other surveys.
The participants had to complete (at the beginning of the session) the Negative Attitudes Towards Robots Scale (NARS) [1]. (See Table 3.2.)

Questions
I would feel uneasy if robots really had emotions
Something bad might happen if robots developed into living beings.
I would feel relaxed talking with robots
I would feel uneasy if I was given a job where I had to use robots.
If robots had emotions I would be able to make friends with them.
I feel comforted being with robots that have emotions.
The word "robot" means nothing to me.
I would feel nervous operating a robot in front of other people
I would hate the idea that robots or artificial intelligence were making judgments about things.
I would feel very nervous just standing in front of a robot.
I feel that if I depend on robots too much, something bad might happen.
I would feel paranoid talking with a robot.
I am concerned that robots would be a bad influence on children.
I feel that in the future society will be dominated by robots.

Table 3.2: NARS Survey [1]

At the end of the session, a survey composed of the Robotic Social Attribute Scale (RoSaS) and Gospeed was used [4, 5, 6, 7]. Additionally, the System Usability Scale (SUS) was used to evaluate the use of NAO robot within the HRC [2, 3]. Finally, we applied our own questions (see Table 3.4) to measure the "NAO errors."
The SUS questionnaire was adapted to measure the user's experience of usability, including aspects such as *learn-ability, efficiency, satisfaction, and ease of use.* This survey has ten (10) statements, all of which are rated on a scale from 1 to 5. These statements are listed in Table. 3.3: Both surveys (SUS and our own) allow the evaluation of parameters, such as perception, reliability, danger, social feeling, and judgments. These parameters can be obtained from the environment and from the human-robot interaction. These areas are essential when evaluating the impact on the perception and interaction of robot applications, such as that presented in this study.

Question
I think I would like to use NAO frequently.
I find NAO unnecessarily complex.
I think working in conjunction with NAO is easy to do.
I think I need the help of a technical person to be able to work together with NAO.
I find several of NAO functions well integrated into the development of the workshop.
I think there was a lot of inconsistency with NAO during the development of the workshop.
I imagine that most people find it easy to use NAO to work together.
I find it uncomfortable to have NAO give me instructions.
I feel confident using NAO to receive instructions.
I need to learn many things before using NAO as a means of guidance for workshop development.

Table 3.3: SUS Survey [2, 3]

Regarding the questions about the errors, we consulted a psychologist who helped us raise questions to achieve the purpose of this work.

3.1.2 Groups of study

For the execution of this work, two scenarios were designed, as presented in Table 3.5. In this way, it will be possible to identify variations in the development of the practical session by the participant in an environment of the physical world and one of the VR. In addition, the effect of using NAO on collaborative work in both environments was identified. Regardless of the physical or virtual environment of the participant, a student from the School of Engineering, Science, and Technology from the last semester will be present during the test. This was to ensure the safety of the participant and verify the correct functioning of the system.

3.2 Proposed Intervention

The following division endorsed by the ethics committee of the Universidad del Rosario (See apendix 1). to carry out the experiments: (1) Call, accept, and provide informed consent. (2) practical sessions and (3) surveys and final feedback. The stages are described as follows.

Aspect	Question
Credibility	consider that NAO was consistent/reliable during the development of the workshop
Simpathy	I consider that NAO was supportive and empathetic during the development of the workshop
Scription of responsability	From 1 to 5, how much responsibility should NAO be given for monitoring and instructing?
Deception and acceptability	I consider that NAO was misleading, if it responds on the scale to an equal or greater number than 3, do you think this was acceptable?
Artificial-realistic	I consider that NAO is very natural giving the instructions
Intelligent	I consider NAO is capable of guiding me for the development of the workshop
Conscientious	I consider that NAO was always present during the workshop and the instructions had sense
Friendly	I consider that NAO was friendly during the development of the workshop
Social	I consider that NAO communicates adequately and eloquently
Strange	I believe that NAO behaved out of the ordinary during the development of the workshop
Dangerous	I perceived that I did not feel any risk to my physical integrity during the development of the workshop

Table 3.4: Godspeed/RoSaS Survey [4, 5, 6, 7]

1. Call, accept, and provide informed consent: At this stage, the call was launched within the student community. The participants were chosen by exclusion and inclusion criteria, and the respective document information is received. Informed Consent to participate and to use Images and Videos was obtained by mail. A period of 3–10 days was required to provide signed consent.
2. Practical session: This stage is divided into several steps, as described below.

Study Group	Description
Physical World Group	The participant will conduct the development of a practical workshop in a robotics laboratory environment. In addition, it will be guided by means of instructions given by NAO in such a way that collaborative work is generated until the participant manages to reach the end of the workshop. The space where the workshop took place was at Bernoulli's laboratory, located on the 6th floor of Ed. El Tiempo.
Virtual Reality Group	The participant will carry out the development of a practical workshop in a VR environment. For this, the physical space of the Bernoulli laboratory will be recreated in a VR environment so that the participant can identify a familiar environment. The participant will be guided by the instructions given by NAO in such a way that collaborative work is generated until the participant manages to reach the end of the workshop. This test will be carried out at Bernoulli's laboratory, located on the 6th floor of Ed. El Tiempo.

Table 3.5: Study groups: Differences between physical and VR world groups.

- The purpose, precautions, and steps of the sessions were explained to the participants. They are also taught in parts of the laboratory, as shown in Fig. 3.3, and some specifications of the breadboard (see Fig. 3.4).

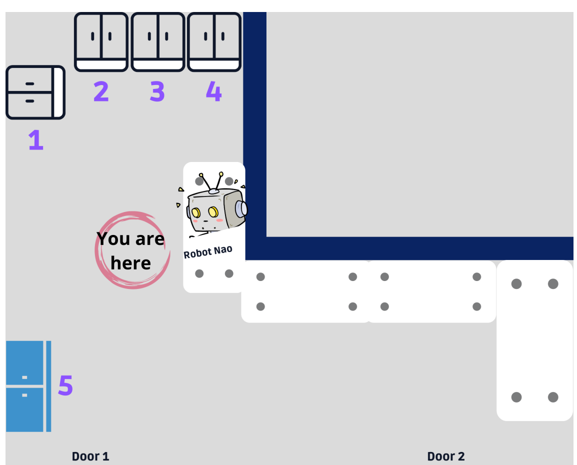

Figure 3.3: Map of the robotics laboratory

- NAO instruction routine began with the development of the session (See Table. 3.6). In this instance, NAO asked if the participant had heard of it correctly.

- NAO will ask the participant to draw the emotions they feel at that moment on a

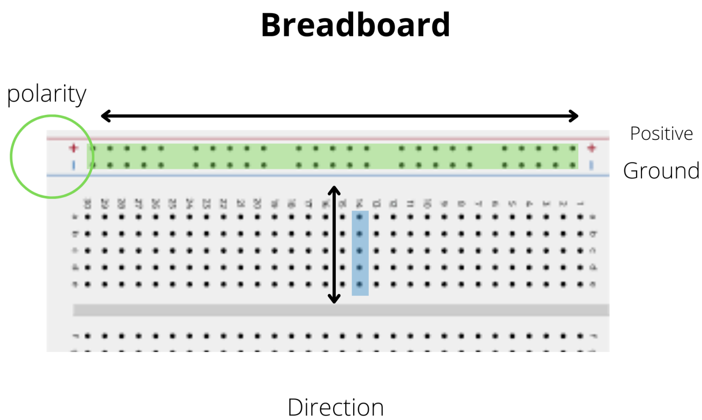

Figure 3.4: Parts of the breadboard

piece of paper. This was to promote the confidence of the participants before starting the practical session [24].

- From NAO instruction No.3 Table. 3.6, the routine will be developed depending on which instruction (with or without error) is given to the participant.

3. Surveys and Final Feedback: During the last stage, the participant no longer interacted with NAO and answered a series of questions established in Microsoft Forms. (See Table. 3.4, Table. 3.7, Table. 3.8 and Table. 3.9). If the participants realized the errors of NAO, they were asked a series of questions, such as *Where was the type of error evidenced?*, and *what they felt?* and the user-friendliness of the system. For the questions in Table 3.7, participants had to answer in paragraphs or short sentences. In Table 3.8, participants had only two options. If the answer was **no**, the session ended; if the answer was **yes**, they continued with the questions in Table. 3.9. Regarding the type of error (Q3 in Table 3.9), three options were available: (1) technical (programming, assembly); (2) environment (instructions, organization); and (3) both (Technical and Environment). The answers to these questions were recorded using a computer system.

3.2.1 Data processing

Python was used for data processing. The analysis was divided into two parts for each environment (physical world and VR), which were the initial and final surveys. In the final survey, we had to perform an analysis by section since each section analyzes different things such as how the participant perceives NAO (godspeed/RoSaS) and what they notice, how they feel, etc.
The data methods used in the analysis are presented below: taking the mean, describing the data set, Likert graphs, word clouds, and analyzing certain interesting cases.

#	Task	Error
1	The robot welcomes the participant	None
2	The robot asks the participant to draw their emotion on a piece of paper	None
3	Participant should open the door of cabinet 1 and take the tweezers, bring them to the table	The door does not open, cabinets 2, 3, and 4 are available
4	Cabinet 3 - Participant should take the jumpers, breadboard, power source and Arduino	The robot does not say arduino (Raspberry//jetsonano)
5	Cabinet 5 - Participant should bring the leds (red, yellow,green), resistors	One of the LED colors is missing (there is red, yellow, and blue)
6	The robot asks the participant to take the necessary materials	None
7	The robot asks the participant to assemble the arduino on the breadboard	The robot repeats the instruction after 5 seconds
8	The robot asks the participant to connect LED 1 to the breadboard	None
9	The robot asks the participant to connect the resistor to one leg	The robot asks the participant to connect the LED incorrectly.
10	The robot asks the participant to connect the LED jumpers to the breadboard	None
11	The robot asks the participant to connect the breadboard jumpers to the arduino	None
12	The robot asks the participant to repeat steps 7 to 10	There is no error, only this time the robot asks to connect the LED correctly (resistor ->long leg)
13	The robot asks the participant to connect the arduino to the power source	None
14	Nao asks if the activity was successful	None

Table 3.6: NAO's Procedure

Question
1. Did you notice something special during the session that you wanted to tell us about?
2. Did your attitude towards the robot change during the sessions? Please explain
3. Would you change anything regarding your interaction with the robot?

Table 3.7: Errors part 1

Question
Did you identify any errors?

Table 3.8: Identification of errors part 2

Question
1. What errors did you identify and who made them?
2. What did you think at that moment, and what did you feel?
3. Type of error identified

Table 3.9: Questions - types of errors

3.2.2 Inclusion and Exclusion Criteria

Inclusion Criteria

Students at the School of Engineering, Science, and Technology at Universidad del Rosario. In addition, they must attend or have previously approved a course in the Fundamentals of Digital Electronics.

Exclusion Criteria

Participants must not present any of the following conditions: light sensibility, partial or full limitations of movement, incapacity for reading, writing, or inability to understand or sign the informed consent form.

3.3 Experimental Setup

Participant Recruitment : Healthy subjects participated in the study. The ethics committee at the Universidad del Rosario approved the study, and all participants read and signed an informed consent document. The participants were 44 volunteers selected from a

random sample of 56 registered students between 18 and 24 years of age. The participants had basic knowledge of electrical circuits and were students of the School of Engineering, Science, and Technology at the Universidad del Rosario.
The practical session took place in the EICT Laboratory at Universidad del Rosario. Two cameras were used to record the development of the practical session in the physical world, and one camera was used for the VR. Each session lasted 30 min and consisted of: i) the welcome phase of the participant and the taking of initial surveys, ii) the development of the practical session, and iii) the taking of surveys and final feedback. In addition, one of the students was present during each session to ensure the participants' safety and to verify the correct functioning of the session.
Additionally, each session had a preliminary preparation stage, where the purpose of this study was explained to each participant, as well as to resolve doubts that the participant had about the elements of the circuit or interaction with NAO.
In fig. 3.5, we can see how the elements were displayed and the organization of the cabi-

Figure 3.5: Materials and cabinets

nets. Fig. 3.6 shows step-by-step the participant's journey in the physical world (see step 1 in 3.6). We explained the map. Next, the participant started recognizing NAO sensors (see step 3 in 3.6). The participant then followed the instructions and went to grab the materials that NAO required (see step 4 in 3.6). With the help of NAO, the participant checked if they had all the materials to start the connections (see step 5 in 3.6). The participant followed NAO's instructions to make the circuit (see step 6 in 3.6). The results are shown, and the participants ended their interactions.
Fig. 3.7 also shows step-by-step the participant's journey, but this time in the VR world (see step 1 in 3.7). We explained the map and basic concepts to the participant (see step 2 in 3.7). A practical session was initiated (see step 3 in 3.7). At the same time, WoZ began (explained in the following section) (see step 4 in 3.7). The first scenario of recognition and learning in VR was initiated (Fig. 3.8) (see step 5 in 3.7). The collection of materials, such as assemblies, began (see step 6 in 3.7). The results of whether the LED was turned

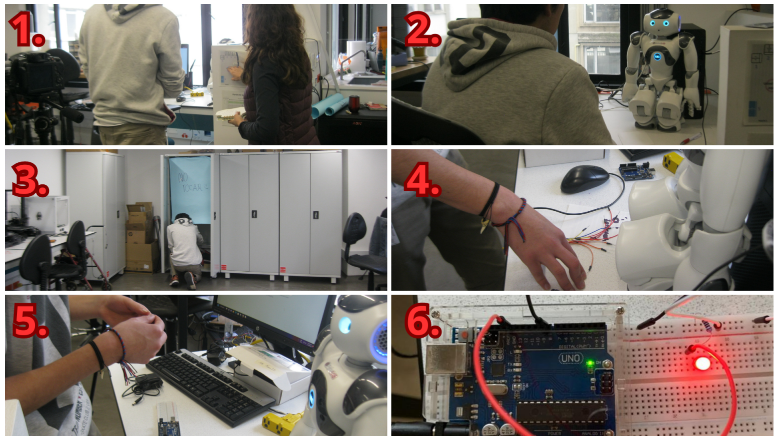

Figure 3.6: Physical World Procedure

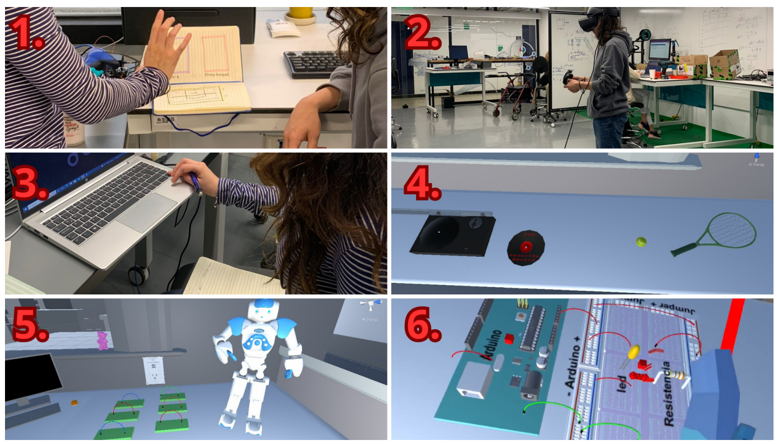

Figure 3.7: VR Procedure

on or not were observed.

3.3.1 Wizard of Oz

WoZ was implemented for VR because although the implementation of NAO in VR was relatively easy, as it was our first scenario in VR, we wanted more control over the experiment to facilitate the participants' experience.

Thus, the following three phases are proposed:

1. Recognition and learning of the environment: The participant listened to a male "human" voice that provided instructions on how to interact with the elements and navigate the laboratory, as shown in Figure 3.8. The participant first had to pick up the tennis racket and ball to learn how to grasp the objects. They then had to pick up the vinyl and place it on the player to understand the concept of object connection in VR, which was achieved through sockets.

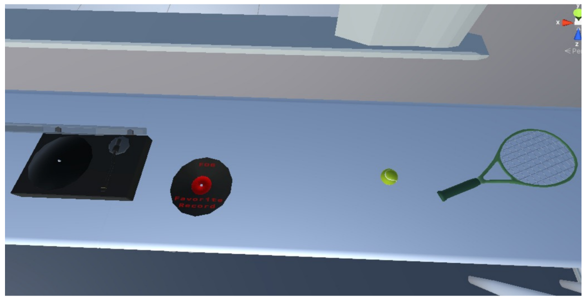

Figure 3.8: First phase - recognition and learning the basics

2. The next two parts were similar to the physical world: First, the participant had to interact with NAO's sensors to identify their locations and familiarize themselves with future interactions.

3. Then, the practical session development began, where NAO started requesting specific materials (some of which were already placed on the table) and provided connection instructions. Both the table and NAO are shown in Figure 3.9.

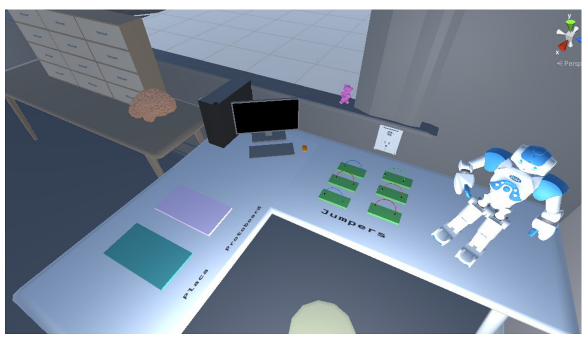

Figure 3.9: Principal Desk - where all the interactions were made

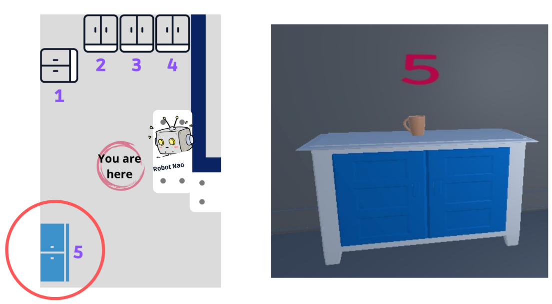

Figure 3.10: Cabinet 5

An important note is that in both VR and the physical world, there was a cabinet (number 5) that could not be opened, and NAO always directed participants to this cabinet as part of intentional errors. The interesting aspect here is that in VR, a “male human voice” would eventually inform participants that the cabinet could not be opened to prevent them from becoming stressed. The cabinets are shown in Figure 3.10.

Chapter 4

Results and Discussion

To see the results, you can check the necessary code at the following Git link: `https://github.com/DanaAcosta/Thesis`. This code will allow you to understand how all the elements we are going to visualize were generated.

This section focuses on reviewing the participants' answers to the surveys and determining their perspectives and behaviors toward NAO. All the surveys ranged from 1 to 5 on a Likert scale, where 1 means totally disagree and 5 means totally agree.

4.1 Physical world

4.1.1 Evaluation of First Surveys

BFI Survey

The survey was sent to the participants. The goal was to determine the spectrum for each of the following variables: extravert, agreeableness, and neuroticism participants were pointing. Thus, we conducted a statistical analysis to determine whether personality traits affect the perception of NAO. In this sense, it was found that about 52.17% tended towards introversion, 47.8% tended to be sympathetic, and 43.48% tended to be nervous or highly strung. This will be discussed in more depth in the NARS by neuroticism and Godspeed/RoSaS extraversion and agreeableness.

NARS Survey

The survey was divided into three sections:

Section 1 has the following questions from Table. 3.2: Q4, Q7, Q8, Q9, Q10, Q12. This section evaluates the negative attitude towards interaction scenarios between the participant and NAO. This means that, while closer to 5 according to the Likert scale, the participant feels more uncomfortable in situations that involve the use of NAO.

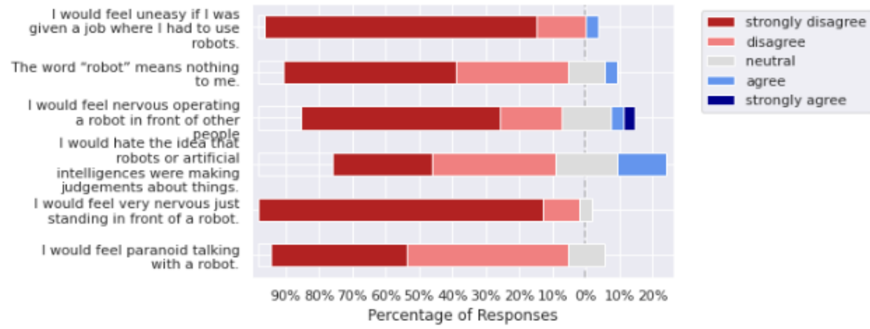

Figure 4.1: Negative attitudes toward situations of interaction with robots

As shown in Figure 4.1, the highest percentage of participants felt comfortable getting involved with NAO during the interactions generated in the practical session (see questions Q4, Q7, Q8, and Q10, Figure 4.1). In addition, the participants agree to share conversations with robots (see questions Q9 and Q12, Figure 4.1)

Section 2 has the questions Q1, Q2, Q11, Q13, Q14 from Table. 3.2. This section defines negative attitudes given by the social influence of NAO. That is, how the participant feels in contexts where the robot has emotions and/or has to use them in a certain social scenario. When the answer is closer to 5, the participants present more uncomfortable negative emotions in this type of case.

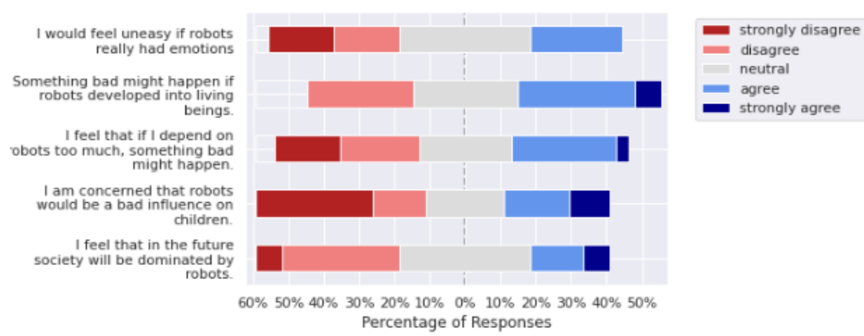

Figure 4.2: Negative attitudes toward the social influence of robots

Figure 4.2 shows that the participants were not ready to share the robot's social influence. The participants were more homogeneous and neutral regarding the aspects related to Section 2. It can be deduced that there is a balance among participants, but there is also uncertainty in safe scenarios with robots.

Section 3 contains questions Q3, Q5, Q6 from Table. 3.2. This section deals with negative attitudes towards human emotions when interacting with NAO. Here, the feelings of the participants were evaluated in relation to the human-like aspects performed by NAO. In this case, only specific emotional contexts were considered. Social contexts are not introduced as happening in the questions in Section 2.

For the questions in section 3, while closer to 5, the participant feels more comfortable when interacting with NAO because it emulates emotions or develops human aspects such as friendship and speaks for itself.

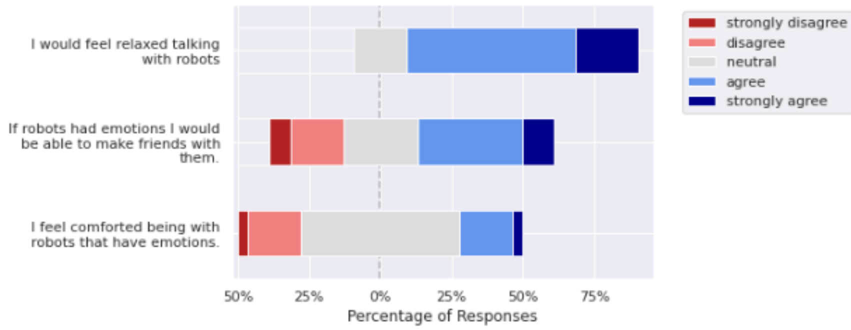

Figure 4.3: negative attitudes toward emotions in interaction with robot

As in the answers to Section 1, the participants confirmed their intention to have conversations with NAO (see question Q3 in Figure 4.3). Such an intention was also perceived in the answers to Q5 (see Figure 4.3). Despite the scenarios of discomfort or neutrality when NAO presents emotions (see question Q6 in Figure 4.3), Figure 4.3 shows that participants are more satisfied and present more positive emotions towards NAO than uncomfortable feelings.

NARS Survey by gender

Conducting a gender analysis of the survey, such as utilizing the NARS, can be instrumental in comprehending attitudes toward robots, as these attitudes may vary based on gender owing to cultural, social, or psychological factors. By examining responses through a gender lens, it is possible to identify significant patterns or disparities in attitudes toward robots between men and women. This analytical approach enhances our understanding of how different groups perceive and engage in robotic technology [69]. Consequently, it facilitates the development of inclusive robotic technology because insights derived from gender analysis in the NARS questionnaire can inform designers about negative attitudes toward robots exhibited by both men and women [69]. In the case of gender analysis, See Fig. 4.4 displays the section averages (as observed in NARS). Graphs pertaining to the individual questions in Table 3.2. are included in Appendix 2 as separate tables.

In this context, the questions were divided into three sections, as previously mentioned. In addition, we calculated the average of each question by gender. According to See Fig. 4.4 the responses by gender do not show a big change, which means, there is no sample that makes us see if exists a difference in how NAO is perceived before the test. Therefore, we analyzed the second category, Neuroticism, from the BFI survey.

NARS Survey by Neuroticism

Through the BFI test, we can access the "neuroticism" score, which indicates that individuals with high scores are prone to experiencing negative emotions including anxiety, worry,

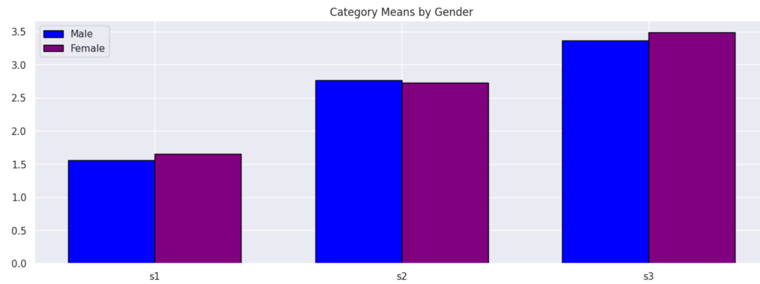

Figure 4.4: Gender means by NARS sections

fear, anger, frustration, envy, jealousy, pessimism, guilt, depressed mood, and loneliness. They are often described as moody, and have a higher likelihood of responding poorly to stressors. We categorized neuroticism into three levels, based on a scale from 0 to 100: *high* (scores above 60), *medium* (scores between 40 and 60), and *low* (scores below 40). This categorization was based on existing literature [73]. Consequently, people with high scores may resort to maladaptive behaviors, such as dissociation, procrastination, or substance use as coping mechanisms to manage negative emotions and seek positive ones. In line with our construct, we aimed to examine how this personality trait influences individuals' evaluation of NAO prior to their interaction.
We arbitrarily chose the category **Negative attitudes toward situations of interaction with robots** because this was what we wanted to evaluate in this study. However, Appendix 2 shows the other two categories (negative attitudes toward the social influence of Robots, Negative attitudes toward emotions in interaction with robots) with their respective levels (high, medium, and low). Upon analyzing the plots for each question within

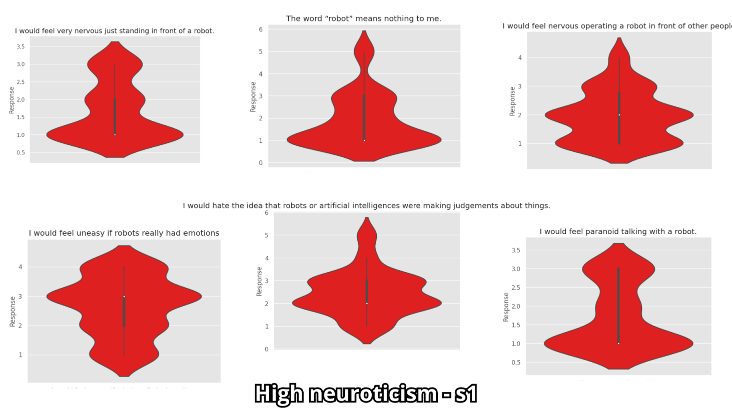

Figure 4.5: Negative attitudes toward situations of interaction with robots - High neuroticism

their respective sections, we observed the following patterns: For individuals with a high level of neuroticism See Fig. 4.5, there was a significant dispersion of responses for questions like “I would feel nervous operating a robot in front of other people” and “I would feel uneasy if robots really had emotions”.

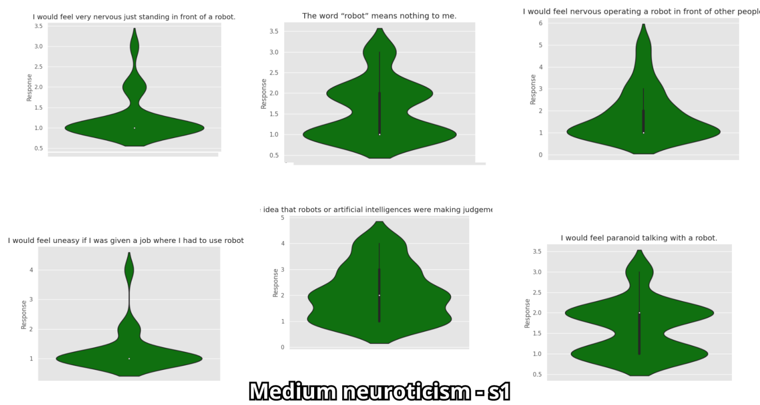

Figure 4.6: Negative attitudes toward situations of interaction with robots - Medium neuroticism

For individuals with a moderate level of neuroticism, See Fig. 4.6, there was a more even and homogeneous distribution of responses.

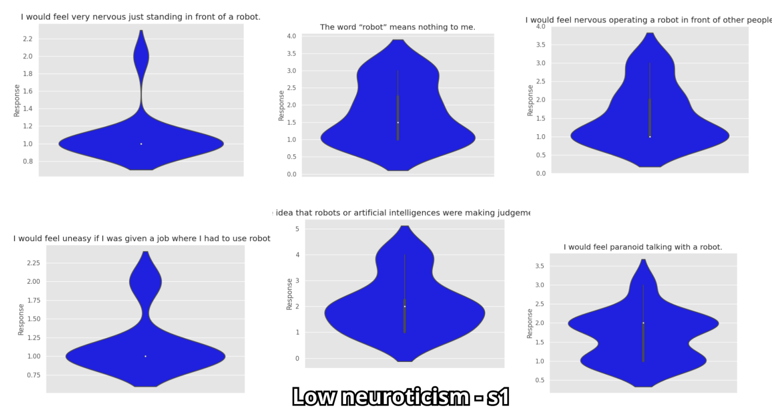

Figure 4.7: Negative attitudes toward situations of interaction with robots - Low neuroticism

Finally, for individuals with a low level of neuroticism (See Fig. 4.7, there was a noticeable similarity between the answers to different questions.

4.1.2 Assessment of the Final Phase of the Practical Session in the physical world

The final survey was divided into two sections since the purpose was to evaluate two fundamental aspects. First, if the robot had certain characteristics that make it suitable for becoming a social being, Godspeed and RoSaS surveys were used. The second was to evaluate whether the participants detected the errors in the instructions given by NAO during the practical session and what they generated. In this sense, questions related to error detection, questions focused on the comparison of how the participants saw NAO before and after the session, and questions about how the interaction with NAO influenced each participant (see Tables 3.7 and 3.9).

Godspeed/RoSaS Survey

Based on the Godspeed/RoSaS surveys, the following aspects that NAO can evaluate: credibility, sympathy, description of responsibility, deception, acceptability, artificial-realistic, Intelligent, Conscientious, Friendly, Social, Strange, and Dangerous. Thus, the values in Table 4.1 show us the mean for each aspect, leading us to analyze these results. Furthermore, Table 4.1 shows that participants had positive opinions about NAO on aspects such as credibility, sympathy, intelligence, conscientiousness, friendliness, and social aspects. However, there are negative opinions regarding aspects such as deception, acceptability, and strangeness. The perception of participants related to the dangerous aspect was high, which could be a consequence of the first experience with a social robot as a teaching assistant.

Aspect	**Mean**
credibility	3.95
sympathy	4.26
scription of responsibility	3.21
deception and acceptability	2.78
artificial-realistic	3.69
Intelligent	3.95
Conscientious	4.04
Friendly	4.43
Social	4.43
Strange	2.04
Dangerous	4.78

Table 4.1: Godspeed/RoSaS means

From Table. 4.1 we can say that the participants perceive NAO being evaluated to be highly credible and sympathetic, likewise, moderately artificial-realistic, intelligent, and conscientious, as well as highly friendly and social. At the same time, we can see that for the scription of responsibility, the value is neutral. Finally, low in deception and acceptability and high in danger, the participants perceived NAO to be strange, with the lowest mean score.

From the GodSpeed/Rosas survey, there is an interesting case (see Question 4 in Table 3.4). If the participant detected that NAO was misleading, he/she was asked if this affected them in any way and why. In this case, answers greater than three (3-neutral, 4-agree, and 5-strongly agree) were selected to obtain the keywords shown in Figure 4.8. Among the total participants for the physical world (23 people), more than half thought NAO was misleading (13 people), but only two people thought this behavior was irrelevant in the session (see Figure 4.9).

Figure 4.8: Word cloud for deception and acceptability

As shown in Figs. 4.9, in the sample, it is not noticeable that there is an inclination for a specific answer. However, taking more or less 50% of the answers, we analyzed the text in which the participants answered 3 (neutral), 4 (agree), and 5 (strongly agree).

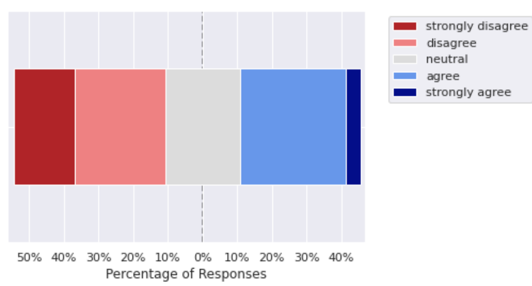

Figure 4.9: Aspect: Deception and acceptability

Godspeed/RoSaS Survey by gender

Moreover, as in the NARS questionnaire, conducting gender analysis was of great importance in this study. Additionally, since we had 11 variables, a factor analysis was conducted to categorize them, resulting in four factors: Responsible Relationships, Social Intelligence, Strange Awareness, and Deceptive Realism.
Appendix 2 contains all of the respective plots for the gender analysis of each question. In Section 4.10, the means for each category are presented and separated by gender.
While the differences may not be significant, as turned out in the NARS questionnaire, we observed differences among genders, particularly in categories such as Strange Awareness and Deceptive Realism.

Godspeed/RoSaS Survey by agreeableness and extraversion

In a similar manner to the NARS survey, we selected neuroticism as one of the personality traits to assess in this study, given its relevance to the survey. Additionally, for the Godspeed and RoSaS questionnaires, we selected two other personality aspects: agreeableness

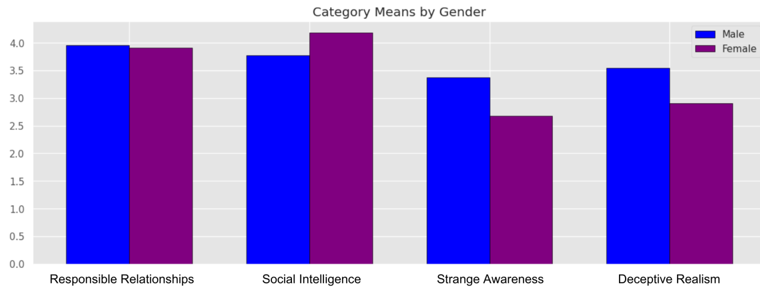

Figure 4.10: Factorial Analysis means by gender

and extraversion.
In this section, we will once again conduct a gender analysis, which separates the data by factors (Responsible Relations and Social Intelligence) and levels of agreeableness and extraversion. Similar to the approach used for Neuroticism, agreeableness, and extraversion were categorized into High, Medium, and Low levels, based on a scale from 0 to 100: *high* (scores above 60), *medium* (scores between 40 and 60), and *low* (scores below 40).
All graphs for the different levels and factors are presented in Appendix 2. However, for the purpose of this analysis, we will focus on figures representing Responsible Relationships and Social Intelligence, as these are the categories we were primarily interested in in this study.
Furthermore, here we will only look at extraversion since, even though there is no correlation, the results for both factors and levels (high, medium, and low) are too similar.

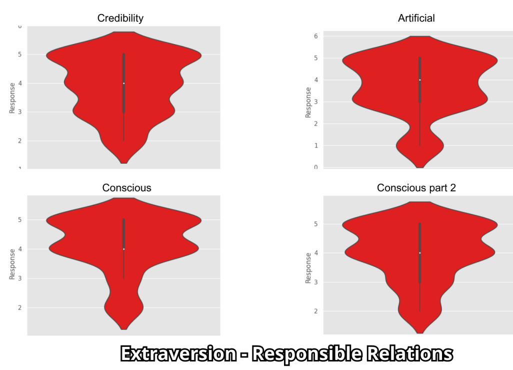

Figure 4.11: a) Responsible Relations - High extraversion

Figure 4.12: b) Social Intelligence - High extraversion

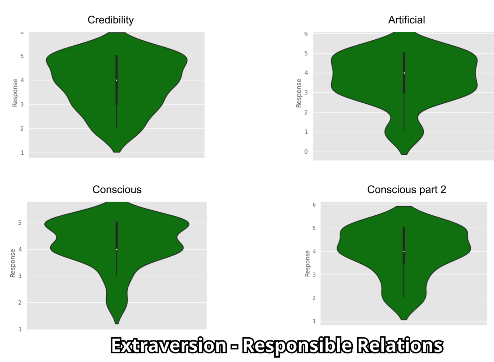

Figure 4.13: c) Responsible Relations - Medium extraversion

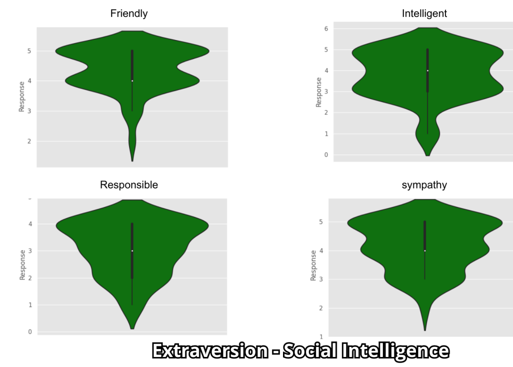

Figure 4.14: d) Social Intelligence - Medium extraversion

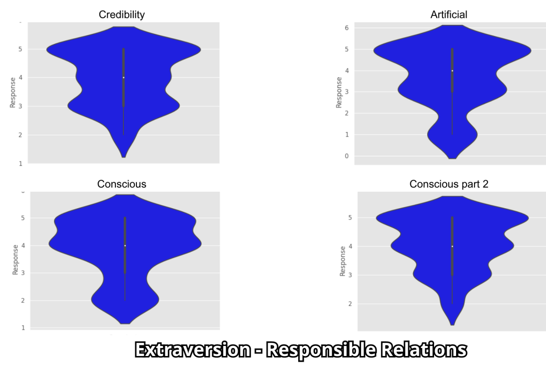

Figure 4.15: e) Responsible Relations - Low extraversion

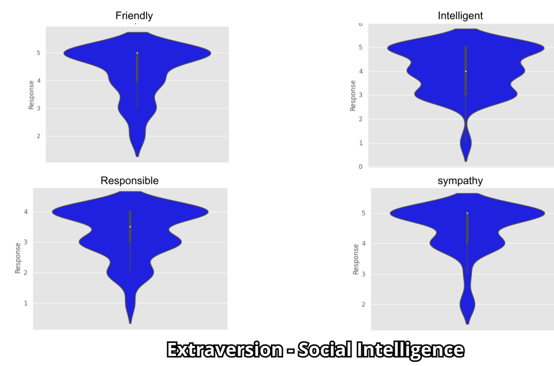

Figure 4.16: f) Social Intelligence - Low extraversion

SUS Survey

The means for the SUS survey are listed in Table. 4.2. These values are used to define several statements. 1) It expresses a positive attitude toward using NAO frequently, 2) There is a low perception of complexity or simplicity towards NAO, 3) statement suggests that working in conjunction with NAO is easy to do, with a mean of 3.92, 4) implies that technical assistance may be required to work together with NAO, indicating a dependency on technical expertise, 5) suggests that several NAO functions are well-integrated into practical session development, indicating a successful integration of the robot's capabilities, 6) suggests that there may be some inconsistency with NAO during the development of the practical session, possibly indicating issues or variability in performance, 7) It implies that some people may find it easy to use NAO to work together, indicating a perception of ease in collaborative interaction, 8) suggests that the participant finds it comfortable to receive instructions from NAO, indicating a positive user experience, 9) It suggests that the participant is moderately confident in using NAO to receive instructions, indicating a moderate level of self-assurance in the robot's guidance and, 10) implies that the participant may need to learn many things before using NAO effectively, highlighting the need for acquiring additional knowledge or skills for the successful utilization of the robot in practical session development.

Question	**Mean**
I think I would like to use NAO frequently.	4.18
I find that NAO is unnecessarily complex.	2.08
I think working in conjunction with NAO is easy to do.	3.92
I think I need the help of a technical person to be able to work together with NAO.	2.60
I find several of NAO functions well integrated into the development of the practical session.	4.21
I think there was a lot of inconsistency with NAO during the development of the practical session.	2.08
I imagine that most people find it easy to use NAO to work together.	3.69
I find it uncomfortable to have the NAO give me instructions.	1.21
I feel confident using the NAO to receive instructions.	3.65
I need to learn many things before using NAO as a means of guidance for practical session development.	2.56

Table 4.2: SUS - means

Hence, in Fig. 4.17 and 4.18 we can see how in Q2, Q6 and Q8. These responses indicate that, in general, people show a strong desire to use NAO frequently, do not perceive their complexity as a problem, and do not feel uncomfortable receiving instructions from NAO. Overall, the Q6 in Table. 3.3 is the most surprising, given that although there were many inconsistencies in NAO, people perceived that everything was going well. Two hypotheses can arise here: (i) the participants did not notice the inconsistencies (which we will see in the next section **errors**), or (ii) although they did notice them, it was *normal* to them.

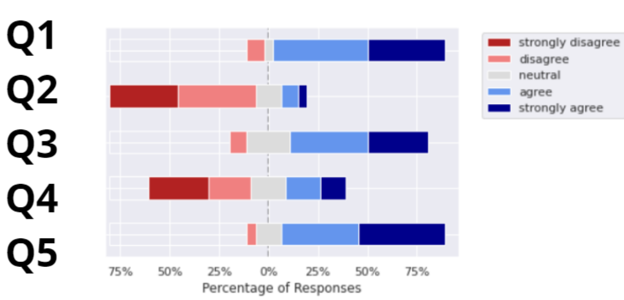

Figure 4.17: SUS Q[1-5] answers in likert scale, Table. 3.3

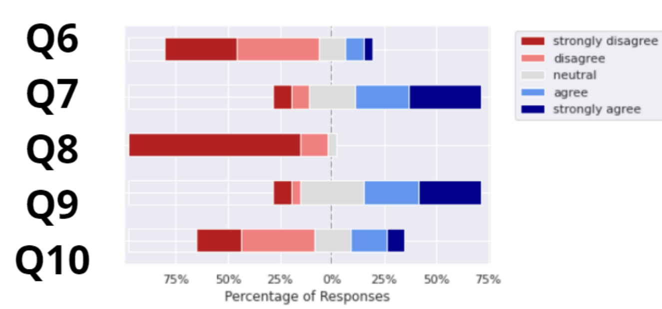

Figure 4.18: SUS Q[6-10] answers in likert scale, Table. 3.3

Errors Perception

This section is divided into three sections.
(i) Perception and self-discovery of errors in the session, which marks if the participants noticed something different or something odd during the practical session. The questions listed in Table 3.7 were asked by the participants.
A frequency word analysis was conducted to detect the most repeated answers for question 1 in Table 3.7 as we wanted to know what the participants found interesting during the practical session. The most common words were *instructions* (9 times), *Nao* (5 times), *one* (4 times), *open* (4 times), *wrong* (3 times), and *drawer* (3 times). The participants recognized the instructions as a highlighted word, even the wrong word, which could mean that participants detected errors.
For Question 2 in Table 3.7, frequency word analysis was also used. Here, we need to determine if the participant's attitude towards NAO changed (for better or for worse), and why. The most common words were: *felt* (six times), *first* (five times), *robot* (five times), *yes* (four times), *instructions* (four times), and *work* (three times). According to the most common words mentioned above, it is necessary to perform a deep analysis of the qualitative information to detect if the participant's attitude has changed.
Finally, for question 3 in Table. 3.7 We obtain another frequency table to visualize which words are repeated the most in the answers because we need to determine if the participant's attitude about the baseline changed before the test. And if this was a negative, positive, or neutral impact. The most repeated words were: *repeat* (8 times), *instructions* (7 times), and *ask* (4 times).
(ii) Do the participants identify errors, here it was asked Table. 3.8, this is to confirm if the participant did perceive an error. Among the 23 participants, 66% noticed any type of error. These mistakes and who made them, are asked in *(iii) Types of errors and sentimental analysis* and *Open, axial, and selective coding for open-ended questions.*
(iii) Types of errors and sentimental analysis For question 1 in Table 3.9 we notice from the frequency word analysis that words such as *NAO*, *instructions*, and *error* are the three words with the highest frequency. Thus, we could identify that the participants believed that NAO was to blame for the error. Based on the answers, these errors were related to how NAO gave instructions or how they were programmed.
Figure 4.19 highlights interesting topics in the word cloud such as. *fault, felt, nothing,*

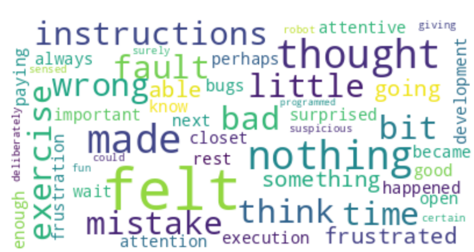

Figure 4.19: What did you think at that moment, and what did you feel?

mistake, instructions, thought, bad. This could be because the participants tended to feel negative emotions each time the robot made a mistake.

Regarding the type of error (see Q3 in Table 3.9), we counted the errors perceived by

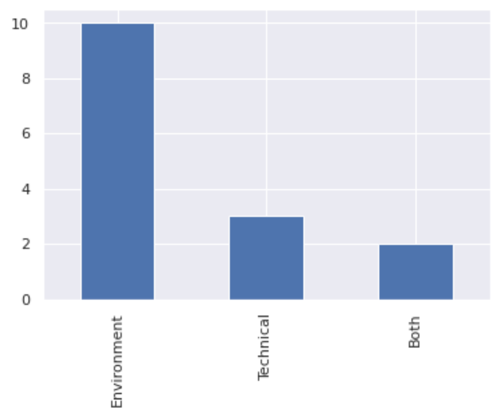

Figure 4.20: Type of error

participants. This method was defined as follows: Technical(3) - This error pertains to failures of NAO, encompassing both programming issues and internal malfunctions such as sensor sensitivity, connectivity problems, and other related factors; Environment(10) - This error refers to environmental faults, which encompass issues such as misplaced items, malfunctioning materials, or other factors related to the physical environment that may have contributed to the error; and both(2).
Most of the participants said that the errors were from the environment, which could mean that it was mostly a fault form the physical environment, not a programming error, Nao's fault, nor the participants' fault.
The two identified errors stem from the same underlying logic discussed in Chapter 2, and from the participant's perspective, they may appear to be the fault of both the programmer and NAO itself. However, it is crucial to note that a more comprehensive analysis of these errors, including participants' perceptions and emotions, will be conducted in the subsequent subsection.

Open, axial and selective coding for open-ended questions

The grounded theory method serves as a valuable tool for conducting a qualitative analysis of open-ended questions, enabling a deeper understanding of the complexities involved in human-robot interactions. By employing open, axial, and selective coding techniques, we can attain a profound comprehension of the essence of human-robot interaction, thereby generating novel insights that can contribute to the advancement of this work. This involves identifying key concepts and categories within the data, which facilitates a deeper understanding of the nature of human-robot collaboration. Additionally, discerning relationships between these concepts and categories aids researchers in developing a more comprehensive understanding of HRC.
Thus, the selective codes derived from the open-ended questions of the error section (Q1 and Q2 in Table. 3.7) were: ***perceived error, frustration, concentration, and confidence***. For Q1 and Q2 in Table. 3.9 The selective codes were: ***Setting responsibility,***

technical error, and participant responsibility.

In this analysis, from the 23 responses, the codes for Table 3.7 exhibited the following distribution: 40% of participants perceived the occurrence of an error. A total of 13.64% of participants expressed feelings of frustration. 18.18% commented on the critical importance of concentration during the experiment. 9% discussed the potential changes in their confidence levels throughout the experiment. For Table 3.9, considering that codes could be repeated depending on the open and axial codes, the findings indicate that 53.4% of the participants attributed the errors encountered during the practical session to themselves. 46.66% concluded that the errors were technical and attributed responsibility to the environment. These percentages provided insight into the participants' perceptions and attributions regarding the errors, highlighting the varying perspectives on the causes and responsibility for the observed errors.
In other words, participants were aware of the error, but often questioned whether it stemmed from the environment or NAO. Despite recognizing the possibility of it being an error caused by NAO or the environment, they still tended to attribute the responsibility to themselves, assuming accountability for the error.

4.2 VR scenario

4.2.1 Evaluation of First Surveys

BFI Survey

Similarly to the physical world experiment, the following characteristics were selected to evaluate,
For extroversion, the values obtained from the participants' responses ranged from 5 to 91, indicating diverse levels of tendency to seek social interaction and the energy derived from it. On average, respondents scored 47.65%, reflecting their individual inclinations towards engaging in social interactions and the level of energy they derive from such interactions.
agreeableness: The values obtained from the participants' responses ranged from 3 to 98, reflecting the degree of willingness to be compassionate, cooperative, and considerate towards others, with an average of 47.65%.
Neuroticism: The values obtained from the participants' responses ranged from 6 to 93 and reflected the degree of emotional stability and the tendency to experience negative emotions, with an average of 50.13%.

NARS Survey

As discussed in Section 4.1, the survey was divided into three sections:

Section 1 This section evaluates the negative attitude towards interaction scenarios between the participant and NAO. It can be observed in Fig. 4.21 is that very few people in the sample agreed or strongly agreed. There was a higher percentage of total disagreement and disagreement. This means that the majority of the sample felt positive according to the situation of interaction with robots in VR.

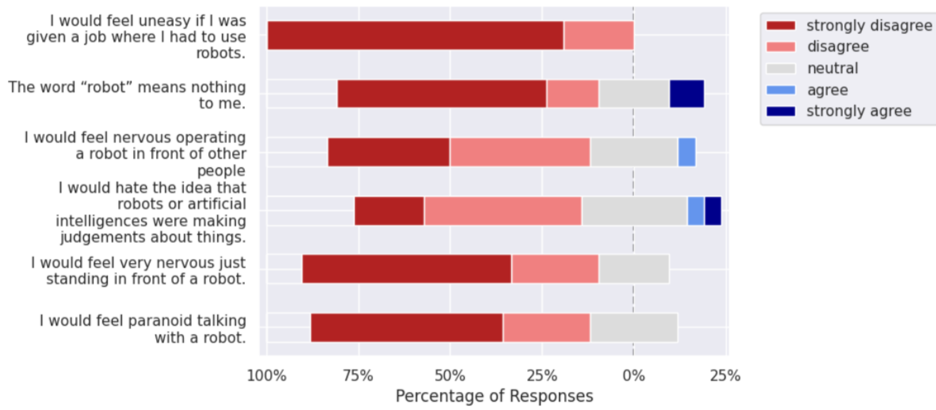

Figure 4.21: Negative attitudes toward situations of interaction with robots in VR

Section 2 This section is focused on the negative attitudes given by the social influence of NAO, in Fig. 4.22 we can notice that the participants showed a similar and neutral response in relation to the aspects discussed in section 2. However, it also reveals uncertainty when it comes to trusting robots in safe scenarios such as control over the future and dependency.

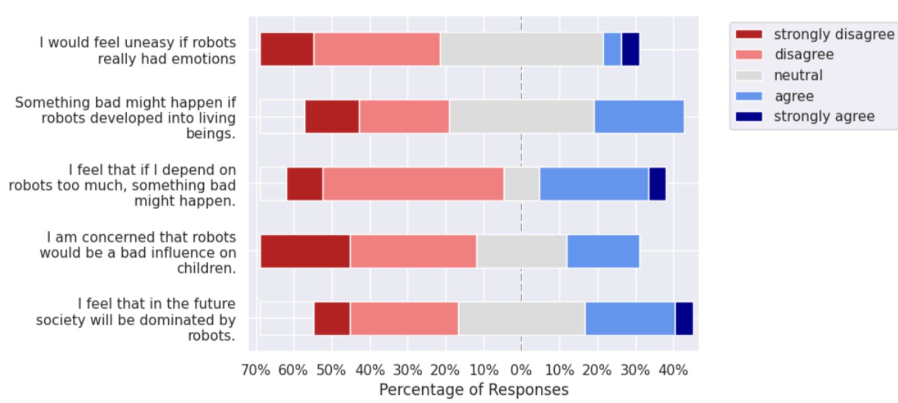

Figure 4.22: Negative attitudes toward the social influence of robots

Section 3 In this section the feelings of participants are evaluated concerning human-like aspects performed by NAO. Here, in 4.23 we observe that the opposite occurs with respect to Fig. 4.22 Fig. 4.21 (previous NARS - Section 4.1). There was more acceptance on the part of the participants regarding attitudes toward emotions in interaction with robots. Thus, there is some uncertainty and significant percentages on the "disagree" side, which is intriguing, especially for the last question.

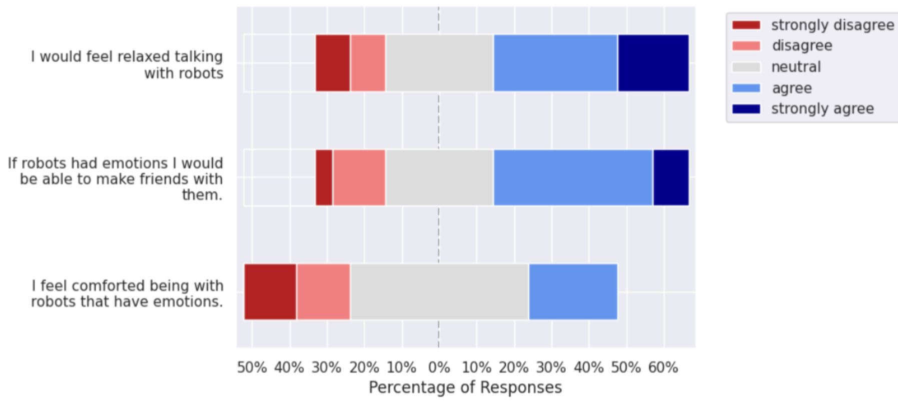

Figure 4.23: Negative attitudes toward emotions in interaction with robot

NARS Survey by gender

Again, we conducted a gender analysis for each question in the NARS questionnaire; the results are shown in Fig. 4.24 revealed some notable differences (refer to appendix 2 for where is displayed the detailed analysis).

Specifically, in the dimensions of "Negative attitudes toward situations of interaction

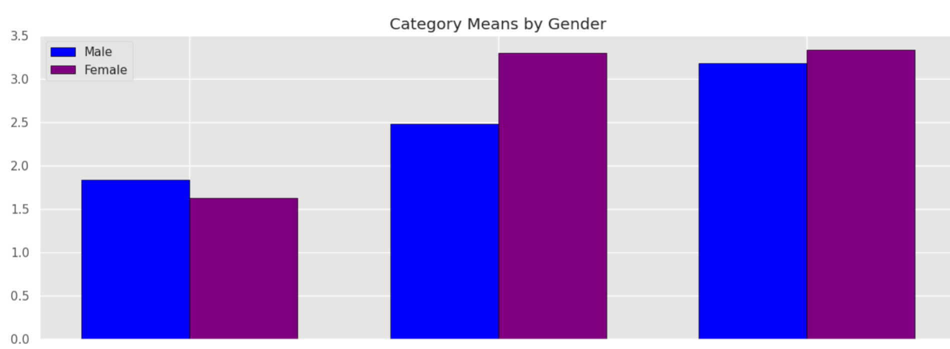

Figure 4.24: NARS - 3 subsections compared by gender

with robots in VR" and "Negative attitudes toward the social influence of robots", the differences between genders were more pronounced. It is remarkable that women tend to express higher levels of disagreement compared to men in the context of negative attitudes toward situations of interaction with robots in VR. On the other hand, women tended to agree to a greater extent than men in relation to negative attitudes toward the social influence of robots.

These findings are particularly intriguing because they highlight sex-specific variations in attitudes towards robots. The fact that women tend to disagree more in terms of VR interactions and agree more regarding the social influence of robots opens up avenues for further exploration and understanding the underlying factors contributing to these differences.

NARS Survey by Neuroticism

Let us delve into the trait of neuroticism once again, focusing on the category "Negative attitudes toward situations of interaction with robots in VR" for comparison purposes.
Upon analyzing the different levels of neuroticism, the following observations can be made: High Neuroticism - Fig. 4.25: There is a notable level of homogeneity, particularly in the graph depicting the question "I would feel nervous operating a robot in front of other people." This question showed more variation in responses than the others.

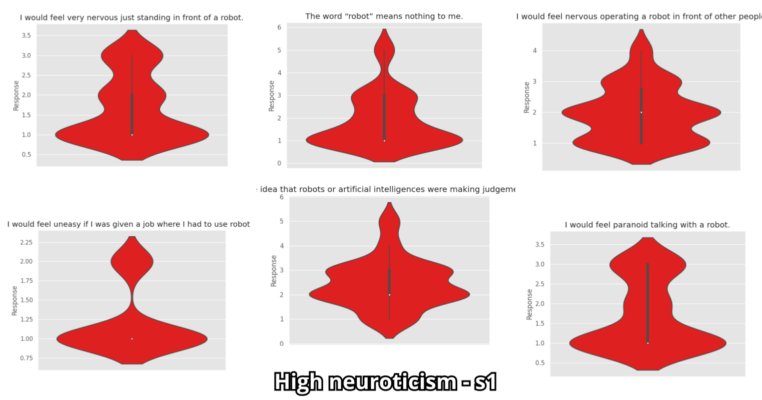

Figure 4.25: Negative attitudes toward situations of interaction with robots - High neuroticism in VR

Medium Neuroticism - Fig.4.26: The responses at this level are very similar to those at the high level. Although there were some smoother curves, we can conclude that there was no significant difference between individuals with high and medium levels of neuroticism.

Low Neuroticism - Fig.4.27: In this category, we observe a higher degree of variety, differentiation, and dispersion among the answers. Although they still bear similarities to responses from other levels, there is a greater density in the frequency distribution.

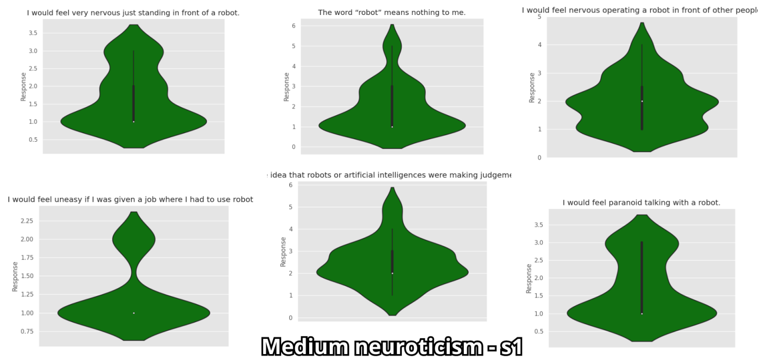

Figure 4.26: Negative attitudes toward situations of interaction with robots - Medium neuroticism in VR

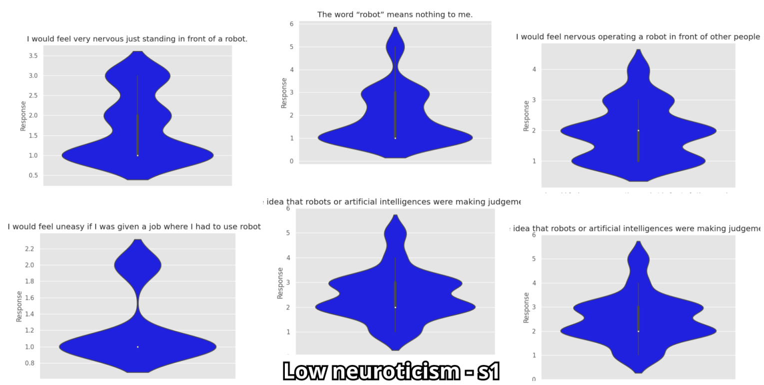

Figure 4.27: Negative attitudes toward situations of interaction with robots - Low neuroticism in VR

4.2.2 Experience with VR

Previous experience: A crucial aspect to consider is whether participants had prior experience with VR. This factor becomes essential in assessing whether their focus was primarily on the VR system itself or whether they already possessed knowledge and expertise that allowed them to concentrate more on the interaction with the robot. This distinction is significant because it can provide insights into how participants' previous exposure to VR technology may have influenced their perceptions and behaviors during this study. Understanding this aspect is crucial, as it allows us to disentangle the effects of VR familiarity from other variables, ultimately providing a more comprehensive understanding of the participants' responses and their engagement with the robotic system.
In this way, we asked the participants (i) if they had previous experience with VR, and (ii) how they felt about trying it that day.
Thus, out of the 21 participants, 14 had previous experiences in VR, of which 4 were recurrent and knew a lot about VR.

4.2.3 Assessment of the Final Phase of the Practical Session in VR

Godspeed/RoSaS Survey

As shown in Table 4.3 participants perceived NAO as moderately credible, indicating a level of trustworthiness in its actions. The robot was also perceived as somewhat sympathetic, suggesting that the participants viewed it as capable of expressing emotions or understanding human feelings to some extent.
However, NAO received lower ratings in terms of deception and acceptability, indicating that the participants had reservations about their trustworthiness in certain situations. This suggests that the participants may have perceived the robot as lacking transparency or potentially engaging in deceptive behaviors.
In terms of artificial-realistic balance, participants viewed NAO as moderately balanced between artificial and realistic. This implies that they recognized the robot's artificial nature, as well as the perceived elements of realism in its behavior or appearance.
Participants perceived NAO as moderately intelligent and conscientious, suggesting that they recognized their capacity for intelligent actions and responsible behavior.
NAO was highly regarded as friendly, indicating that participants viewed it as approachable and amicable.
Regarding social interaction, participants perceived NAO as moderately social, implying that they believed the robot had some capability to engage in social interactions.
On the other hand, NAO received lower ratings in terms of being strange, indicating that participants found it less unusual or unfamiliar. However, the robot was perceived as more dangerous, suggesting that the participants were concerned about the potential risks associated with its behavior or characteristics.

Aspect	**Mean**
credibility	4.04
sympathy	4.24
responsibility	3.86
deception and acceptability	1.90
artificial-realistic	3.24
Intelligent	3.86
Conscientious	3.90
Friendly	4.57
Social	3.90
Strange	1.80
Dangerous	4.47

Table 4.3: Godspeed/RoSaS means

We see in Fig. 4.28 that the majority of participants thought that NAO was not misleading, and the impressive thing is that no one fully agreed. Of the 21 participants, only 6 responded that it was misleading and believed it was relevant. Below is a word cloud with responses to Q4 3.4. The word cloud shown in Fig.4.29 the presence of words such as

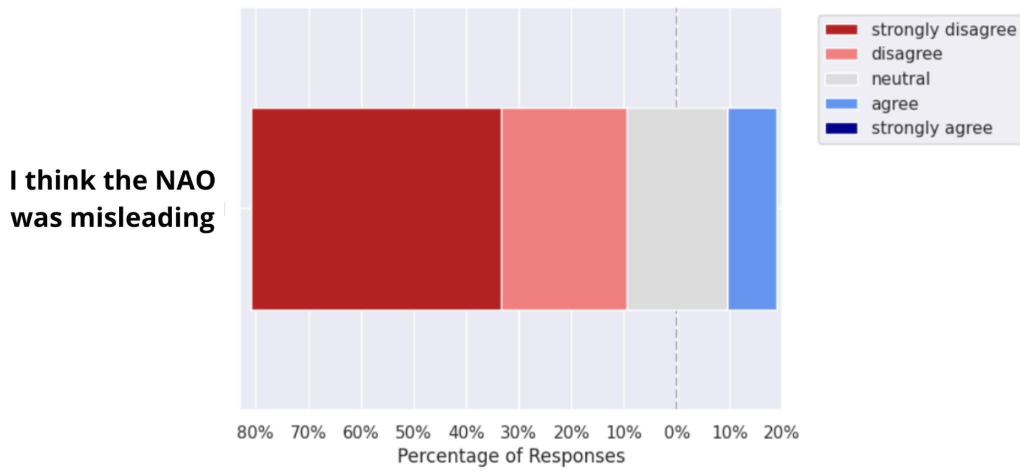

Figure 4.28: Aspect: Deception and acceptability

could, asked, instructions (which will be discussed later), and *learning.* are highlighted.

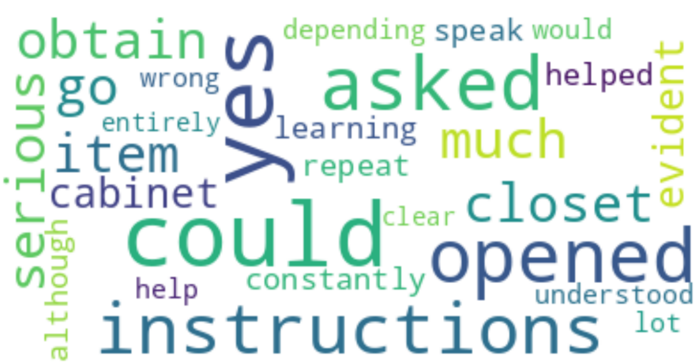

Figure 4.29: Word cloud for Deception and acceptability

This suggests that participants found NAO to be capable and responsive, as indicated by the word *could.* They also mentioned asking the robot for assistance or information, reflected by the word *asked.* The mention of *instructions* indicates that participants found the guidance provided by NAO to be relevant and important. Lastly, the word *learning* suggests that participants recognized the potential for acquiring new knowledge or skills through interactions with NAO.

Godspeed/RoSaS Survey by gender

Once again, we analyzed the responses from the Godspeed and RoSaS questionnaires by gender. However, there is a difference this time, as we needed to conduct additional statistical analysis to (i) specifically analyze the responses related to VR, which exhibit considerable differences among the participants, and (ii) to analyze the change in environment from the physical world to VR. With this shift, the dynamics and factors influencing the participants' perceptions and experiences may differ. Therefore, it is necessary to re-evaluate the underlying factors that contribute to the participants' responses in this new VR setting. By conducting a fresh factor analysis with the responses in Table 3.4, we can identify and categorize the relevant factors specific to the VR context, allowing for a more accurate understanding and interpretation of the data.

Table 4.4 summarizes the correlations between Factor 1, labeled as "Social Interactions", and several variables. This reveals a strong positive correlation between Factor 1 and the variable "Friendly" (0.82). Additionally, other variables, such as "Social" (0.78), "Artificial-realistic" (0.71), and "Responsibility attachment" (0.69) also exhibited significant correlations with Factor 1. These findings suggest that individuals perceive the robot as friendly, sociable, and possess a realistic appearance, while also feeling a sense of responsibility towards it.

Variable	**Correlation**
Friendly	0.82
Social	0.78
Artificial-realistic	0.71
Responsibility attachment	0.69

Table 4.4: Correlation Analysis: Factor 1 - Social Interactions

Variable	**Correlation**
Dangerous	0.43
Strange	0.36
Sympathy	0.13

Table 4.5: Correlation Analysis: Factor 2 - Perception of Risk and Attraction

Table. 4.5 presents the correlations between Factor 2, labeled as "Perception of Risk and Attraction", and several variables. The most significant correlation existed between Factor 2 and the variable "Dangerous" (0.43). Furthermore, variables such as "Strange" (0.36) and "Sympathy"(0.13) exhibited moderate correlations with Factor 2. These findings suggest that individuals perceive the robot as potentially dangerous, with a sense of unfamiliarity and lack of sympathy towards it.

It is worth noting that the distinction between the variables "Conscientious" and "Conscientious2" was made to measure the level of consciousness that people perceived in the

Variable	Correlation
Conscientious2	-0.55
Conscientious	-0.50
Responsibility attachment	0.20

Table 4.6: Correlation Analysis: Factor 3 - Awareness and Responsibility

robot, and both variables represent different questions but aim for the same objective. ”Conscientious” was assessed with the question: ”Do you consider that the NAO robot always had an active role during the workshop?” and ”Conscientious2” with the question: ”Did the instructions given by the NAO robot make sense?”
That way, Table 4.6 presents the correlations between Factor 3, labeled as “Awareness and Responsibility”, and several variables. This reveals that the strongest negative correlation exists between Factor 3 and the variable “Conscientious2” (-0.55). Furthermore, variables such as “Conscientious” (-0.50) and “Responsibility attachment” (0.20) also demonstrate significant correlations with Factor 3. These findings suggest that individuals perceive a robot as less conscientious or less dependable, which may be related to their sense of responsibility.

These factor analyses allow for a better understanding of the underlying dimensions within the survey responses, providing insights into how individuals perceive and relate to the robot across different aspects, such as friendliness, danger, and conscientiousness. From Figure 4.30, it can be observed that there were no significant differences between genders in terms of their perceptions. In the category of Social Interactions, both genders tend to agree that NAO possesses characteristics such as being sympathetic and friendly. However, in the categories of Perception of Risk and Attraction, there is a more neutral stance in which both genders do not strongly agree or disagree. Similarly, in the categories of Awareness and Responsibility, there was a general agreement between both genders. Overall, the findings suggest that there are no substantial variations between genders in their perceptions of NAO's characteristics.

Godspeed/RoSaS Survey by agreeableness and extraversion

In an approach similar to the physical world section, we focused on agreeableness in the VR context, as it yielded similar results to extraversion. Although these two traits are independent and uncorrelated, they exhibit comparable patterns. However, for brevity, we chose to present the results for high, medium, and low levels of agreeableness within the Social Interaction factor. This factor is particularly relevant because it allows us to explore how social interactions unfold in the VR environment. For a comprehensive view, all other relevant graphs are presented in Appendix 2.

While we do not delve into each individual graph, it is worth noting that across all levels of agreeableness, the mean scores and responses demonstrate remarkable similarity. This suggests that the level of agreeableness does not significantly impact individuals'

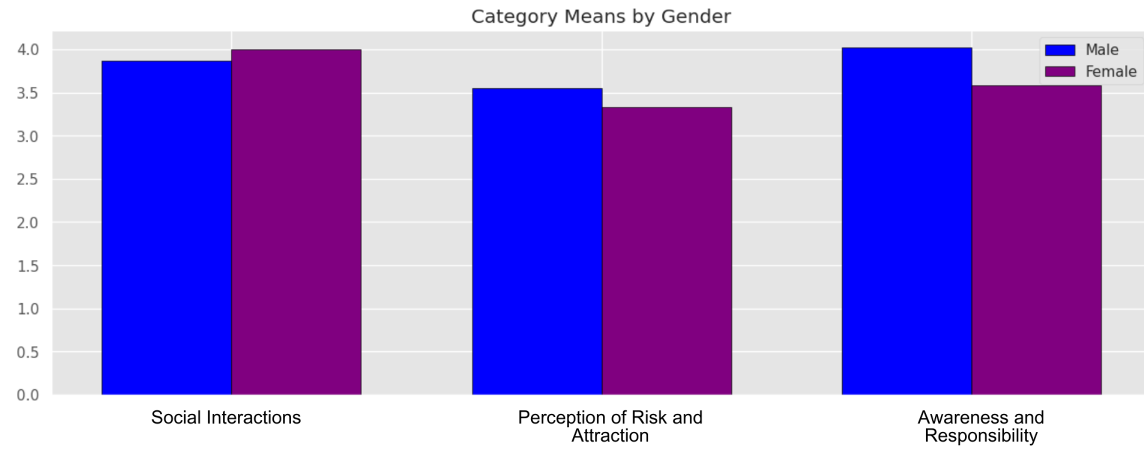

Figure 4.30: Means by gender grouped by factor

Figure 4.31: Social Interactions - High agreeableness in VR

perceptions and experiences of social interaction in the VR environment. Regardless of whether individuals possess high, medium, or low levels of agreeableness, their overall assessments and responses to social interaction factors remain consistent. This implies that agreeableness, as a personality trait, may not play a substantial role in shaping individuals' attitudes or behaviors during virtual social interactions. Further analysis and exploration of other factors or variables may be required to uncover any potential associations or differences related to agreeableness in the VR context.

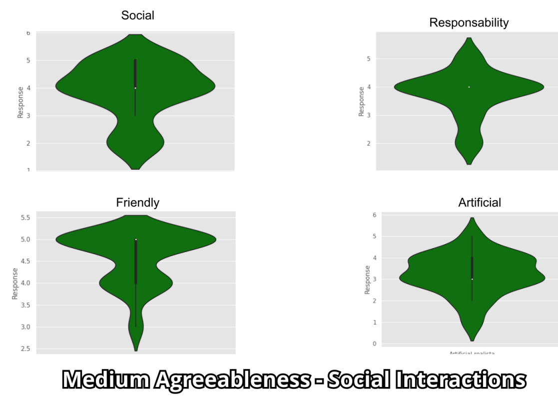

Figure 4.32: Social Interactions - Medium agreeableness in VR

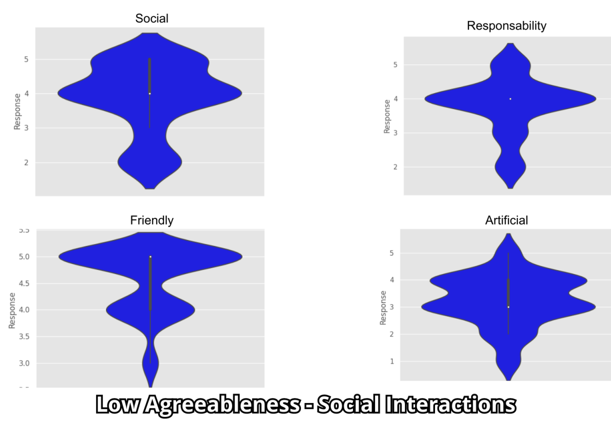

Figure 4.33: Social Interactions - Low agreeableness in VR

SUS Survey

Table 4.7 displays the mean ratings for each statement, indicating the participants' responses to various aspects of NAO. Let us analyze the following findings:

The participants' perceptions of NAO in a practical session setting were assessed through a series of statements. The results indicated that participants expressed a moderate level of interest in using NAO frequently (mean rating:3.76). They generally disagreed with the notion that NAO was unnecessarily complex (mean rating =1.80). Participants perceived a moderate level of ease when collaborating with NAO (mean rating:3.71), although they expressed some uncertainty about their ability to work with the robot independently, indicating a moderate reliance on technical assistance (mean rating:2.95). Participants generally perceived the integration of several NAO functions into the practical session development process to be effective (mean rating:4.04). However, they also reported experiencing inconsistencies or irregularities during practical session development (mean rating:1.95). Participants believed that it was easy to collaborate with NAO (mean rating:3.52) and generally disagreed with feeling uncomfortable when receiving instructions

Question	Mean
I think I would like to use NAO frequently.	3.76
I find NAO unnecessarily complex.	1.80
I think working in conjunction with NAO is easy to do.	3.71
I think I need the help of a technical person to be able to work together with NAO.	2.95
I find several of NAO functions well integrated into the development of the practical session.	4.04
I think there was a lot of inconsistency with NAO during the development of the practical session.	1.95
I imagine that most people find it easy to use NAO to work together.	3.52
I find it uncomfortable to have the NAO give me instructions.	1.28
I feel confident using the NAO to receive instructions.	3.90
I need to learn many things before using NAO as a means of guidance for practical session development.	2.90

Table 4.7: SUS - means in VR

from the robot (mean rating:1.28). They expressed confidence in their ability to receive instructions from NAO (mean rating:3.90) but recognized the need to acquire additional knowledge or skills for utilizing the robot as a means of practical session guidance (mean rating:2.90). These findings shed light on the participants' perceptions of NAO's usability, complexity, integration, and potential areas for improvement in the practical session context.

These findings suggest that participants generally held positive perceptions of NAO in a practical session setting. They expressed interest in using NAO frequently and perceived several of its functions as well integrated into the practical session development process. The participants also felt confident receiving instructions from NAO, implying a certain level of trust and comfort in its guidance.

However, some concerns emerged as participants reported the perceived complexity of NAO and the need for technical assistance. Inconsistencies were also noted during the practical session development process, indicating potential areas for improvement.

Both of this findings are mostly easy to see in Fig.4.34 and Fig.4.35

Experience with VR

At the outset, the participants were queried about their prior experience in VR to establish a baseline understanding. Towards the end of the study, we sought to delve deeper into

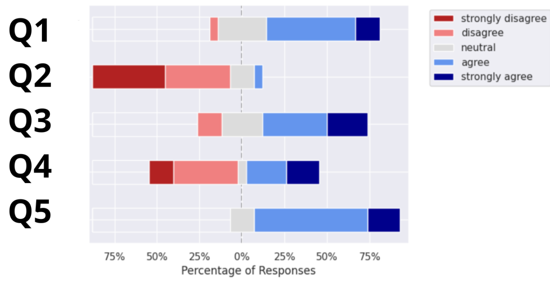

Figure 4.34: SUS[1-5] answers in likert scale

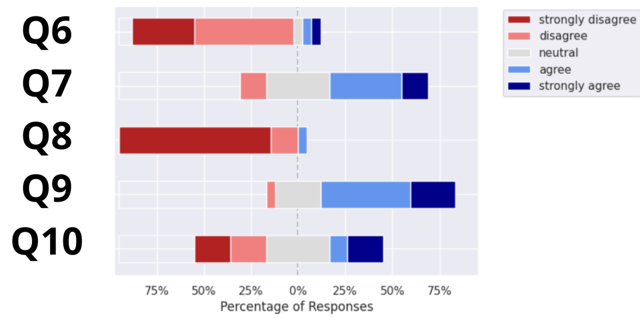

Figure 4.35: SUS[6-10] answers in likert scale

their perceptions of VR, beyond their interactions with NAO and collaborative tasks. In order to capture a comprehensive understanding of participants' overall impressions and evaluations of the VR environment, we specifically asked them, "What did you think of this VR experience?" Their responses provided valuable insights into their perspectives on the potential advantages and disadvantages of VR.
In Fig. 4.36, we present a word cloud analysis that highlights the most frequently repeated words from participants' responses. This visual representation allowed us to identify the key themes and sentiments expressed by the participants regarding their VR experience. By analyzing the word cloud, we can gain further insight into their overall impressions and perceptions.

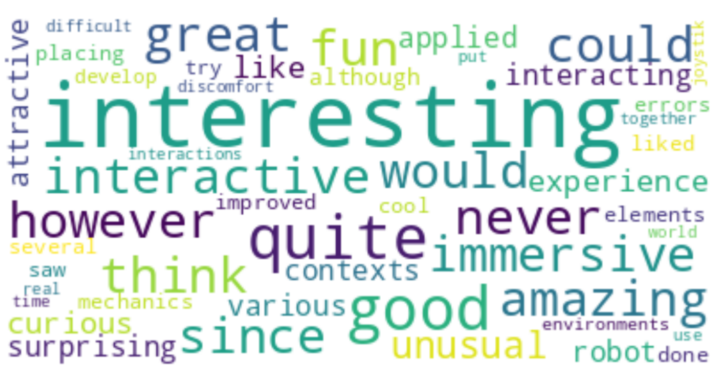

Figure 4.36: What did you think of this VR experience?

This comprehensive exploration of participants' perceptions and evaluations of the VR environment is essential to inform future research and potential improvements in VR technology and its applications. It provides valuable feedback for researchers and developers to enhance user experience, address concerns, and optimize the potential benefits of VR technology.

Errors Perception

This section was divided into three parts.

(i) Perception and self-discovery of errors in the session Analyzing the perception and self-discovery of errors in a session provides valuable insights into individuals' cognitive processes and problem-solving abilities. It helps assess their attention to details and the effectiveness of the task or system being evaluated. Understanding how participants perceive and identify errors can guide improvements in the system design and identify areas for enhancement.

Furthermore, studying participants' ability to self-discover errors offers valuable information regarding their self-awareness and proactive error management. This indicates their capacity to recognize and rectify mistakes independently, which is crucial for real-world situations. By identifying any biases or tendencies in error detection, interventions and training programs can be developed to address specific areas of improvement, leading to enhanced performance, accuracy, and user experience. Ultimately, analyzing the perception and self-discovery of errors contributes to a deeper understanding of human cognition and behavior, informing the development of more effective and user-friendly systems and interfaces.

The questions shown in Table 3.7 were asked of the participants. Fig.4.37 shows the word cloud where the noteworthy words are *Instructions, NAO, and voice.* This makes sense because people tell us that these were things that caught their attention. In other words, several participants in this initial stage noticed errors either in the instructions or in NAO, although later on they may no longer have seen it as an error. Here, they confirmed that they noticed it. As for the voice, many made the recommendation to make it more "natural" and more "human."

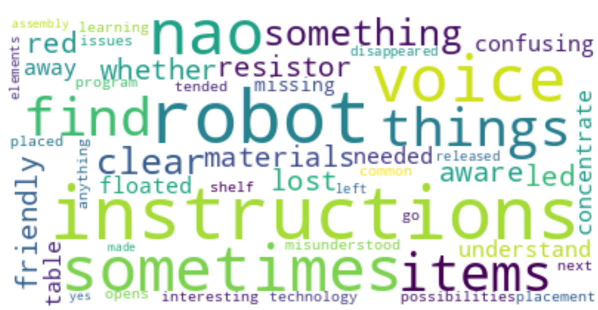

Figure 4.37: Did you notice something special during the session that you want to tell us about?

Some of the words in Fig.4.38 explain how the participant's attitude changed and why. In Fig. 4.38, near the middle, the word *Yes* indicates that the attitude of certain individuals did change in the interaction with NAO. Later, we will understand whether this is a positive or negative change.

Finally, for Question 3 (See Table. 3.7), almost half of the participants (42.85% of the sample) said they wouldn't change anything regarding the interaction with NAO. However,

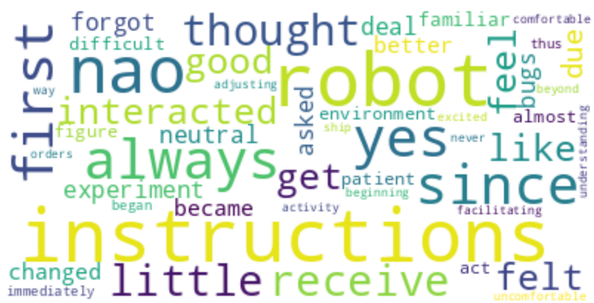

Figure 4.38: Did your attitude towards the robot change during the session? Please explain

28.58% of the sample mentioned that voice should be changed to sound more natural. As for notable responses, one participant mentioned that NAO should be more empathetic, while another participant stated that the experience should be more personalized and individualized.

(ii) Do the participants identify errors: The analysis of participants' ability to identify errors is a critical aspect of this study. By assessing whether participants noticed errors during the session, valuable insights were gained regarding their attentiveness and error perception. In Table 3.8, the participants were asked whether they perceived any errors, providing an opportunity to confirm their awareness of these issues.

Among the 21 participants, 12 individuals (57.14 % of the sample) successfully identified errors. This finding highlights that a significant proportion of the participants demonstrated a keen eye for detecting and recognizing errors within the task or system under evaluation.

(iii) Types of errors and sentimental analysis For Question 1 in Table 3.9 we display the following words in Fig. 4.39 to a large extent: NAO, controls, disappear, and think.
Participants may have noticed that NAO made errors, that the controls did not function properly, and that some objects disappeared. The latter two are errors in the development of the VR scenarios. On the other hand, the repetition of the word *think* is due to the fact that many participants mentioned their thoughts or beliefs. We further explored this in the selected codes. Now for question 2 in Table 3.9, what we see in 4.40 is *discomfort, VR*, and

Figure 4.39: What errors did you identify and who made them?

understandable, where, given the question, we can conclude that people felt discomfort, stress, or similar emotions. This could be attributed more to the VR environment than to NAO errors. However, participants believed that these feelings were understandable, both because of the nature of the development and the errors of NAO.

Figure 4.40: What did you think at that moment, and what did you feel?

Regarding the type of error (see Q3 in Table 3.9), we count the errors that participants perceived. This way, we obtained Technical (9) and both(2) 4.41. This indicates that out of the 21 participants in virtual reality (VR), 11 of them responded that they did identify errors. However, none of them attributed the errors to the environment, but rather they attributed them to the technician or both, but none pointed out that it was solely the environment's fault.

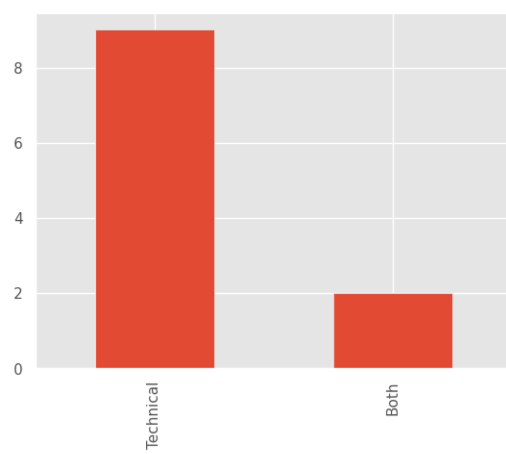

Figure 4.41: Type of error

Open, axial and selective coding for open-ended questions - in VR

Once again, we repeated the grounded theory method in the physical world to analyze open-ended responses. Thus we arrive at the following selective codes for Q1 and Q2 of

Table. 3.7: ***i) Comprehension and interaction, ii) NAO emotions and usefulness, iii) perceived error, iv) program failure, and v) perception of NAO.*** The categorization of the responses is as follows:

- "Program failure": This category includes the key phrases "program failure", "program failures", and "perceived error".
- "Perception of NAO": This category includes the key phrases "perception of NAO as 'very' *robot*" and "perception of NAO, voice."
- "Comprehension and interaction": This category includes the key phrases "comprehension of instructions", "concentration", "memory", and "achieve the goal."
- "NAO emotions and usefulness": This category includes the key phrases "fear of NAO having emotions" and "useful as a lab assistant."

These categories allowed for a systematic analysis of the responses, enabling a better understanding of the participants' perspectives on different aspects of NAO.

The breakdown of the categories in Table 3.9 is as follows.

Table 3.9: Error Categories

- Technical error: Refers to NAO's failure of the code or system.
- VR: Indicates game or controller failure.
- Participant responsibility: Denotes the participant taking accountability for the errors or mistakes presented.
- Setting responsibility: Implies that something, besides the VR, was placed wrong or intentionally did not work.

These categories provide a clear understanding of the factors that contribute to errors and their attributes. By analyzing the responses and categorizing them accordingly, we can gain insights into the various aspects that may have led to errors during the study.
Thus, the results show that:42% of the participants perceived an error, as well as 19% of the participants noticed something unusual in terms of understanding and interacting with NAO, 19.05% talked about the emotions and usefulness of NAO both in the practical session and in other proposed uses of the same participants in the future, such as their use in other classes or jobs, 19.05% also talked about the perception of NAO, in terms of reaction times and the *knowing* it brought, and finally 14.28% noticed a failure within the VR world.
For questions in Table. 3.9 : taking into account that the codes could also be repeated depending on the open and axial codes, 41.66% of the participants stated that it was a technical error, 33.4% that it was an error or responsibility of the RV, 25% that it was their responsibility and only 16.7% said that the setting was responsible.

4.3 Comparison

4.3.1 Evaluation of First Surveys

BFI Survey

To compare the BFI results, we considered percentages for each scenario. In the physical world, 52.17% tended towards introversion, whereas in VR (VR), it was 47.65%. In addition, 47.8% tended to be sympathetic in the physical world and 47.65 % in VR. Finally, 43.48% tended to be nervous or highly strung in the physical world, whereas in VR, it was 50.13%.
These findings led us to recognize that the samples were not significantly different in terms of personality traits. Therefore, we conclude that the results can be compared. If notable differences arise, they are likely due to the environment or interaction with NAO rather than being completely different and incompatible samples.
Overall, this suggests that the use of VR does not significantly alter individuals' personality traits compared to the physical world.

NARS Survey

Comparing the two sections, it can be observed that participants generally feel more comfortable and positive when interacting with NAO in the VR environment (see Fig. 4.21) compared to the physical world (see Fig. 4.1). The VR environment (Fig. 4.21) seems to mitigate any negative attitudes or discomfort that participants may have had during practical interactions with NAO in the physical world.

In **Section 2** of the NARS survey, it was observed that participants in both physical world 4.2 and the VR environment Fig. 4.22 displayed a similar level of uncertainty and neutrality regarding the social influence of NAO. The participants' responses in both cases indicated a lack of readiness to share or fully trust the robot's social influence, suggesting a cautious approach towards robot-human interactions in social scenarios.
Comparison of two scenarios 4.3 and Fig.4.23 of **Section 3** of the NARS survey, it can be observed that participants in the VR environment show more acceptance and comfort towards NAO's human-like aspects, including emotions and self-expression, compared to participants in the physical world. However, there was still a notable level of uncertainty and disagreement among participants in the VR context, especially regarding the last question. Further exploration is needed to understand the reasons behind this uncertainty and the factors influencing participants' attitudes towards human-like aspects performed by NAO in VR.

NARS Survey by gender

The responses in Fig. 4.4 do not exhibit significant changes or differences that indicate variations in how NAO is perceived among genders before the test. The results suggest

that, on average, men and women share similar attitudes toward NAO.
In VR (see Fig.4.24), reveal notable differences, especially in the dimensions of "Negative attitudes toward situations of interaction with robots in VR" and "Negative attitudes toward the social influence of robots." It is interesting to observe that women tend to express higher levels of disagreement than men regarding negative attitudes toward VR interactions with robots. On the other hand, women tended to agree to a greater extent than men concerning negative attitudes toward the social influence of robots. These findings highlight gender-specific variations in attitudes toward robots and open avenues for further exploration of the underlying factors that contribute to these differences.
By considering the gender analysis in both sections, it can be concluded that while there were no significant gender differences in attitudes toward NAO before the test in the physical world (see Fig. 4.4), notable variations emerged in attitudes toward VR interactions and the social influence of robots (see Fig.4.24.) These findings emphasize the importance of understanding gender-specific perspectives and designing robotic technology that caters to the diverse needs and concerns of different sexes.

NARS Survey by Neuroticism

In the physical world (Fig.4.5), individuals with high neuroticism display varied responses, indicating a wider range of negative attitudes. In the VR (see Fig.4.25) context, individuals with high neuroticism exhibit a more consistent level of nervousness, particularly in social interaction scenarios with robots. These findings highlight the importance of considering individual differences, such as neuroticism, when examining attitudes toward robot interactions in different contexts.

This comparison suggests that individuals with medium neuroticism exhibit more consistent attitudes towards situations of interaction with robots, regardless of the context (physical world (see Fig.4.6) or VR). The similarity in responses among individuals with medium and high levels of neuroticism in VR (Fig.4.26) context indicates that neuroticism might have a consistent impact on attitudes towards robot interactions, regardless of the specific level. However, further analysis and investigation are required to fully understand the nuances and implications of neuroticism in different contexts.

This comparison revealed that individuals with low neuroticism exhibited more consistent and similar attitudes towards situations of interaction with robots in the physical world (see Fig.4.7). However, in VR (see Fig.4.27) context, individuals with low neuroticism display a higher degree of variation and diversity in their attitudes. This indicates that the impact of neuroticism on attitudes toward robot interactions may vary depending on the context.

Overall, these comparisons demonstrated the influence of neuroticism on attitudes toward robot interactions in different contexts. While individuals with high neuroticism tend to exhibit more negative attitudes, those with medium and low neuroticism show varying levels of consistency in their attitudes. Further research is necessary to delve deeper into the underlying factors contributing to these differences and their implications in designing effective robot interactions.

4.3.2 Assessment of the Final Phase of the Practical Session

Godspeed/RoSaS Survey

From the participants' mean ratings (Tables 4.1 and 4.3), we can compare and say that they perceive NAO to be highly credible and sympathetic. Additionally, it is considered moderately artificial-realistic, intelligent, and conscientious. The participants also perceived NAO to be highly friendly and moderately social. However, they rated NAO lower in terms of deception and acceptability, indicating reservations about its trustworthiness in certain situations. There is also the perception that NAO is more dangerous and less strange.
Furthermore, when examining participants' responses regarding NAO's potentially misleading behavior, it is noteworthy that the majority did not perceive it as misleading. Participants also found NAO to be capable and responsive, with relevant guidance and opportunities to acquire new knowledge or skills.

In general, participants held positive perceptions of NAO, considering it credible, sympathetic, friendly, moderately intelligent, and conscientious. However, concerns have been raised regarding its potential deception and acceptability as well as its perceived level of danger. The analysis of participants' responses also provided insights into NAO's positive attributes, such as its capability, interactive nature, and facilitation of learning through instruction.

Godspeed/RoSaS Survey by gender

These comparisons suggest that while there may not be significant differences among genders in perceptions of NAO characteristics according to the NARS questionnaire (for physical world see Fig. 4.10 and VR Fig. 4.30), there could be more nuanced variations when considering different factors or dimensions (for example, extraversion or each independent factor).

Godspeed/RoSaS Survey by extraversion

To compare the two factorial analyses conducted, the categories of Social Intelligence and Social Interactions were chosen for the Godspeed/RoSaS Survey by extraversion because they share more variables, specifically responsibility and friendliness. These categories were selected to measure how NAO is reflected in social environments and to understand how extraversion influences individuals' perceptions of responsibility and friendliness in human-robot interactions. By examining these variables, we can gain insights into the impact of extraversion on individuals' perceptions of NAO's social behavior and their overall social experience with the robot. This analysis contributes to a deeper understanding of how personality traits influence the perception of robots in social contexts. Furthermore, all the following graphs are divided by the personality trait of extraversion (the other factors and agreeableness trait can be found in Appendix 2). Thus, we can begin a comparison with a high extraversion.

Regarding the variable *friendliness*, we noticed similar responses. However, for *responsibility*, there is a notable difference between responses, where in VR (see Fig.4.31) it is more homogeneous, indicating that participants had more doubts in the physical world regarding NAO's responsibility. In terms of the other categories, we observed consistently high responses in the physical world (see Fig.4.12), we see more homogeneity compared to the VR world. This suggests that high extraversion leads people to perceive NAO as socially capable.
For the medium level, although there is a similarity in *friendship*, there is more distance between high and medium scores in VR (see Fig.4.32). Similarly, for *responsibility*, there is more similarity among the levels of extraversion than between the scenarios. As for the other categories, there was less similarity, indicating more variability in responses across different categories in the physical world (see Fig.4.14), while in VR, it is somewhat more homogeneous, with responses tending towards high scores. This suggests that the scenario is more relevant than extraversion in this case.
Finally, for the low level, there are more differences between variables, including *friendliness* and the others. In *friendliness*, although the scores remain high, there is a difference in the probability of response, as shown in Fig.4.16 and Fig.4.33. Likewise, *responsibility* is completely different. Overall, while high scores were still noticeable, there was much more variability between scenarios and levels of extraversion.

SUS Survey

In general, both observations (Physical World (see Fig.4.17 and Fig.4.18) and VR (see Fig.4.34 and Fig.4.35)) provide insights into participants' perceptions of NAO setting.
They revealed positive attitudes, interest in frequent use, perceived effectiveness of function integration, and confidence in receiving instructions. However, challenges related to complexity, inconsistencies, and need for technical assistance have also been identified.

Errors Perception

In this section, we explore the participants' perception and self-discovery of errors in the session, their attitudes towards the robot, the identification of errors, and the types of errors encountered. These findings provide insights into participants' cognitive processes, emotional responses, and overall evaluation of the session in both physical and VR environments. The analysis of their perception, attitude, error identification, and emotional experiences contributes to a comprehensive understanding of the session and can inform future improvements in human-robot interaction and VR technology. **(i) Perception and self-discovery of errors in the session**:

- *Physical world:* Participants noticed something different or odd during the practical session. The most common words mentioned were "instructions", "NAO", "wrong", and "drawer." Participants recognized errors and highlighted the word "wrong" in their responses.
- *VR:* Analyzing the perception and self-discovery of errors provides insights into participants' cognitive processes. Participants noticed errors related to the instructions, NAO, and disappearing objects. They also mentioned their thoughts and beliefs about the errors. The most commonly mentioned words were Instructions, NAO and Voice.

(ii) Attitude towards the robot:

- *Physical world:* Participants' attitudes towards NAO may have changed during the practical session. The most common words mentioned were "felt", "first", "robot", and "instructions." Further qualitative analysis is needed to determine the nature of attitude change.
- *VR:* Participants were asked if their attitude towards the robot changed during the session. Some participants mentioned feeling discomfort, stress, or similar emotions, possibly related to the VR environment. It was also mentioned that these feelings were understandable given the nature of the development and NAO's errors.

(iii) Identification of errors:

- *Physical world:* Participants were asked if they identified any errors. 66% of participants noticed errors, indicating a good level of error perception.
- *VR:* Among the participants, 57.14% successfully identified the errors, highlighting their attentiveness and error perception.

(iv) Types of errors and sentiment analysis:

- *Physical world:* Participants believed that NAO was to blame for the errors identified. Errors were related to NAO's instructions or programming. Some negative emotions were associated with the robot's mistakes.
- *VR:* Participants identified errors related to NAO, controls, and objects disappearing. Discomfort and stress were mentioned, possibly due to the VR environment. The types of errors perceived included technical errors and errors in both NAO and VR development. A huge difference is that, in VR, participants only said technical or both. In the physical world, they chose three 3 categories.

Open, axial and selective coding for open-ended questions

Through the application of coding techniques, key concepts and categories were identified to provide insights into the nature of the collaboration between humans and robots.
In the Physical world, selective codes were derived from the error-related questions, resulting in codes such as "perceived error", "frustration", "concentration", and "confidence." Additionally, for Q1 and Q2 in Table. 3.9, codes like "setting responsibility", "technical error", and "participant responsibility" were obtained. The percentages of each code were provided to reveal the participants' perspectives on errors, responsibility, and emotional states during the experiment.
In VR, the grounded theory method was applied again, resulting in selective codes for Q1 and Q2 of Table. 3.7, including "comprehension and interaction", "NAO emotions and usefulness", "perceived error", and "program failure." For Table. 3.9, codes such as "technical error", "VR", "participant responsibility", and "setting responsibility" were identified. The percentages of each code were also mentioned in each section (physical world and VR), shedding light on participants' observations related to errors, NAO's capabilities and emotions, comprehension, and responsibility.
When comparing the two scenarios, it can be observed that there are some overlapping codes and themes, such as *perceived error* and *technical error.* Both statements highlight participants' awareness of errors and their interpretations of the causes, whether related to NAO, the environment, or technical issues. Additionally, emotions, understanding of NAO, and participants' responsibilities were discussed in both statements.
Overall, the grounded theory method provided valuable insights into participants' experiences and perceptions during the human-robot interactions. This allowed for a comprehensive analysis of open-ended responses, uncovering important aspects such as errors, emotions, comprehension, responsibility, and the perception of NAO's capabilities.

Chapter 5

Conclusions and Future Work

5.1 Conclusions

65.22% of the participants were able to develop the human-robot collaborative work during the execution of the practical session. The participants followed the instructions given by NAO to reach the end of the session without any problems. Additionally, we identified the effect of a social robot as a teaching assistant on collaborative work with humans, which was timely, comfortable, and enjoyable for participants, despite errors in the instruction provided by NAO. Furthermore, we evaluated the perception of participants in a situation involving social, emotional, and personal aspects. The results of this study show that social robots can be used in scenarios oriented toward undergraduate programs with a technological focus.

The present study successfully achieved the design and implementation of a practical session and the evaluation of the impact of NAO on human-robot collaborative collaboration. Furthermore, it aimed to assess the participants' perceptions of the interaction with NAO. The findings of this study demonstrate that a social assistance robot, such as an NAO, can effectively facilitate collaborative human–robot work. NAO successfully guided the participants throughout the practical session, and they expressed positive attitudes toward their interaction with NAO. These outcomes have noteworthy implications for the future of human-robot collaboration. The results indicate that social assistance robots have the potential to enhance the efficiency and effectiveness of human-robot teams. Consequently, this finding may pave the way for the development of novel applications of robots in diverse domains, including manufacturing, healthcare, and education. Beyond the implications for the future of human-robot collaboration, this study also bears significance for the design of social assistance robots. The results suggest that social assistance robots should be designed with user friendliness and ease of interaction. Moreover, they should be able to provide clear and concise instructions.

Participants in both studies demonstrated the ability to perceive errors during the practical session, indicating good error-perception skills and attention to detail. In both scenarios, the physical world and VR. Participants noticed errors related to the instructions, NAO, and object disappearance, suggesting that these were the main points of attention for the participants and that they had a good understanding of the assigned tasks. Participants' attitudes toward NAO varied during the session, with some experiencing a change in attitude and others expressing feelings of discomfort or stress related to the VR environment. These findings indicate that the interaction with NAO and the context in which the session took place can influence participants' attitudes. Additionally, both studies revealed negative emotions associated with errors, suggesting that participants may experience frustration or disappointment when encountering errors in NAO interactions or VR development.

Participants showed a considerable ability to identify errors in both studies, with slightly higher error identification rates observed in the physical world study. This indicates that participants were attentive and able to recognize discrepancies between expectations and observations. The context of the VR environment may have influenced participants' emotional responses. These conclusions highlight the importance of considering error perception and emotional responses in the design of robotic interactions and VR development.

In summary, this study achieved its objectives and yielded substantial results with implications for both the future of human-robot collaboration and the design of social assistance robots. Additionally, the findings regarding error perception and emotional responses provided valuable insights for improving the design and implementation of robot interactions and VR environments.

5.2 Future work

Future work will address the following items: (i) conducting a more extensive and rigorous quantitative and qualitative analysis to make better use of the information provided to implement IA algorithms, and (ii) exploring the implementation of reinforcement learning techniques in the human-robot interaction system to improve the robot's adaptability to human responses and actions. These considerations may allow us to improve the quality of human-robot interactions and increase the system's ability to adapt to more complex situations. In addition, NAO will be addressed to conduct an HRC task with people that have not been related to STEM areas.

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