Wiley
Human Behavior and Emerging Technologies
Volume 2024, Article ID 7058933, 11 pages
https://doi.org/10.1155/2024/7058933

Research Article

Enhancing Cobot Design Through User Experience Goals: An Investigation of Human–Robot Collaboration in Picking Tasks

Ana Pinto,[1] **Inês Duarte**,[2] **Carla Carvalho**,[3] **Luís Rocha**,[4] **and Joana Santos**[5,6]

[1]*Centre for Business and Economics Research (CEBER), Faculty of Sciences and Technology, University of Coimbra, 3030-790 Coimbra, Portugal*
[2]*Faculty of Psychology and Educational Sciences, University of Coimbra, Coimbra, Portugal*
[3]*Center for Research in Neuropsychology and Cognitive Behavioral Intervention (CINEICC), Faculty of Psychology and Educational Sciences, University of Coimbra, 3000-115 Coimbra, Portugal*
[4]*Institute for Systems and Computer Engineering, Technology and Science (INESC TEC), 4200-465 Porto, Portugal*
[5]*Center for Translational Health and Medical Biotechnology Research (TBIO), School of Health (ESS), Polytechnic of Porto, 4200-072 Porto, Portugal*
[6]*Associated Laboratory for Energy, Transports and Aeronautics (PROA/LAETA), Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal*

Correspondence should be addressed to Ana Pinto; ana.pinto@dem.uc.pt

Received 17 October 2023; Revised 13 July 2024; Accepted 1 August 2024

Academic Editor: Pinaki Chakraborty

The use of collaborative robots in industries is growing rapidly. To ensure the successful implementation of these devices, it is essential to consider the user experience (UX) during their design process. This study is aimed at testing the UX goals that emerge when users interact with a collaborative robot during the programming and collaborating phases. A framework on UX goals will be tested, in the geographical context of Portugal. For that, an experimental setup was introduced in the form of a laboratory case study in which the human–robot collaboration (HRC) was evaluated by the combination of both quantitative (applying the User Experience Questionnaire [UEQ]) and qualitative (semistructured interviews) metrics. The sample was constituted by 19 university students. The quantitative approach showed positive overall ratings for the programming phase UX, with attractiveness having the highest average value ($M = 2.21$; SD = 0.59) and dependability the lowest ($M = 1.64$; SD = 0.65). For the collaboration phase, all UX ratings were positive, with attractiveness having the highest average value ($M = 2.46$; SD = 0.78) and efficiency the lowest ($M = 1.93$; SD = 0.77). Only perspicuity showed significant differences between the two phases ($t(18) = -4.335$, $p = 0.002$). The qualitative approach, at the light of the framework used, showed that efficiency, inspiration, and usability are the most mentioned UX goals emerging from the content analysis. These findings enhance manufacturing workers' well-being by improving cobot design in organizations.

1. Introduction

Robots are increasingly used in the industry, as a result of the fourth industrial revolution. There are several reasons for this. Firstly, these machines can take on the most dangerous, difficult, or monotonous tasks, as well as those that are least ergonomic [1], thereby reducing both physical and cognitive human efforts [2]. Such reduction is enabled by technological advancements, as in the realm of robotics, which entail a decrease of the rate and cost of making a product or delivering a service, while increasing the efficiency and even the sustainability associated with aforesaid processes [3].

Production [4] and customization [5] are core characteristics of Industry 4.0, whereas the emergent Industry 5.0 focuses on personalization [5], emphasizing the role of humans. Nonetheless, they both acknowledge that the collaboration between humans and robots is a fundamental aspect to fulfill their objectives.

Collaborative functionality is not always achieved. This is because the tasks performed by human–robot teams are typically either sequential or simultaneous [2], lacking a shared purpose [6]. To effectively implement human–robot collaboration (HRC), robotic systems must adopt a supportive role in their interactions with humans, ensuring the completion of a shared task [7]. This implies the existence of a common workspace, time, goal, and resources, as well as direct physical contact between the user and the technological device (e.g., [8]). Collaborative robot (also so called cobot) is defined as a "robot designed for direct interaction with a human within a defined collaborative workspace" [9].

Cobots have built-in sensors that cause them to stop if they become overloaded, for instance, by hitting a worker (e.g., [10]), through the programming of their force and torque [2, 11]. Even if a collision occurs, they do not cause significant harm due to their typically rounded shapes, which distribute the force over a larger surface area, thereby reducing the applied pressure. Consequently, cobots are able to operate alongside humans without any additional safety features, like a switch or fence [11]. Furthermore, their onboard sensors and smart software even allow them to become self-learners, denoting the ability to rapidly adjust [12]. Despite these benefits, the adoption of cobots does not bypasses the conductance of a thorough risk analysis, taking into account, for example, the parts of the human body exposed to possible health and safety risks, the tools handled by the robot and the loads it can carry, the situations that might lead to the necessity of reducing its operating velocity, or even the need to take safety strategies defined by the International Organization for Standardization.

In the current industrial landscape, cobots are used in various applications, including improving assembly performance, surface finishing operations, and soldering tasks. For instance, Salunkhe et al. [13] concluded that using cobots in nut assembly significantly benefits the assembly station, particularly by eliminating issues related to quality and ergonomics.. Other studies demonstrated that cobots can improve human talents safely in the manufacturing context [14, 15]. Improve the worker safety [16], intelligent communication [17], and production efficiency [18] and flexibility [19] were also applications of cobots in industry explored by another authors.

In the HRC, the human contributes with extensive cognitive and sensorimotor skills and the robot accounts for force, accuracy, and endurance [20].

The more recent conceptual models or methodological approaches to optimize the design of HRC include a holistic perspective of collaboration integrating multiple key parameters as legal, technical, and psychological requirements as well as the technological complexity, HRC relevance, benefit/cost indicators, ergonomics, and safety and logistic interfaces [21–24].

Despite the promising results of the ongoing research, a completely human-centered collaborative workstation, which satisfies all the physical and cognitive ergonomic principles, was not yet possible to design, due to the diversity of knowledge fields involved in this process [6, 25].

Notwithstanding, as a result of their advantages, these machines are usually considered as ideal coworkers for users [10], as they favor human–cobot interaction, both while programming and when collaborating, the two steps of the user experience (UX) [26]. UX can be defined as the sum total of all perceptions, emotions, and responses that users experience before, during, and after the interaction with some technological tool [27].

Nonetheless, a common mistake is to confound UX with mere usability. Usability is related to the achievement of objectives, in an effective, efficient, and satisfactory way [28]. For a positive UX, a product needs indeed to be usable, but that is just one of the seven factors that the Interaction Design Foundation (n.d.) has distinguished as influencing factors of the experiences reported by users. Apart from that one, the elicited UX shall include the characterization of a product as useful (i.e., delivers benefits for the beholder), findable (i.e., the product and the content within it is easy to find), credible (i.e., users can trust in it), desirable (i.e., the user not only desires it, they also lead others to do so), accessible (i.e., possible to use by operators within the full spectrum of (dis)abilities), and valuable (i.e., brings value for both the developers and the users).

Similarly, usability pertains to pragmatic attributes of a product, which are usually prioritized [26]. Despite that, Hassenzahl [29] declares that UX integrates both pragmatic (i.e., fulfillment of a behavioral task) and hedonic (i.e., an individual's psychological state) aspects. The two types of attributes should be utilized by designers [30], to guarantee an experience-driven design [31]. In such a design, the intended UX must be priorly defined [32] by identifying UX goals [29]. These goals are the starting point of the design [31], aiming for a resulting pleasurable experience [33]. They can be classified by their pragmatic (i.e., *do-goals*) or hedonic (i.e., *be-goals*) nature [30].

An example of a model that describes attainable intentions for the interaction with a device is the one proposed by Preece, Rogers, and Sharp [34] and Andren et al. [35], comprising the 10 following goals: (a) satisfying, (b) enjoyable, (c) fun, (d) entertaining, (e) helpful, (f) motivating, (g) aesthetically pleasing, (h) supportive of creativity, (i) rewarding, and (j) emotionally fulfilling. These would characterize a desirable UX.

Considering that HRC implies an augmented level of interaction between human and robotic systems, interfaces serve as pivotal conduits facilitating communication between the involved entities. Thus, interfaces play central roles as the main communication channels. According to Goodrich and Schultz [36], human–robot interfaces can be classified into four categories, (i) visual displays, (ii) gestural, (iii) voice and natural language, and (iv) physical and haptic interactions, and depends on the level of interaction, which can be categorized in (i) human–robot coexistence, (ii) human–robot cooperation, and (iii) HRC. In an HRC scenario, there are three main elements: (i) agents (robots and humans), (ii) the working environment (ambient light, noise, etc.), and (iii) parts and operations [37]. According

Apraiz, Lasa, and Mazmela [38], the interaction with a contemporary technological system goes beyond usability and extends to the emotions before, during, and after using the system. Additionally, these authors identified theoretical frameworks that emphasized safety and risk perception as the factors that determine individuals' performance and their emotions in a human–robot interaction (HRI) [39, 40].

Lindblom and Alenljung [41] presented a systematic evaluation framework of action and intention recognition between humans and robots from a UX perspective. This framework is integrated within a methodological approach known as ANEMONE (action and intention recognition in HRI). It was suggested that the UX evaluation process for HRI, from preparation to thorough identification of UX problems, is comprehensively outlined. The overall procedure is detailed for all, emphasizing the significant issue of the importance of defining context to establish product goals and select the appropriate type of UX evaluation. ANEMONE focused on the evaluation procedure rather than the evaluation measure level.

Prati et al. [2] proposed a structured UX-oriented method to examine the interaction between humans and robots, particularly during collaborative task execution, with the ultimate goal of eliciting requirements for designing meaningful HRI. Aligned with the human-centered design approach, this method prioritizes placing the user in the center and follows an iterative process. The initial step involves gathering requirements, which entails collaboration among a multidisciplinary team, user analysis (for which a toolkit is suggested), activity analysis, and interaction visualization. The subsequent step involves interface design, followed by prototyping and, ultimately, UX evaluation. Regarding the evaluation phase, the authors recommended user testing; however, they did not present any specific process, technique, or tool for conducting the evaluation.

Particularly in the domain of cobots, Chowdhury et al. [26] identified the following four prominent UX goals: (a) fellowship and sympathy, (b) inspiration, (c) safety and trust, and (d) accomplishment. These goals are considered as positive experiences; hence, designing for negative experiences should not occur in HRC. In Duarte et al. [42], the systematic review of literature that supports this study identified the following seven UX goals: (a) safety, (b) relationship, (c) usability, (d) inspiration, (e) flexibility, (f) efficiency, and (g) accomplishment. These researchers further distinguished these goals into do-goals (i.e., usability, efficiency, and flexibility) and be-goals (i.e., relationship, inspiration, and accomplishment), with safety being perceived as both.

The present study is of an exploratory nature and intends to empirically test if suchlike goals are evoked when programming and interacting with the universal robot, while testing if other UX goals arise. The final objective is to evaluate what UX arises during the interaction of a user with a cobot, to assure that its design leads to a positive UX. Accordingly, the main research question can be phrased as follows: What UXs arise during the human–cobot interaction with the universal robot? This research question can be subdivided into the two following ones: (a) What UXs arise while programming the cobot and (b) what UXs arise while collaborating with the cobot. To properly answer the aforementioned questions and in accordance with the vision of Marvel et al. [6], a mixed-method, using a convergent design, will be employed, as the combination of both quantitative and qualitative metrics providing more integrative insight.

2. Method

2.1. Participants. The sample was recruited in Portugal and was constituted of 19 subjects, all of which were university students. This sample was chosen based on accessibility, given that there are not yet many cobots in an industrial setting in Portugal. The majority of the sample was feminine, with only three male subjects, which can potentially lead to robustness and generalizability limitations. Their ages ranged from 21 to 28 years old ($M = 23.05$, $SD = 2.09$). None of the participants had any previous experience with cobots, but three of them did have some previous experience with other kinds of robots. None of them reported having any medical condition that prevented them from taking part in our experiments.

2.2. Procedure. The present study sought ethical approval from the Ethics Committee at the Faculty of Psychology and Education Sciences of the University of Coimbra (CEDI/FPCEUC:65/2) and with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. Informed consent was obtained from all participants prior to their involvement in the study. Participants were provided with comprehensive information regarding the purpose, procedures, potential risks, and benefits of the research, and they voluntarily agreed to participate. To protect confidentiality, all data collected were anonymized by removing any identifying information that could link responses to specific individuals. Furthermore, strict measures were implemented to ensure the secure handling and storage of data, including restricted access only to authorized research personnel. These procedures were designed to safeguard the privacy and anonymity of participants throughout the study. The recruitment process occurred via direct contact with some of the participants, who were also asked for referrals. Each session—programming and collaborating—lasted approximately 45 min.

Once participants entered the laboratory, the procedure was explained and they were asked to give their consent to participate and to answer a few sociodemographic questions. Consent form and demographic questionnaire were accessible through its specific QR code, which means that participants were able to use their own devices to fill them in, with some exceptions, using the online survey tool LimeSurvey [43]. Regarding the consent statement, which included a request for audio recordings, participants were assured that no harm would come to them and no malpractice would be attempted at their data. Additionally, to maintain anonymity, each participant was assigned a numeric code. Regarding the sociodemographic information, it addressed age, gender, occupation, previous contact with cobots and other kinds of robots, and potential motor or sensory disorders. In the case of the participant being a student, three more questions appeared, regarding their course, faculty, and year.

Afterward, the subjects performed a task with the universal robot, which involved programming the cobot beforehand (see Figure 1). The task consisted of picking polystyrene squares from a pallet and placing them in a central pallet. The robot and the user had their own pallets filled with squares, and they both have the purpose of filling the same central pallet. For that, part of the experience was already programmed, specifically the location of the robot's pallet and the opening of the grip. The participants still had to teach the robot to move its arm to the central pallet, the locations for placing the squares, and how to open the grip to land the squares in the assigned positions. During the programming phase, the participants were assisted by a video that explained the steps to follow and by occasional comments from the researcher. Subsequently, the program was initiated, and both the cobot and the participant would perform the task simultaneously, continually sharing their working space.

The exemplar used was the Universal Robot UR5, a lightweight collaborative industrial robot. It is flexible and highly adaptable, enabling a balance between size and power (Universal Robots, n.d.). It weighs 18.4 kg and has a payload of 5 kg and 850 mm of reach [44]. It has six rotating joints, with a speed of 180°/s. The robot requires an installation, being a component of it, and not a complete machine per se [45]. The 15 advanced safety functions it includes allow contemplating as safe. It can be programmed to move a tool alongside a designated trajectory and communicate with other machines through electrical signals. Its polyscope graphical user interface is on 12-in. touch-sensitive screen with mounting and allows running existing programs or creating new ones easily. UR5 consumes approximately 200 W using a typical program, working in a temperature range from 0°C to 50°C. It is suitable for a number of different functions, especially for pallet operations similar to the one previously described, for which it has a preprogrammed sequence of motions in a set of places given as a pattern. The pick and place tasks were executed in a low speed, which was also preprogrammed, to assure the safety and comfort of the users during the interaction.

After programming and after interacting with the robot to complete the assigned task, the Portuguese version of the User Experience Questionnaire (UEQ) [46] was applied as a quantitative approach, also using LimeSurvey [43] and accessing it with a QR code. This questionnaire was transformed and validated for the Portuguese language in 2014, and that was the version used in the experiments. This instrument is a comprehensive measure of UX, consisting of 26 items assessed on a seven-stage scale, ranging from −3 as the most negative answer to +3 as the most positive. Six scales distribute the items: (a) attractiveness, (b) perspicuity, (c) efficiency, (d) dependability, (e) stimulation, and (f) novelty. Attractiveness is purely a valence dimension and comprises six items, whereas all the others are constituted by four items and relate to pragmatic (perspicuity, efficiency, and dependability) or hedonic (stimulation and novelty) aspects of UX. To fulfill it, 3–5 min is required, which indicates that, at most, its fulfillment took up 10 min of the overall session, once it was answered twice.

Finally, qualitative data were also collected by means of semistructured interviews that proceed the interaction with the cobot. A deeper understanding of the accomplished UX was unveiled at this stage, through participant's responses towards their overall HRC experience, the positive and negative aspects of it, how convenient was operating the interface and the cobot per se, the expectations they had throughout the session, their description of the learning experience, and, lastly, if they felt any safety concern while collaborating with the robot. The questions that constituted the structure of the interview were based on the ones inquired in the experiences conducted by Chowdhury et al. [26]. These interviews were conducted by one person, who asked these questions, maintaining eye contact during the conversation. So, following the recommendations from the [47], the interviews' audio was recorded, to prevent the researcher from having to take notes of all the relevant details and getting distracted from the interviewees. Each interview lasted for approximately 5 min.

2.3. Statistical Analyses

2.3.1. Quantitative Approach. For the quantitative data, statistical analyses were computed using Microsoft Excel sheets provided by the authors of UEQ [48]. Descriptive statistics of the demographic information were obtained with IBM SPSS Statistics for Windows, Version 25.0, so as to provide an accurate description of the sample. Then, the means for each scale of the UEQ were calculated over the total sample to get the general tendency and compared to the standard values proposed by Schrepp [48], both for the programming and the collaborating phases, using the Data Analysis Tool sheet.

A positive evaluation of the UX elicited during the interaction with the universal robot is considered for values superior to 0.8, whereas if the mean values are inferior to −0.8, the experience can be classified as negative. These thresholds were defined by the UEQ authors based on their studies, but it is important to highlight the need to conduct more longitudinal studies to accurately classify UX as positive or negative, given that UX can evolve over time [49]. Lastly, two sample t-tests assuming unequal variances were computed for each UX goal to examine if there were significant differences between the two phases (i.e., programming and collaborating), with the use of the Compare Scale Means Tool.

2.3.2. Qualitative Approach. The audio recordings of the interviews were transcribed into an electronic text format to facilitate analysis, except for one participant, whose recording was damaged. Initially, relevant comments from each of the 18 participants were outlined to identify emerging themes. The statistical analyses for the qualitative data were performed using Microsoft Excel.

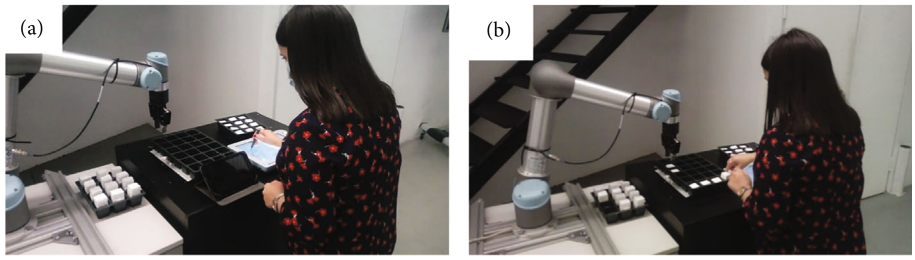

Figure 1: Photographs of the experiments showing students (a) programming and (b) performing a task with the universal robot.

In this study, conventional content analysis was used. This method is the most commonly applied for analysis in studies aimed at describing the properties of text and phenomena [50]. This method is considered an integrative view of text and its related contexts in order for the researcher to understand social phenomenon in a subjective yet scientific manner [51]. Numerous key steps were required and necessary to support valid and reliable inferences derived from the data. These steps included (a) preparing the data (transcription of interviews), (b) reading transcripts repeatedly to achieve immersion and obtain a sense of the whole [52], (c) making notes on the transcripts listing the different types of information found in the text, (d) defining the unit of analysis using themes (representing expressions of ideas or an issue of relevance [51]) as the unit of analysis versus linguistic units, and (e) developing a coding scheme to organize data in a comprehensible way. Data can be coded before beginning analysis or categories can emerge during analysis, such as with grounded theory methodology: (f) code all text, (g) make conclusions from coded data, and (h) describe and interpret findings [53].

This program allows conducting a content analysis, derived from the semistructured interviews' input, in a simple and cost-effective way [54]. The data retracted from the interviews were categorized into the UX goals evoked in Duarte et al. [42] study, while simultaneously searching for more possible categories. For that, the data was compiled into one Microsoft Excel spreadsheet, which allows the comparison of the excerpts and the consequent better understanding of the definition and comprehensiveness of each code [55]. Only one of the researchers was responsible for the coding, avoiding interrater reliability [56], even though all the authors revised the final categorization. Aforesaid categories shall be as exclusive, homogeneous, and exhaustive as possible.

To enhance the validity and credibility of our findings, we applied an investigator triangulation. Two researchers were involved in the data analysis process to reduce individual bias and enhance the validity of the results. Each investigator independently coded and analyzed the data, identifying themes. This approach ensured that diverse perspectives were considered and that no single researcher's bias dominated the interpretation. Following the independent analyses, the research team held consensus meetings to discuss and reconcile discrepancies in their findings. These discussions allowed the researchers to combine their individual insights and reach a cohesive interpretation of the data. Each investigator brought their unique perspective, contributing to a more balanced and nuanced analysis [57, 58].

3. Results

3.1. Quantitative Approach. For the quantitative approach, to determine the reliability, we calculated Cronbach's alpha for the different dimensions of the UX with cobots. The two studies (with Amazon and Skype) conducted by Cota et al. [46] revealed sufficient reliability values for the six subscales, with Cronbach's α ranging from 0.51 to 0.86 in one study and from 0.64 to 0.85 in the other. In our study, during programming, we obtained Cronbach's α ranging from 0.37 to 0.89 and, during collaboration, from 0.48 to 0.95. Specifically, the reliability values for programming were as follows: attractiveness: 0.77, perspicuity: 0.89, efficiency: 0.57, dependability: 0.37, stimulation: 0.86, and novelty: 0.52. For collaboration, the values were as follows: attractiveness: 0.88, perspicuity: 0.95, efficiency: 0.48, dependability: 0.53, stimulation: 0.87, and novelty: 0.51.

The UX of the programming phase was overall rated as positive (see Figure 2). It should be noted that in this study, we considered the fact that 3 students had experience with a different type of robot, whereas 16 students had no prior experience with robots. This distinction was applied to each analyzed UX goal, encompassing both programming and collaboration. To address this, a t-test was performed, yielding significance values consistently greater than 0.05 ($p > 0.05$), suggesting no discernible differences between the two groups examined.

The average value for attractiveness was 2.21 (SD = 0.59), 1.22 (SD = 1.06) for perspicuity, 1.90 (SD = 0.70) for efficiency, 1.64 (SD = 0.65) for dependability, 2.14 (SD = 0.82) for stimulation, and 2.08 (SD = 0.68) for novelty. Compared with the benchmark set by the authors [48], attractiveness, stimulation, and novelty results were classified as excellent (i.e., in the range of the 10% best results), efficiency and dependability were good (better than 75% of the results), and perspicuity was below average (better than 25% of the results). Grouping the scales by their pragmatic or hedonic quality, the former one was evaluated with an average of 1.59, whereas the latter's value corresponded to 2.11.

Regarding the collaboration phase, the ratings of the UEQ were all positive as well (see Figure 3). Attractiveness had an average of 2.46 (SD = 0.78), perspicuity of 2.38 (SD = 1.09), efficiency of 1.93 (SD = 0.77), dependability of 2.05 (SD = 0.79), stimulation of 2.18 (SD = 0.89), and novelty of 2.12 (SD = 0.72). These six values can be interpreted

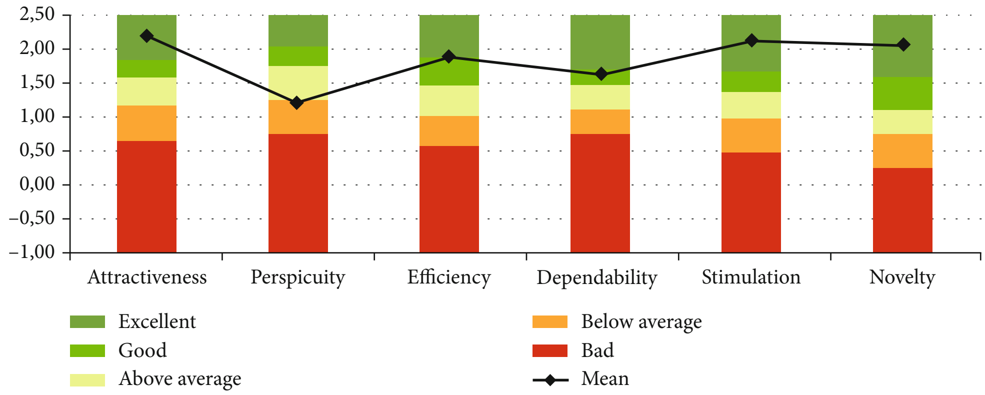

FIGURE 2: Means of UEQ scales for programming a cobot.

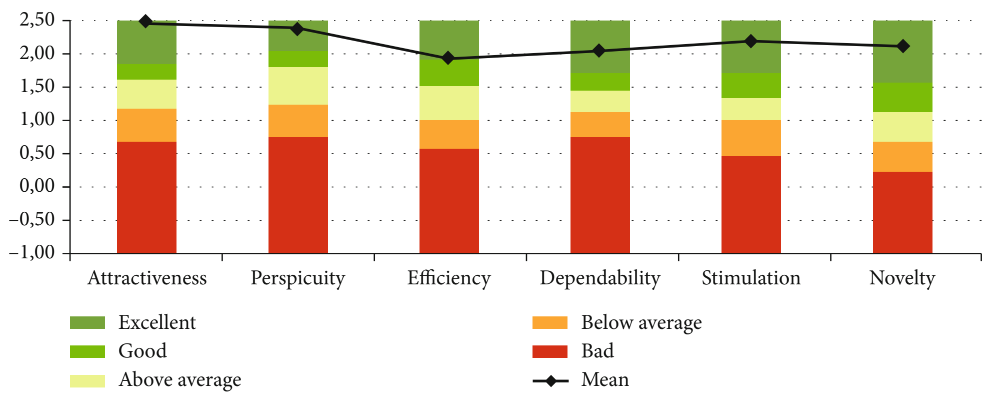

FIGURE 3: Means of UEQ scales for collaborating with a cobot.

as excellent (i.e., in the range of the 10% best results) when compared with the benchmark defined by the questionnaire's authors [48]. In what concerns the pragmatic and hedonic categorization, 2.12 was the average for the pragmatic quality, and 2.15 was the average for the hedonic one.

By simply comparing the means of the two phases, it is possible to observe that the collaboration stage had slightly higher values, possibly denoting a more positive UX (see Figure 4). Two sample t-tests assuming unequal variances were used to assess the significance of such differences. Significant differences were observed for perspicuity ($t(18) = -4.335$, $p = 0.002$) only. The differences respecting attractiveness ($t(18) = -1.455$, $p = 0.280$), efficiency ($t(18) = -0.243$, $p = 0.870$), dependability ($t(18) = -2.121$, $p = 0.091$), stimulation ($t(18) = -0.220$, $p = 0.889$), and novelty ($t(18) = -0.318$, $p = 0.863$) were nonsignificant.

3.2. Qualitative Approach. A total of 88 comments were cut out from the transcribed data and thematically analyzed. This analysis enabled to match each of the comments with one of the UX goals defined by Duarte et al. [42] (see Table 1). No other additional goals were identified in this case study.

Each participant pointed to an average of three UX goals (SD = 1.14). Specifically, efficiency, inspiration, and usability were the three most mentioned UX goals, being referred by 13, 12, and 11 of the total number of participants, respectively. Safety was spoken of by six subjects, whereas relationship and accomplishment were both cited by five people.

Flexibility was the least mentioned goal, with only two participants referring to it.

In what relates to the pragmatic nature of these categories, it was noted that all the participants mentioned do-goals. Two participants did not refer to be-goals; all the others contributed to the hedonic categories. Safety was cited by six of the 18 individuals.

Considering quantitative approach and qualitative approach, the most prominent factors were attractiveness and perspicuity (collaboration), attractiveness and stimulation (programming), efficiency, and inspiration. There should be a greater concern with the following UX goals: perspicuity (in programming) and efficiency (in collaboration), both related to pragmatic aspects. The UX goal efficiency appears in both methods used (quantitative and qualitative).

4. Discussion

The industry is progressively adopting cobots in its operations [9]. For the successful adoption of these robots, they must offer a positive UX [27], not only during the performance of a collaborative task but also while programming the device before the collaboration [26].

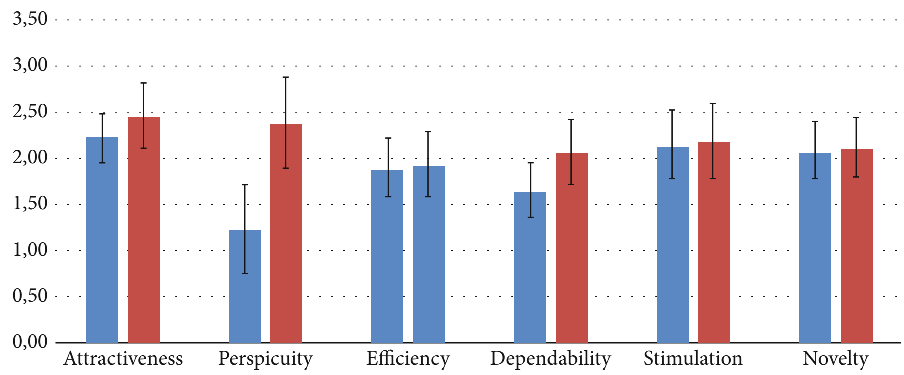

FIGURE 4: Comparative analysis of UEQ scores for programming and collaborating with a cobot. Note. The programming score is indicated in blue for each scale, while the collaboration score is indicated in red.

TABLE 1: UX goals evoked during the interaction with a cobot.

Participant	Safety	Relationship	Usability	Inspiration	Flexibility	Efficiency	Accomplishment	Score (participant)
JD31071992	0	0	+	0	0	+	+	3
TS30111995	0	0	0	0	0	+	0	1
IB24011999	0	0	+	+	0	0	0	2
AS01041997	0	0	0	+	0	+	0	2
ES21091999	0	+	+	0	0	+	0	3
RS22051998	+	0	0	+	0	+	+	4
ML27061998	+	+	+	+	0	+	0	5
OS10101999	0	+	0	+	0	+	0	3
SF24041998	0	0	+	+	0	0	0	2
MR20052000	0	0	+	0	0	0	+	2
AS07101993	+	0	+	+	0	+	0	4
BM12012000	0	0	+	0	+	0	0	2
SP16071996	+	0	+	0	0	0	+	3
RS13012000	+	0	+	+	0	+	0	4
DS25111999	0	0	+	+	0	+	+	4
CR06061998	+	+	0	+	+	+	0	5
SM24031998	0	0	0	+	0	+	0	2
AM30081995	0	+	0	+	0	+	0	3
Score (item)	6	5	11	12	2	13	5	

Note: The reference of each UX goal by the participants is represented by the symbol "+," whereas its lack is represented by "0".

One aspect we considered in the quantitative approach regarding UX goals was to examine whether there were differences between participants with prior robot experience and those without. In contrast to the findings of Hwang et al. [59], our study did not observe significant differences between the two groups, even though it involved social robots. The perceptual consistency among users in both interaction phases, along with the sample size [60], may explain our results. Despite the lower Cronbach's alpha values in some dimensions, such as efficiency and dependability in programming and collaboration, the results still provide valuable insights. These lower alpha values can be attributed to several factors, including, for instance, the context in which the scale was applied (cobots) may differ significantly from previous studies (with Amazon and Skype). Additionally, some items on the scale might not be as relevant or appropriately worded for the context of programming and collaboration with cobots, leading to inconsistent responses.

To evaluate the UX that arose while programming the cobot, the participants answered the UEQ right after completing the designated program using the interface. Answering the programming-related research question, this initial part of the experiment was positively rated by the participants. Interestingly, the hedonic side of the UX had a slightly higher ranking than the pragmatic one. This is a notable result, especially given the tendency to prioritize the pragmatic aspects [26]. In this case, more consideration was attributed to the hedonic aspects of programming. A possible explanation for that concerns the sample used, which was constituted by students instead of professionals, who might have different motivations, while lacking a realistic perception of the industrial contexts [31].

To address the subsequent research question, the participants were administered the same questionnaire after collaboratively completing the assigned task with the robotic device. Similarly, the evaluation of the UX yielded positive results, with identical ratings for both the hedonic and pragmatic attributes. This finding aligns with the perspective of Raskin [30], who advocates for designers to consider both types of attributes. When comparing these two phases with the benchmark set by Schrepp [48], it was observed that the six scales that measure UX were classified as excellent for the collaboration stage, while only three of them had the same classification for the programming stage, with the remaining scales having lower classifications. One possible explanation for that could be that the people who participated in the present study were not students of the engineering field, most of them not familiar with this type of technology. Students might exhibit different attitudes towards technology based on their different backgrounds [61].

No differences were found between programming and collaborating phases for UX goals, except for perspicuity. Considering the human-oriented design studied by Fogli et al. [62] and Papetti et al. [63], in the field of programming and HRC, respectively, it is possible to verify that both mentioned that it is essential to have knowledge about the environment (e.g., available space and constraints), task (e.g., task sequence), user characteristics (e.g., user preferences), robot capabilities (e.g., flexibility), design suitable collaboration (e.g., safe user–robot collaboration), and interface (e.g., language). Therefore, it can be concluded that these phases present similar user requirements.

Alongside this quantitative approach, qualitative data was obtained from interviews conducted after the questionnaires were completed. This qualitative data was then compared with previously reviewed data to assess its correspondence with the seven UX goals identified in the study by Duarte et al. [42]. The results indicated that the subjects' comments fitted the categories of safety, relationship, usability, inspiration, flexibility, efficiency, and accomplishment. These goals constitute the response to the main research question regarding the UXs that arise during human–cobot interactions with the universal robot. Including two investigators in the interpretation process of qualitative data ensured that a different of perspectives were considered [64].

Specifically, efficiency was the most prominent UX goal, denoting the need to comprehensively combine the best competencies of robots and its users, when performing a shared task. This goal was followed by the goal of inspiration, the requirement to feel motivated, challenged, and engaged in the interaction. Usability was ranked third and comprised all the specific requirement that might enable a task to become easier and more effortless to complete. After these top three goals, safety was ranked next, including features such as trust and comfort. Relationship (i.e., the creation of a bond and multiple relationships between the user and the cobot) and accomplishment (i.e., the feeling of success in the collaboration) came after safety in the ranking, with equal importance attributed to them. The least cited UX goal was the flexibility to handle the robotic device. All the participants mentioned at least one of the categories that correspond to do-goals. The ones corresponding to be-goals were only not mentioned by two participants. Regardless of this slight difference, it is conceivable to note a relative balance between the two kinds of aspects.

Many are the UX goals that positively influence effective collaboration between a human and a cobot (e.g., [26]). In this study, when comparing quantitative and qualitative studies, the most prominent were attractiveness, perspicuity (collaboration), stimulation (programming), efficiency, and inspiration. Similar to other studies (e.g., [65]), it was found that the UX goal of attractiveness, in terms of quantitative analysis, stands out among all others. It is also noted that there was a greater need for attention regarding certain UX objectives, specifically perspicuity in programming (it is necessary to have greater clarity and understanding of the interface and instructions provided during the programming process) and efficiency in collaboration (it is necessary to ensure more robustly and effectively that tasks are performed more quickly, accurately, and seamlessly). The UX goal efficiency is a common UX goal in both approaches—quantitative and qualitative—which is not surprising given that it is a fundamental driver that is always aligned with a company's strategic objectives [66]. According to Meshcheryakov [67], the effectiveness of HRC is significantly influenced by how humans perceive the robot, as well as their emotional and cognitive responses. Efficiency of use is an integral component of the concept of "usability" that implies the need for systems to be equally usable for all users, adapting to accommodate the unique abilities and characteristics of each user [68].

5. Conclusion

The present study stands out as one of the few that examines the UX goals arising from the complete interaction with a collaborative robot. It also represents the first empirical test of the seven-goal framework identified in the systematic literature review conducted by Duarte et al. [42]. This research is aligned with the recommendations of various authors (e.g., [69]) advocating for the application of mixed-method approaches, particularly employing a convergent design that combines questionnaires and interviews, to explore UX in depth. By integrating quantitative and qualitative methodologies, this mixed approach provides a more comprehensive and detailed understanding of users' perceptions of their interaction experience with collaborative robots. Consequently, this study offers valuable insights for the successful design and deployment of collaborative robots in industrial settings. By identifying the UX goals associated with collaborative robot interaction, organizations can enhance their design processes to improve the overall UX. Additionally, the study highlights the importance of leveraging these findings to inform the development of guidelines and regulations aimed at promoting the safe and effective design and implementation of collaborative robots. This proactive approach not only protects the health and safety of workers but also promotes increased productivity and innovation across the industry.

6. Limitations of the Study

Despite that, a number of limitations might reduce the reliability and generality of the presented results and conclusions. First, some of the questions could induce the answers, by containing a reference to some UX goal. That was the case of asking for safety concerns, which was also done in previous studies (e.g., [26]), but that could possibly be rethought. Another limitation was that the sample size was small, and it was entirely constituted of students, two factors which might affect the results. The limited sample of 19 university students may not accurately represent the general population that would typically use cobots in an industrial setting. This lack of representativeness is crucial because students' experiences, skills, and perceptions might significantly differ from those of industrial workers. For instance, factory workers may have different levels of familiarity with robotic technology, varying usability expectations, and distinct safety concerns. Additionally, the academic context of the participants could bias their responses. Students, particularly those in technical or engineering fields, might be more inclined to adopt new technologies and may have a different learning curve compared to industrial workers with established work habits and routines. This could lead to an overly positive perception of HRIs that does not fully reflect the potential challenges faced by workers with less technical training. Furthermore, the homogeneity of the sample is a notable limitation. A sample entirely composed of students fails to capture the demographic diversity present in typical workplaces, where factors such as age, gender, professional experience, and educational background significantly influence technology interaction. These limitations suggest that the study's findings should be interpreted cautiously. While providing valuable insights into HRI within the studied context, generalizing these results to a broader and more diverse population could be problematic.

7. Future Research

Future studies could employ more specific questions, to better distinguish the UX goals that are present in the distinct phases of the user–cobot interaction (i.e., programming and collaborating), not mentioning actual UX goals in its formulation. In addition, subjects from different populations that are not students, with diverse backgrounds, could be sampled in order to better support the conclusions.

Data Availability Statement

Data is available on request from the authors.

Conflicts of Interest

The authors declare no conflicts of interest.

Funding

This research was funded by national funds through FCT (Fundação para a Ciência e a Tecnologia), I.P. (grant number UIDB/05037/2020).

Acknowledgments

This research was funded by national funds through FCT (Fundação para a Ciência e a Tecnologia), I.P. (grant number UIDB/05037/2020).

References

[1] K. A. Demir, G. Döven, and B. Sezen, "Industry 5.0 and human-robot co-working," *Procedia Computer Science*, vol. 158, pp. 688–695, 2019.

[2] E. Prati, M. Peruzzini, M. Pellicciari, and R. Raffaeli, "How to include user experience in the design of human-robot interaction," *Robotics and Computer-Integrated Manufacturing*, vol. 68, article 102072, 2021.

[3] L. Koh, G. Orzes, and F. Jia, "The fourth industrial revolution (Industry 4.0): technologies disruption on operations and supply chain management," *International Journal of Operations and Production Management*, vol. 39, no. 6/7/8, pp. 817–828, 2019.

[4] M. I. Hanif and L. Iftikhar, "Post COVID-19 industrial revolution 5.0. The dawn of cobot, chipbot and curbot," *Pakistan Journal of Surgery and Medicine*, vol. 1, no. 2, pp. 122–126, 2020.

[5] M. Javaid and A. Haleem, "Critical components of Industry 5.0 towards a successful adoption in the field of manufacturing," *Journal of Industrial Integration and Management*, vol. 5, no. 3, pp. 327–348, 2020.

[6] J. A. Marvel, S. Bagchi, M. Zimmerman, and B. Antonishek, "Towards effective interface designs for collaborative HRI in manufacturing," *ACM Transactions on Human-Robot Interaction*, vol. 9, no. 4, pp. 1–55, 2020.

[7] E. Helms, R. D. Schraft, and M. Hagele, "rob@work: Robot assistant in industrial environments," in *Proceedings 11th IEEE International Workshop on Robot and Human Interactive Communication*, pp. 399–404, Berlin, Germany, 2002.

[8] J. Schmidtler, V. Knott, C. Hölzel, and K. Bengler, "Human centered assistance applications for the working environment of the future," *Occupational Ergonomics*, vol. 12, no. 3, pp. 83–95, 2015.

[9] ISO 10218-2; 2011, *Robots and robotic devices — safety requirements for industrial robots — part 2: robot systems and integration*, International Organization for Standardization, 2011.

[10] Robotiq, "Collaborative Robots Buyer's Guide -7th Edition," in *Collaborative Robots Buyer's Guide*, Robotiq, 2018.

[11] S. ZaatariEl, M. Marei, W. Li, and Z. Usman, "Cobot programming for collaborative industrial tasks: an overview," *Robotics and Autonomous Systems*, vol. 116, pp. 162–180, 2019.

[12] R. Galin, R. Meshcheryakov, S. Kamesheva, and A. Samoshina, "Cobots and the Benefits of Their Implementation in Intelligent Manufacturing," *IOP Conference Series: Materials Science and Engineering*, vol. 862, no. 3, article 032075, 2020.

[13] O. Salunkhe, O. Stensöta, M. Åkerman, Å. F. Berglund, and P. A. Alveflo, "Assembly 4.0: wheel hub nut assembly using a cobot," *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 1632–1637, 2019.

[14] R. Kumar and K. Kumar, "Intelligence-assisted cobots in smart manufacturing," in *Advanced Computational Methods in Mechanical and Materials Engineering*, CRC Press, 2021.

[15] S. ZaatariEl, Y. Wang, W. Li, and Y. Peng, "ITP-LfD: improved task parametrised learning from demonstration for adaptive path generation of cobot," *Robotics and Computer-Integrated Manufacturing*, vol. 69, article 102109, 2021.

[16] A. A. Malik and A. Bilberg, "Digital twins of human robot collaboration in a production setting," *Procedia Manufacturing*, vol. 17, pp. 278–285, 2018.

[17] A. Quenehen, J. Pocachard, and N. Klement, "Process optimisation using collaborative robots-comparative case study," *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 60–65, 2019.

[18] Y. A. Shchenikov, O. S. Gromova, and E. A. Smeshchuk, "The human-cobot collaboration in mounting and assembly operations in instrument making," *Journal of Physics: Conference Series*, vol. 1889, no. 4, article 042055, 2021.

[19] A. S. Mangat, J. Mangler, and S. Rinderle-Ma, "Interactive process automation based on lightweight object detection in manufacturing processes," *Computers in Industry*, vol. 130, article 103482, 2021.

[20] M. Faber, S. Kuz, A. Mertens, and C. M. Schlick, "Model-Based Evaluation of Cooperative Assembly Processes in Human-Robot Collaboration," in *Advances in Ergonomics of Manufacturing: Managing the Enterprise of the Future. Advances in Intelligent Systems and Computing*, C. Schlick and S. Trzcieliński, Eds., vol. 490, Springer, Cham, 2016.

[21] A. Kolbeinsson, E. Lagerstedt, and J. Lindblom, "Classification of collaboration levels for human-robot cooperation in manufacturing," in *Advances in Transdisciplinary Engineering*, vol. 8, pp. 151–156, Advances in Manufacturing Technology XXXII, 2018.

[22] A. Kolbeinsson, E. Lagerstedt, and J. Lindblom, "Foundation for a classification of collaboration levels for human-robot cooperation in manufacturing," *Production & Manufacturing Research*, vol. 7, no. 1, pp. 448–471, 2019.

[23] A. C. Simões, A. Pinto, J. Santos, S. Pinheiro, and D. Romero, "Designing human-robot collaboration (HRC) workspaces in industrial settings: a systematic literature review," *Journal of Manufacturing Systems*, vol. 62, pp. 28–43, 2022.

[24] A. Zanella, A. Cisi, M. Costantino, M. Di Pardo, G. Pasquettaz, and G. Vivo, "Criteria definition for the identification of HRC use cases in automotive manufacturing," *Procedia Manufacturing*, vol. 11, pp. 372–379, 2017.

[25] X. Liu, L. Zheng, Y. Wang et al., "Human-centric collaborative assembly system for large-scale space deployable mechanism driven by digital twins and wearable AR devices," *Journal of Manufacturing Systems*, vol. 65, pp. 720–742, 2022.

[26] A. Chowdhury, A. Ahtinen, R. Pieters, and K. Vaananen, "User experience goals for designing industrial human-cobot collaboration: a case study of Franka Panda robot," in *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society*, Tallinn, Estonia, 2020.

[27] International Organization for Standardization, *ISO 9241-210: Ergonomics of Human–System Interaction-Human-Centred Design for Interactive Systems*, International Organization for Standardization, 2010.

[28] International Organization For Standardization, *ISO 9241-11*, International Organization, 1998.

[29] M. Hassenzahl, "The thing and I: understanding the relationship between user and product," in *Human-Computer Interaction Series*, Springer, Dordrecht, 2003.

[30] M. Hassenzhahl and V. Roto, "Being and doing a perspective on user experience and its measurement," *Interfaces*, vol. 72, pp. 10–12, 2007.

[31] T. Olsson, K. Väänänen-Vainio-Mattila, T. Saari, A. Lucero, and J. Arrasvuori, "Reflections on experience-driven design: a case study on designing for playful experiences," in *Proceedings of the 6th International Conference on Designing Pleasurable Products and Interfaces, DPPI 2013*, Newcastle upon Tyne, United Kingdom, 2013.

[32] E. Kaasinen, V. Roto, J. Hakulinen et al., "Defining user experience goals to guide the design of industrial systems," *Behaviour & Information Technology*, vol. 34, no. 10, pp. 976–991, 2015.

[33] M. Hassenzahl, *Encyclopedia entry on user experience and experience design*, Interaction-Design.Org, 2011.

[34] J. Preece, Y. Rogers, and H. Sharp, *Interaction design: beyond human-computer interaction*, John Wiley & Sons, 2002.

[35] L. Andren, D. Papp, E. Penno, and A. Vallas, *Interaction design: beyond human-computer interaction (3rd Ed)*, Eesti Teadusliku Seltsi Rootsis: Aastaraamat. Annales Societatis Litterarum Estonicae in Svecia, 2011.

[36] M. A. Goodrich and A. C. Schultz, "Human-robot interaction: a survey," *Foundations and Trends in Human-Computer Interaction*, vol. 1, no. 3, pp. 203–275, 2007.

[37] X. V. Wang, Z. Kemény, J. Váncza, and L. Wang, "Human–robot collaborative assembly in cyber-physical production: classification framework and implementation," *CIRP Annals*, vol. 66, no. 1, pp. 5–8, 2017.

[38] A. Apraiz, G. Lasa, and M. Mazmela, "Evaluation of user experience in human–robot interaction: a systematic literature review," *International Journal of Social Robotics*, vol. 15, no. 2, pp. 187–210, 2023.

[39] A. Meissner, A. Trübswetter, A. S. Conti-Kufner, and J. Schmidtler, "Friend or foe? Understanding assembly workers' acceptance of human-robot collaboration," *ACM Transactions on Human-Robot Interaction*, vol. 10, no. 1, pp. 1–30, 2021.

[40] V. Villani, F. Pini, F. Leali, and C. Secchi, "Survey on human–robot collaboration in industrial settings: safety, intuitive interfaces and applications," *Mechatronics*, vol. 55, pp. 248–266, 2018.

[41] J. Lindblom and B. Alenljung, "The anemone: theoretical foundations for UX evaluation of action and intention recognition in human-robot interaction," *Sensors*, vol. 20, no. 15, p. 4284, 2020.

[42] I. M. Duarte, A. Pinto, C. Carvalho, A. Zornoza, and J. Santos, "The contribution of the user experiences goals for designing better cobots: a systematic literature review," *Applied System Innovation*, vol. 5, no. 6, p. 119, 2022.

[43] LimeSurveyGmbH, "LimeSurvey: An Open-Source Survey Tool," p. 2017, 2017, http://www.limesurvey.org.

[44] Universal Robots, "UR5 Technical Specifications," 2016, https://www.universal-robots.com/media/50588/ur5_en.pdf.

[45] Universal Robots, "User Manual. Version 1.6 Robot: UR5 CB2, US Version," 2012, manual_en_UR5_CB2_1.6_US.pdf.

[46] M. P. Cota, J. Thomaschewski, M. Schrepp, and R. Gonçalves, "Efficient measurement of the user experience. A Portuguese

version," *Procedia Computer Science*, vol. 27, pp. 491–498, 2014.

[47] M. Schrepp, A. Hinderks, and J. Thomaschewski, "Construction of a benchmark for the User Experience Questionnaire (UEQ)," *International Journal of Interactive Multimedia and Artificial Intelligence*, vol. 4, no. 4, pp. 40–44, 2017.

[48] M. Schrepp, "User Experience Questionnaire Handbook Version 8," *User Experience Questionnaire Handbook*, 2019.

[49] W. T. Nakamura, I. Ahmed, D. Redmiles et al., "Are Ux evaluation methods providing the same big picture?," *Sensors*, vol. 21, no. 10, p. 3480, 2021.

[50] H. F. Hsieh and S. E. Shannon, "Three approaches to qualitative content analysis," *Qualitative Health Research*, vol. 15, no. 9, pp. 1277–1288, 2005.

[51] Y. Zhang and B. M. Wildemuth, "Qualitative analysis of content," in *Applications of Social Research Methods to Questions in Information and Library Science*, B. M. Wildemuth, Ed., pp. 308–319, Libraries Unlimited, Westport, CT, 2009.

[52] R. Tesch, *Qualitative Research: Analysis Types and Software Tools*, Falmer Press, Bristol, PA, 1990.

[53] J. Saldaña, *The Coding Manual for Qualitative Researchers*, Sage, Los Angeles, CA, 2009.

[54] R. T. Bree and G. Gallagher, "Using Microsoft Excel to code and thematically analyse qualitative data: a simple, cost-effective approach," *All Ireland Journal of Higher Education*, vol. 8, no. 2, 2016.

[55] A. M. McAlister, D. M. Lee, K. M. Ehlert, R. L. Kajfez, C. J. Faber, and M. S. Kennedy, "Qualitative coding: an approach to assess inter-rater reliability," in *2017 ASEE Annual Conference & Exposition*, Columbus, Ohio, 2017.

[56] C. O'Connor and H. Joffe, "Intercoder reliability in qualitative research: debates and practical guidelines," *International Journal of Qualitative Methods*, vol. 19, article 160940691989922, 2020.

[57] R. Heale and D. Forbes, "Understanding triangulation in research," *Evidence-Based Nursing*, vol. 16, no. 4, p. 98, 2013.

[58] M. Q. Patton, "Enhancing the quality and credibility of qualitative analysis," *Health Services Research*, vol. 34, 5 Part 2, pp. 1189–1208, 1999.

[59] J. Hwang, K. C. Lee, and J. Jeong, "Examining the impact of a user's previous experience with pets on robot-assisted therapy," *Communications in Computer and Information Science*, vol. 351, 2012.

[60] K. M. T. Collins and A. J. Onwuegbuzie, "A typology of mixed methods sampling designs in social science research," *The Qualitative Report*, vol. 12, no. 2, 2007.

[61] A. Pollak, M. Paliga, M. M. Pulopulos, B. Kozusznik, and M. W. Kozusznik, "Stress in manual and autonomous modes of collaboration with a cobot," *Computers in Human Behavior*, vol. 112, p. 106469, 2020.

[62] D. Fogli, L. Gargioni, G. Guida, and F. Tampalini, "A hybrid approach to user-oriented programming of collaborative robots," *Robotics and Computer-Integrated Manufacturing*, vol. 73, article 102234, 2022.

[63] A. Papetti, M. Ciccarelli, C. Scoccia, G. Palmieri, and M. Germani, "A human-oriented design process for collaborative robotics," *International Journal of Computer Integrated Manufacturing*, vol. 36, no. 12, pp. 1760–1782, 2023.

[64] H. Noble and R. Heale, "Triangulation in research, with examples," *Evidence-Based Nursing*, vol. 22, no. 3, pp. 67-68, 2019.

[65] I. J. Sunardi, D. F. Murad, and R. Y. Riva'i, "Combining UEQ and Eye-Tracking Method as Usability Evaluation for Mobile Apps," in *2021 3rd International Conference on Cybernetics and Intelligent System (ICORIS)*, pp. 1–6, Makasar, Indonesia, 2021.

[66] A. C. Simões, A. Lucas Soares, and A. C. Barros, "Drivers Impacting Cobots Adoption in Manufacturing Context: A Qualitative Study," in *Advances in Manufacturing II. MANUFACTURING 2019*, Lecture Notes in Mechanical Engineering, J. Trojanowska, O. Ciszak, J. Machado, and I. Pavlenko, Eds., Springer, Cham, 2019.

[67] A. Kravets, *Robotics: Industry 4.0 Issues & Amp; New Intelligent Control Paradigms*, A. G. Kravets, Ed., vol. 272, Springer International Publishing, Cham, 2020.

[68] N. Fronemann, K. Pollmann, and W. Loh, "Should my robot know what's best for me? Human–robot interaction between user experience and ethical design," *AI & Society*, vol. 37, no. 2, pp. 517–533, 2022.

[69] T. Partala and A. Kallinen, "Understanding the most satisfying and unsatisfying user experiences: emotions, psychological needs, and context," *Interacting with Computers*, vol. 24, no. 1, pp. 25–34, 2012.