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THE CONTRIBUTION OF THE USER EXPERIENCES GOALS FOR DESIGNING BETTER COBOTS

A SYSTEMATIC LITERATURE REVIEW AND A CASE STUDY OF HUMAN-ROBOT COLLABORATION IN A PICKING TASK

VOLUME 1

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1. General Introduction

The present Dissertation has the purpose of enhancing the knowledge regarding the user experience (UX) of collaborative robots (or cobots). The usage of these technological devices is constantly increasing in industrial settings (Galin et al., 2020), emphasizing the need to investigate the conditions that leverage its adoption (i.e., UX goals).

In that sense, two studies were conducted, constituting Sections 2 and 3, respectively a systematic literature review and a case study of human–robot collaboration in a picking task. The scope, aim, methods, results, discussion, and conclusions of each of them are described in detail in the corresponding sections. At the end, a general conclusion reinforces the relation between them both.

2. The contribution of the user experiences goals for designing better cobots: A systematic literature review

Abstract

Collaborative robots are an indispensable element of both industry 4.0 and industry 5.0, the latter of which gives special emphasis to the human facet of the human-robot collaboration. To facilitate such an interaction, attention should be given to the design of the cobot, including its interface, which enables communication with the user. Programming through the interface and performing a task with the robotic device are responsible for the user experience, which comprises both pragmatic and hedonic aspects. In order to design for the most positive experience for users, their perspectives must be considered, which is achieved through the identification of UX goals. In this respect, a systematic review was conducted to revise the UX goals present in the literature. The following seven UX goals were identified: safety, relationship, usability, inspiration, flexibility, efficiency, and accomplishment. These findings represent the first systematic categorization of UX goals for the design of cobots specifically, that should be empirically tested.

Keywords: collaborative robot (cobot), experience-driven design, industries 4.0 and 5.0, user experience (UX) goals

2.1. Introduction

In the context of the fourth industrial revolution, robots are being increasingly used in the industrial workforce. Industry 4.0 is characterized by mass production (Hanif & Iftikhar, 2020) and mass customization (Javaid & Haleem, 2020). The target is smart manufacturing with high rates of productivity, achieved through different innovative technology, namely robotics and artificial intelligence (Demir et al., 2019), that complement humans' capacities. The presence of humans is therefore still recognized as necessary for achieving the required customization in manufacturing, as they take responsibility for the tasks that require higher levels of cognition (Prati et al., 2021).

Notwithstanding, the role of human workers is further enhanced considering the emergent industry 5.0, whose core target is to achieve mass personalization (Javaid & Haleem, 2020). According to Hanif and Iftikhar (2020), contrary to the previous four phases, which stepped into dehumanization, this fifth industrial revolution emphasizes how technology should be used for the benefit of individuals, by focusing on the personalized demands and requirements of customers (Javaid & Haleem, 2020). To achieve that, Demir and colleagues (2019) suggest humans shall co-work with the robotic machines in all possible situations and contexts, through the vast integration of robots in organizations.

Despite the controversy revolving around whether this fifth revolution has started yet (Hanif & Iftikhar, 2020), both industry 4.0 (Prati et al., 2021) and industry 5.0 (Javaid & Haleem, 2020) highlight human-robot collaboration (HRC) as a key aspect when pursuing the fulfillment of their respective objectives.

An example of a robotic system that enables HRC, present in both industry 4.0 (Koh et al., 2019) and industry 5.0 (Hanif & Iftikhar, 2020), is one of the collaborative robots. A cobot is a "robot designed for direct interaction with a human within a defined collaborative workspace”, as defined by the International Organization for Standardization (ISO, 2011b, Section 3.2). This kind of robot is being adopted at unprecedented rates in organizations, and it is expected to become the main tool of manufacturing globally, due to its particular characteristics, such as safe interaction with humans (Galin et al., 2020). These machines support production flexibility and efficiency, favoring human-robot interaction.

HRC can be identified as the third level of human-robot interaction (Prati et al., 2021). The first level is coexistence, which implies common workspace and time. Cooperation is the second level, implying common workspace, time, aim, and resources. In addition to those, the collaboration of a robot and a human implies the existence of direct physical contact between them (e.g., Schmidtle et al., 2015). For that, user interfaces (UIs) are of extreme importance, as they are the main channel of communication connecting the two mentioned entities (Prati et al., 2021) and contribute to its efficiency and efficacy (Marvel and colleagues, 2020).

Given the complexity of human-robot interaction, an interdisciplinary approach is beneficial, including inputs both from the engineering and the psychological fields of knowledge (Kooijmans et al., 2007), both encompassed by cobots. They can be considered the “ideal new coworker” (Robotiq, 2020, p. 2) for its users, who program the robots’ motion and collaborate with them in some determined task, which are two steps responsible for the UX (Chowdhury et al., 2020).

UX can be defined as the sum total of all perceptions, emotions, and responses that users experience when interacting with some technological tool, as well as the ones experienced before and after such an interaction (ISO, 2019). Therefore, UX derives from the combined result of the expectations prior to the experience, the actual experience during the interaction, and the post-interaction experience (Adikari et al., 2015), trying to holistically understand the humans' side of this relation (Interaction Design Foundation, n.d.). Tubin and colleagues (2021) advocate that it is necessary to assess UX at different times and use combined methods to fully understand its related aspects.

Hassenzahl (2003) affirms that UX integrates both pragmatic and hedonic aspects. On the one hand, the pragmatic or instrumental component of the author's Model of User Experience emphasizes the fulfillment of a behavioral task by an individual, being intrinsically related to the manipulation of the mentioned product. On the other hand, the hedonic component is not focused on the task at hand, but instead on the individual's psychological state. The latter can be related to stimulation that results in personal development, identification with the objects as a way of self-expression, or evocation of valued memories. Designers should aim at the balance between pragmatic and hedonic attributes of UX (Hassenzahl & Roto, 2007).

UX has become increasingly important on account of the spreading of technology in a society that is shifting from a materialistic to an experiential culture (Hassenzahl, 2011), and its importance has been recognized by both researchers and practitioners (Alenljung et al., 2017; Hassenzahl & Tractinsky, 2006). Given its centrality, a trend towards experience-driven design has arisen. Olsson (2013, p.165) defined such a design through three assumptions: (a) "takes (user) experience as a starting point; «valuing the whole person behind the 'user'»", (b) "uses the targeted experience, and stories around them, as a central concept of the design vision", and (c) "focuses on the key design elements: context, interpretation, participation".

Hassenzahl and Tractinsky (2006) clarify that the aim is not to design an experience, but instead to design *for* an experience. Therefore, first, the intended UX must be defined, and only after that is it possible to come to a decision on how to conjure it (Kaasinen et al., 2015). Olsson (2013) emphasizes that this decision might benefit from the dialogue between designers and users, to ensure that the perspectives of the latter are taken into consideration.

Throughout this whole design process, UX goals are expected to be identified and utilized (Hassenzahl, 2013). UX goals, which concern the intended experiences that the technology used should provide its users, can be classified as *do-goals* and *be-goals*, by its pragmatic or hedonic nature (Hassenzahl & Roto, 2007). They can also be designated as instrumental (e.g., ease of use) and non-instrumental (e.g., visual aesthetics) qualities, respectively, as in the Components of User Experience Model developed by Mahlke and Thüring (2007), which endorses that both types of characteristics influence the emotional reactions and consequent judgment by users in an interactive context. The instrumental attributes can be considered as staying in an inferior hierarchical position in comparison to the others, and so derive from them (e.g., Carver & Scheier, 2000). Some authors even consider that non-task-related goals are the great focus of this kind of design (Adikari et al., 2015; Kaasinen et al., 2015).

Anyhow, the goals that users need to be met through the interaction with a cobot or other technological device should be the starting point for the experience-driven design (Olsson, 2013). The priority is to create a pleasurable experience, inasmuch as the product remains secondary (Hassenzahl, 2011). For the reaching of such experience, UX goals must be clearly defined (Kaasinen et al., 2015; Klumpp, 2019). Such goals must also be precise, measurable, and achievable, though they can be refined and altered throughout the design process (Varsaluoma et al., 2015).

In short, the first step when designing some robot is to formulate the goals intended at the time of the HRC entire process. Thereafter, the necessary technological functionality will be contemplated and, hopefully, concretized (Hassenzahl, 2011).

This study aims to meet the need for more in-depth research to explore how cobots are being used and how can they be improved, to guarantee that UX designs successfully fulfill their purpose of creating positive physical and psychological responses. For that purpose, a systematic review of the feasible UX goals for HRC present in the literature of the last eleven years was conducted. It has the intention of enhancing the knowledge of the UX goals as a guide to design cobots, through the contribution of diverse research areas. Besides understanding which are the UX goals described in the literature, the possible dissimilar importance attributed to them was also investigated.

Apart from this first introductory section, this paper is structured as follows: Section 2 describes the method used for conducting this systematic literature review; Section 3 presents its results and discusses the descriptive and content analyses; and Section 4 addresses the conclusions of this research.

2.2. Methods

The present systematic literature review was undertaken following the stages proposed by Donato and Donato (2019). According to these authors, systematic reviews differ from traditional ones in the sense that they are replicable and unbiased. It must be exhaustive, so as to cover all the relevant literature and follow a rigorous methodology.

The first step is to formulate the research questions. Once the research that will be answered in the review is well-established, the inclusion and exclusion criteria must be defined, as well as the search strategy. After that, the papers shall be selected and their quality evaluated. Finally, the data is extracted and synthetically analyzed. The methodological description of these stages is documented in the following subsections, following the PRISMA framework (Moher et al., 2009).

PICo structure (Population or Problem, Interest, **C**ontext) (Murdoch University, n.d.) was used to define the research questions. Considering the problem related to the application of UX goals in cobot design, in the industrial context, the following research question was defined: Which UX goals should be considered for the cobots design in the industrial context? Additionally, to analyze the relevance of the different UX goals in the cobots design, another question was defined: Do those UX goals have different importance?

2.2.1. Search strategy protocol

The search strategy consisted of a comprehensive search that could locate the widest spectrum of articles for consideration and was performed in selected electronic databases, namely: Scopus and Web of Science (Core Collection). The keywords used in this literature review were: ‘cobot’, ‘design’, ‘user’, ‘experience’, and ‘goal’. All these keywords were combined with their synonyms, as can be seen in Table 1.

Table 1

Keywords and their synonyms

Keywords	Synonyms
Cobot	Cobotic Human-robot interaction Human-interactive robot HRI Human-robot collaboration HRC Human-cobot interaction Human-collaborative robot HCI Collaborative robot Collaboration human-robot Human-robot collaborative workstation Co-robotic
Design	Plan Delineation

	Representation Model Proposal Method Framework Experience-driven design EDD User-centered/centred design Human-centered/centred design HCD Design thinking Interaction design Research through design RtD User experience design UXD
User	Operator Programmer Human controller Supervisor Facilitator Worker Teammate Human agent
Experience	Sense Understanding Perception Usability UX UE Emotion Feeling Event Impression
Goal	Aim Purpose Objective Target Intention Ambition Requirement Need/necessity Outcome Effect Value Task Accomplishment

Safety
Trust
Fellowship
Sympathy
Inspiration
Satisfying
Enjoyable
Fun
Entertaining
Helpful
Motivating
Aesthetically pleasing
Supportive of creativity
Rewarding
Emotionally fulfilling

Only studies published between January 2010 and 31st December 2021 were included. From the year 2021, only the publications until the 22nd July were considered, hence the search was done on the 23rd July.

This time span allows revising the publications that followed the definition of the term ‘user experience’ by the International Organization for Standardization (ISO, 2019) until the present time. This is especially pertinent given that job opportunities for UX designers are estimated to have increased by 13% from the year 2010 on (Interaction Design Foundation, n.d.).

Posterior to the search stage, the retrieval of the results was conducted in two distinct phases (see Appendix A). In the first moment, they were entered into an electronic spreadsheet and duplicated studies were removed. Then, the title, abstracts, and keywords of all the remaining papers were read and evaluated following the established criteria. Fulfilling at least two of the three criteria defined above is a condition to transition to the next phase. In the cases where the belonging to those criteria was not clear, they transitioned too.

2.2.2. Eligibility criteria

This review includes literature that was written in English, from a variety of disciplines (e.g., social sciences, robotics, human-robot interaction). Only articles or conference papers were included. The studies that were not fitting the theme were excluded. The remaining studies were analyzed by reading the full text. Only articles with a focus on the interaction between humans and cobots, add to the knowledge of UX goals, and refer to the industrial context and that answered the research questions described above were included.

2.2.3. Analysis of the studies

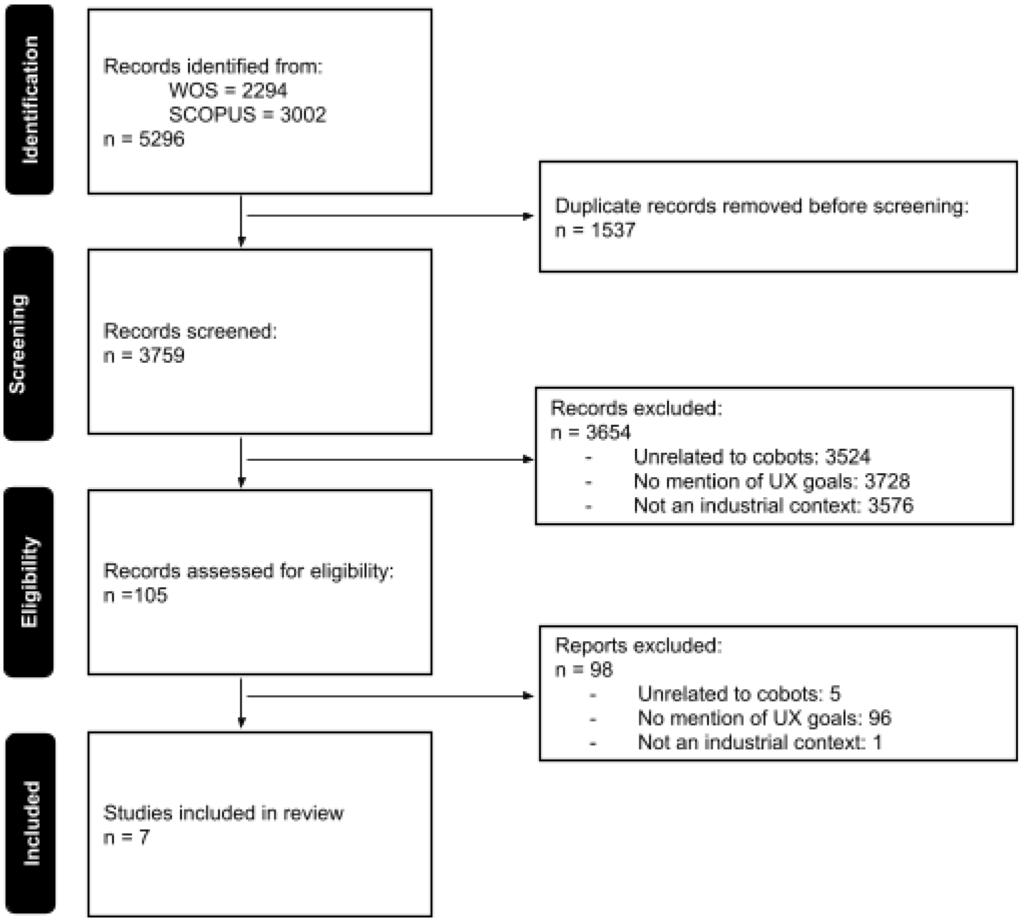
For data analysis, Microsoft Excel (2019) was used, enabling the synthesis of the results and their interpretation. While reading the articles, UX goals are identified, as well as the expressions that characterize it. Both the counting of the number of UX goals present in each article (i.e., score of the studies) and the counting of in how many papers each UX goal was cited (i.e., score of the items) is reported.

2.3. Results and discussion

The flow diagram of the PRISMA Statement methodology is presented in Figure 1. A total of 3759 records were obtained (after removing 1537 duplicates). After the application of eligibility criteria, 7 studies were included.

Figure 1

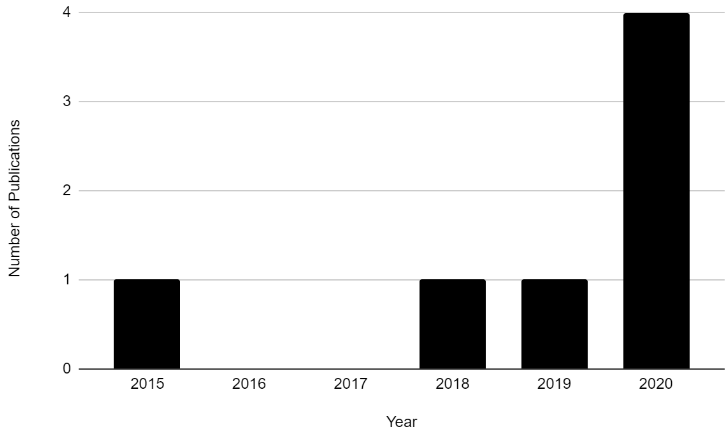
PRISMA Statement flow diagram



The first selected paper was published in 2015, followed by a two-year gap. After that, there was a slight increase in publications about the topic under study, with four articles being published in 2020 (see Figure 2). There were six conference papers included and one article, all of which provided insights related to how the design of cobots can be enhanced.

Figure 2

Number of publications throughout the years



Interestingly, even though we included papers published since 2010 in our search, only papers after the year 2015 were considered eligible for the analysis, most of which were published from 2018 on. This might indicate that the use of UX goals as a guide for the designing process of collaborative robots started gaining more relevance only quite recently.

Two of the studies were carried out in Finland, and the others in, Spain, Italy, Germany, Turkey, and the United States of America.

These studies focused on a variety of topics, namely industry 4.0 (e.g., Murali et al., 2020), collaborative robots (e.g., Aaltonen & Salmi, 2019), human-robot collaboration (e.g., Arntz et al., 2020); user experience, experience-driven design, and UX Goals (e.g., Chowdhury et al., 2020). Additionally, other topics were explored, namely, but not exclusively, barriers and development needs (Aaltonen & Salmi, 2019), virtual reality, augmented communication, and artificial intelligence (Arntz et al., 2020), safety (Kildal et al., 2018), task planning (Murali et al., 2020), technology adoption and social cues (Sauppé & Mutlu, 2015), robot motion and animation principles (Terzioglu et al., 2020).

The samples studied were quite diverse. It included students (Arntz et al., Chowdhury et al., 2020; 2020; Kildal et al., 2018; Terzioglu et al., 2020), as well as researchers and scientists (Aaltonen & Salmi, 2019; Chowdhury et al., 2020), in the representation of the academia. The industry was also represented, by several industrial professionals, from the management and supervision roles (Murali et al., 2020; Sauppé & Mutlu, 2015) to the different operational ones (Sauppé & Mutlu, 2015; Kildal et al., 2018; Aaltonen & Salmi, 2019; Chowdhury et al., 2020; Murali et al., 2020), and even end-users (Aaltonen & Salmi, 2019). The sample size ranged from a minimum of 10 to a maximum of 140 participants (see Table 2).

Regarding the study design, one paper used quantitative methods (Aaltonen & Salmi, 2019), three used qualitative ones (Sauppé & Mutlu, 2015; Kildal et al., 2018; Arntz et al., 2020), and three followed a mixed-method approach (Chowdhury et al., 2020; Murali et al., 2020; Terzioglu et al., 2020). Data collection was conducted in various ways, the most frequent ones being questionnaires and semi-structured interviews (see Table 2).

Five of the seven studies performed experiences with actual cobots, two of which were conducted in real industrial settings (see Table 2). Another study used a virtual reality setting to perform its experiments. Some of the robotic devices were the Kuka robot (Arntz et al., 2020), the Franka Panda cobot (Chowdhury et al., 2020), the Universal Robot (Murali et al., 2020; Terzioglu et al., 2020), and the Baxter robot (Sauppé & Mutlu, 2015).

Table 2

Summary of the studies reviewed

Reference	Sample	Research Design	Methods and Instruments	Barrier(s) to the UX goals application	Outcome*s*
(Aaltonen & Salmi, 2019)	75 members of The Robotics Society	Quantitative	Webropol survey platform; online questionnaire	The most significant barrier was the lack of knowledge of, for example, potential applications, reference cases, safety legislation, and ease-of-use.	The most significant development needs were about new ways of allocating work between human workers and cobots, and safety technology.
(Arntz et al., 2020)	80 students.	Qualitative	Content analysis	-	The benefits identified across all conditions were combined into the categories of efficiency, assistance, and relationship.
(Chowdhury et al., 2020)	22 millennials	Mixed-method	Observations; semi-structured interviews, short version of User Experience Questionnaire	-	Four user experience goals were identified, namely fellowship and sympathy, inspiration, safety and trust, and accomplishment.
(Kildal et al., 2018)	140 participants	Qualitative	Hands-on demonstration; questionnaires	The main barriers identified included safety, cost, workers' acceptance, and lack of knowledge. Some features expected in a cobot were a universal programming language, programming by demonstration, modularity, and safety features.	The main requirements were considered to be safety, usability, flexibility, and efficiency.

(Murali et al., 2020)	10 employees at Schaeffler Group	Mixed-method	Pick-and-place palletization task; Likert-scale questionnaires	-	The developed system ensured flexibility and comfort, enabling a fluent human-robot collaboration.
(Sauppé & Mutlu, 2015)	17 manufacturing workers	Qualitative	Observations; semi-structured interviews	-	The themes that emerged from the analysis can be grouped into two key implications for the design of cobots, namely the importance sociality and the need to support relationships with several stakeholders.
(Terzioglu et al., 2020)	72 students	Mixed-method	Questionnaires; semi-structured interviews	-	The principles of appeal, secondary action, and arcing had a significant positive effect on most outcomes, improving robot perceptions and user experience.

The experience of users is increasingly being considered when designing technological devices (Olsson, 2013). This experience-driven design is enabled by the definition and application of UX goals, that guide the whole process (Hassenzahl, 2013). In this systematic literature review, we intended to get to know what were the UX goals present in the work published since 2010 that could contribute to an enhanced design of industrial cobots. Table 3 shows how we proceeded to analyze and synthesize the data extracted from the seven selected studies, through its categorization.

Table 3

UX goals for the designing of cobots

Reference	Safety	Relationship	Usability	Inspiration	Flexibility	Efficiency	Accomplishment	Score (study)
(Aaltonen & Salmi, 2019)	+	0	+	0	0	+	0	3
(Arntz et al., 2020)	+	+	0	0	0	+	0	3
(Chowdhury et al., 2020)	+	+	0	+	0	0	+	4
(Kildal et al., 2018)	+	0	+	0	+	+	0	4
Murali et al., 2020)	+	0	+	+	+	0	+	5
(Sauppé & Mutlu, 2015)	0	+	0	0	0	0	0	1
(Terzioglu et al., 2020)	0	+	+	+	0	0	0	3
Score (item)	5	4	4	3	3	3	2	

Note. The presence of each UX goal in the articles is represented by the symbol '+', whereas its lack is represented by '0'.

Safety is one of the UX goals most mentioned in the literature (Chowdhury et al., 2020) and it includes all the aspects, both physical and psychological, that contribute to reduce, or even avoid, the potential anxiety derived from the interaction with a cobot, while perceiving it as safe. It was mentioned by Aaltonen and Salmi (2019) when they considered safety technologies, design methods for safety and hygiene requirements as needs for the development of cobots. Arntz and colleagues (2020) identified assistance as a positive aspect, which can be considered under the safety category, once the robotic device assists the human in the least safe tasks. Murali and colleagues (2020) highlighted the importance of the feature of comfort, in the sense of feeling safe. Chowdhuryand colleagues (2020) considered the UX goal of safety and trust, as well as Kildal and colleagues (2018), who identified safety as a requirement in this context.

Relationship is related to the tendency, also identified by Chowdhury and colleagues (2020), to treat collaborative robots in an anthropomorphic way, through the presence of social cues. This goal was identified as a positive element of the experiences run by Arntz and colleagues (2020). Chowdhury and colleagues (2020) further emphasized relationship as a UX goal, by mentioning fellowship and sympathy as means to create a bond between the user and the cobot. Sauppé and Mutlu (2015) pointed out the social aspects of a relationship and the need to develop multiple relationships as implications when designing cobots. Terzioglu and colleagues (2020) referred to the principle of secondary action, which does not contribute to a defined purpose but adds to the life-likeness of a cobot, and so to the building of a relationship with it.

The *Usability* category involves the characteristics that make a cobot easy to use in the pursue of a determined objective (Kildal et al., 2018). It was extensively present in the study by Aaltonen and Salmi (2019), which contemplated development goals, such as mobile robot cells, utilization of machine vision, utilization of artificial intelligence, new kinds of user interfaces, utilization of other sensors, programming methods, and mobility. Kildal and colleagues (2018) also identified usability as a requirement to take into account considering cobots. When Murali and colleagues (2020) referred to physical effortlessness, that could be linked with usability, by concerning a physical aspect of a task. Following the same logic, arcing, one of the principles of the study of Terzioglu and colleagues (2020), can be seen as linked to this category, by addressing the trajectory of the interaction.

Inspiration can be defined as the set of attributes that make the collaboration experience as enjoyable and as fluent as possible (Chowdhury et al., 2020). It was described by Chowdhury and colleagues (2020) as a UX goal that relates to feeling motivated and challenged. Murali and colleagues (2020) mentioned the feature of mental effortlessness, which can contribute to this goal of inspiration. Terzioglu and colleagues (2020) studied how turning a cobot more appealing can elicit interest and engagement with it, i.e., inspiration.

The UX goal of *Flexibility* encompasses a certain degree of adaptability and freedom of choice during the process of collaboration (Murali et al., 2020). The present goal was acknowledged by both Kildal and colleagues (2018) and Murali and colleagues (2020). Arntz and colleagues (2020) pointed out the flexibility of material handling devices as a development need, which also integrated the present category.

As belonging to the *Efficiency* category, are all the features that allow a cobot to serve the requirements of an industrial process (Kildal et al., 2018). Aaltonen and Salmi (2019) enumerated the following need for cobots development: new ways of allocating work between human workers and cobots; developing performance, and comprehensive solutions taking advantage of the best of robots and humans. Similarly, Arntz and colleagues (2020) and Kildal and colleagues (2018) identified this goal in their researches.

The UX goal *Accomplishment* refers to the feelings associated with the completion of a task or objective, collaboratively (Chowdhury et al., 2020). Chowdhury and colleagues (2020) nominated the sense of success derived from HRC as belonging to the accomplishment goal. The study from Murali and colleagues (2020) also refers to this goal as one of its features.

By this categorization, it was possible to observe that not all the aforementioned goals were addressed the same number of times. The number of articles in which they appear can be understood as a measure of their importance within the reviewed literature. This way, safety is ranked as the most relevant, being mentioned in five of the seven articles reviewed. It is followed by the UX goals of relationship and usability, which were both mentioned four time. Then come inspiration, flexibility, and efficiency, with three mentions each. Lastly, accomplishment was phrased in two of the selected articles, being the least relevant of this literature review.

If we try to make the link between the seven UX goals and the distinction between pragmatic and hedonic goals (Hassenzahl & Roto, 2007), usability, efficiency, and flexibility would be do-goals because of relating to more instrumental aspects of HRC; whereas relationship, inspiration, and accomplishment would be understood as be-goals for concerning non-instrumental aspects. Safety could possibly be perceived as both a pragmatic and hedonic goal, once it comprises task-related aspects (e.g., assistance), but also aspects that relate to the individual psychological state (e.g., comfort). Thereafter, there seems to be a balance between these two types of attributes among the UX goals found in the reviewed studies.

It is possible to aggregate the studies by research design, to understand which clusters elicited which of the seven UX goals. Beginning with the quantitative approach (Aaltonen & Salmi, 2019), the single study in which this design was used mentioned the safety, usability, and efficiency goals. The studies composing the qualitative cluster (Sauppé & Mutlu, 2015; Kildal et al., 2018; Arntz et al., 2020), referred to the UX goals of safety, relationship, usability, flexibility, and efficiency. Finally, the cluster constituted by the mixed-method articles (Chowdhury et al., 2020; Murali et al., 2020; Terzioglu et al., 2020) included all the goals except for the efficiency one.

In terms of the pragmatic or hedonic nature of the UX goals, it was observed that all the clusters added to the safety goal, that can be understood as both pragmatic and hedonic. They all also evoked other pragmatic goals. However, only the studies with qualitative and mixed methods designs contributed to the hedonic ones. It was also noted that the inspiration and accomplishment goals were only cited in papers from the mixed-methods cluster.

2.4. Conclusion

This systematic literature review enabled to identify a gap in the literature regarding the few empirical articles found that investigate UX goals in HRC. So, the most evident practical implication of this fisrt study is that it is possible to empirically test if actual cobots match the seven UX goals categorized. That can be done, for instance, through the application of questionnaires and the conductance of interviews. Another important contribution is that these goals can and must be used at the designing stage of collaborative robotic devices, so as to ensure that they will comply with the desired UX from the start.

A theoretical implication of our work is that it is the first categorization of the different UX goals that can be utilized for the designing of cobots in a manufacturing setting, and the determined categories can be of use for further research on this topic. To our best knowledge, no attempts to systematically review UX goals have been made, which means this is a pioneering study in that sense. One example of how these categories can be applied is by the development of a single questionnaire for the evaluation of these seven UX goals specifically.

Nonetheless, this categorization process has its inherent subjectivity. This can constitute a limitation, related to the fact that not all the authors referenced in this review addressed the UX goals as such. So, some of them were inferred as UX goals, given their description, even though this is a procedure that has the inevitable risk of biases.

Furthermore, as this is a recent topic, we suggest that a systematic literature review similar to the present one is done in some years' time, in order to check if the reported UX goals for the designing of cobots are still being used, if new ones have arisen, and what is their relative importance. Future research could also include more and different databases in its search, since this review only comprised publications of two databases, which could pose as a limitation of our results. These two limitations may hinder the aforementioned results to be generalized, given the low number of studies involved.

3. The contribution of the user experiences goals for designing better cobots: A case study of human-robot collaboration in a picking task

Abstract

Industries are adhering to the use of collaborative robots at an increasingly high rate. For the success of the implementation of these devices, it is crucial to consider the experience of users at the time of their designing. So, to improve their design, it is useful to understand what are the user experience goals that arise when programming and when collaborating with cobots. A previous systematic literature review has identified seven feasible goals, namely safety, relationship, usability, inspiration, flexibility, efficiency, and accomplishment. The present study constitutes the first attempt to empirically test the aforementioned framework. In this work, an experimental setup is introduced in the form of a laboratory case study in which the human-robot collaboration was evaluated by semi-structured interviews and applying the User Experience Questionnaire. The evoked user experience was positively rated, and the UX goals derived from it matched the ones of the said literature review. These findings are expected to benefit the well-being of manufacturing employees, by seeking the improvement of these cobots used in organizations and their subsequent enhanced acceptance.

Keywords: collaborative robot, pragmatic goals, hedonic goals, experience-driven design, empirical study

3.1. Introduction

Robots are increasingly used in the industry, as a result of the fourth industrial revolution. There are various reasons for that, the first of which is that these machines can be responsible for the most dangerous, hard, or boring work tasks, as well as the least ergonomic ones (Demir et al., 2019), reducing human efforts, both physical and cognitive ones (Prati et al., 2021). 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 (Koh et al., 2019).

Production (Hanif & Iftikhar, 2020) and customization (Javaid & Haleem, 2020) are core characteristics of industry 4.0; whereas the emergent industry 5.0 focuses on personalization (Javaid & Haleem, 2020), emphasizing the role of humans. Nonetheless, they both acknowledge that the collaboration between humans and robots is a fundamental aspect to fulfill their objectives. It comprises common workspace, time, aim, and resources, as well as the existence of direct physical contact between the two entities (e.g., Schmidtle et al., 2015).

But collaborative functionality is not always achieved. This is because the tasks performed by human-robot teams are usually of a merely sequential or simultaneous nature (Prati et al., 2021), none of which comprising a shared purpose (Marvel et al., 2020). In order to actually implement human-robot collaboration (HRC) as defined before, robotic systems must take up a supportive role in the interaction with humans, assuring, this way, the completion of a common task (Helms et al., 2002). That implies the existence of common workspace, time, aim, and resources, besides direct physical contact between the user and the technological device (e.g., Schmidtle et al., 2015). A robotic system that enables this is the case of a cobot (i.e., collaborative robot), defined as a "robot designed for direct interaction with a human within a defined collaborative workspace" (ISO, 2011b, Section 3.2).

Cobots have built-in sensors that make it stop when it is overloaded by, for instance, hitting a worker (e.g., Robotiq, 2020), through the programming of their force and torque (El Zaatari et al., 2019; Prati et al., 2021). Even if they collide, they do not cause much harm, because of their usually round shapes that spread the force over the surface and, thus, reduce the applied pressure. Consequently, cobots are able to operate alongside humans without any additional safety features, like a switch or fence (El Zaatari et al., 2019). Furthermore, their onboard sensors and smart software even allow them to become self-learners, denoting the ability to rapidly adjust (Galin et al., 2020).

Despite these benefits, the adoption of cobots does not bypasses the conductance of a thorought 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 (ISO, 2011a).

Notwithstanding, as a result of their advantages, these machines are usually considered as ideal coworkers for users (Robotiq, 2020, p. 2), as they favor human-cobot interaction, both while programming and when collaborating, the two steps of the user experience (UX; Chowdhury et al., 2020). 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 (ISO, 2019).

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 (ISO, 2018). 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 (Chowdhury, 2020). Despite that, Hassenzahl (2003) 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 (Hassenzahl & Roto, 2007), to guarantee an experience-driven design (Olsson, 2013).

In such a design, the intended UX must be priorly defined (Kaasinen et al., 2015) by identifying UX goals (Hassenzahl, 2013). These goals are the starting point of the design (Olsson, 2013), aiming for a resulting pleasurable experience (Hassenzahl, 2011). They can be classified by their pragmatic (i.e., *do-goals*) or hedonic (i.e., *be-goals*) nature (Hassenzahl & Roto, 2007).

An example of a model that describes attainable intentions for the interaction with a device is the one proposed by Preece and colleagues (2002) and updated by the same authors (Rogers et al., 2011), 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.

Particularly in the domain of cobots, Chowdhury and colleagues (2020) 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 the previous chapter, this and other studies were systematically reviewed using cobots in industrial settings, and 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 arise 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 user experiences arise during the human-cobot interaction with the Universal Robot? This research question can be subdivided into the two following ones: (a) What user experiences arise while programming the cobot? and (b) What user experiences arise while collaborating with the cobot? To properly answer the aforementioned questions, and in accordance with the vision of Marvel and colleagues (2020), a mixed-method will be employed, as the combination of both quantitative and qualitative metrics provides more integrative insight.

After this first introductory section, this paper is structured as follows: Section 2 describes the method used for conducting the experiences; Section 3 presents its results; Section 4 discusses the quantitative and qualitative analyses; and Section 5 is dedicated to the conclusions of the research.

3.2 Materials and methods

3.2.1. Participants

The sample was recruited in Portugal and was constituted of 19 subjects, all of which were university students. The majority of the sample was feminine, with only three male subjects. 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 3 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.

3.2.2. Procedure

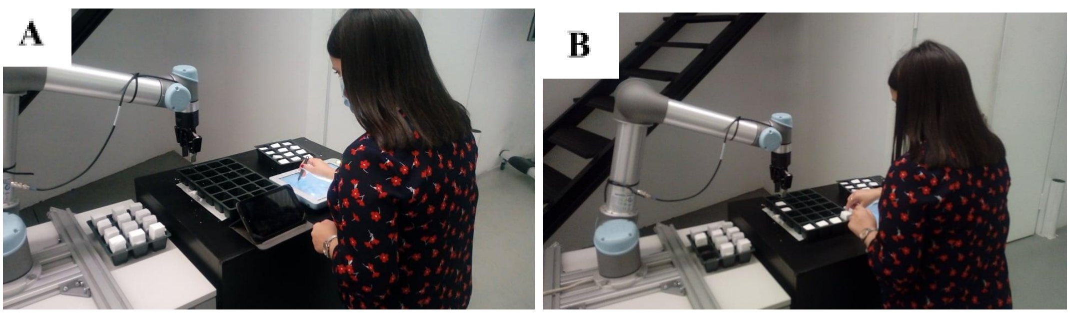
The present study sought ethical approval from the Ethics Committee at the Faculty of Psychology and Education Sciences of the University of Coimbra. The recruitment process occurred via direct contact with some of the participants, who were also asked for referrals. Data collection took place in July 2021, in the Industry and Innovation Lab (iilab) of the Institute for Systems and Computer Engineering, Technology and Science (INESC TEC). Each session lasted approximately 45 minutes.

Once participants entered the laboratory, the procedure was explained to them and they were asked to give their consent to participate and to answer a few demographic questions. Both the consent form and the demographic questionnaire were accessible through its specific QR code, which means participants were able to use their own devices to fill them in, with some exceptions, using the online survey tool LimeSurvey (LimeSurvey, 2017). With regard to the consent statement, which included a request for audio recordings, besides the assurance that no harm would be caused to them and no malpractice would be attempted at their data (see Appendix B). The input collected remains anonymous by the assignment of a numeric code to each subject. Regarding the demographic information, it addressed age, gender, occupation, previous contact with cobots and other kinds of robots, and potential motor or sensory disorders (see Appendix C). In the case of the participant being a student, three more questions appeared, regarding their course, faculty, and year.

Afterward, subjects performed a task with the Universal robot, which involved programming the cobot beforehand (see Figure 3). 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. 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, 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.

Figure 3

Photographs of the Experiments Showing Students Programming (A) and Performing a Task (B) with the Universal Robot



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 (Universal Robot, 2016). It has 6 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* (Universal Robots, 2012). 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-inch touch-sensitive screen with mounting, and allows running existing programs or creating new ones easily. UR5 consumes approximately 200 watts using a typical program, working in a temperature range from 0 °C to 50 °C. It is suitable for a number of different functions, specially for pallet operations similar to the one previously described, for which it has a pre-programmed sequence of motions in a set of places given as a pattern. The pick and place task was executed in a low speed, which was also pre-programmed, 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 UEQ (Cota et al., 2014) was applied as a quantitative approach (see Appendix D), also using LimeSurvey (2017) and accessing it with a QR code. 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, three to five minutes are required, which indicates that, at most, its fulfillment took up 10 minutes of the overall session, once it was answered twice. Two studies conducted by the authors 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 (Cota et al., 2014).

Finally, qualitative data were also collected by means of semi-structured interviews that proceed the interaction with the cobot (see Appendix E for interview questions). 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 and colleagues (2020). These interviews were conducted by one person, who asked these questions, maintaining eye contact during the conversation. So, following the recommendations from the Interaction Design Foundation (n.d.), 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 minutes.

3.2.3. Statistical Analyses

3.2.3.1. Quantitative approach. For the quantitative data, statistical analyses were computed using Microsoft Excel sheets (2019) provided by the authors of UEQ (Schrepp et al., 2019). 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 and colleagues (2019), 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. 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.

3.2.3.2. Qualitative approach. The audio recordings of the interviews were transcribed to electronic text format to facilitate analysis, with the exception of one participant, whose recording file was damaged in the process. Initially, relevant comments from each of the 18 participants were outlined, to pinpoint emerging themes. The statistical analyses for the qualitative data were computed in Microsoft Excel (2019). This program allows conducting a content analysis, derived from the semi-structured interviews' input, in a simple and cost-effective way (Bree & Gallagher, 2016). The data retracted from the interviews were categorized into the UX goals evoked in the previous study, while simultaneously searching for more possible categories. Aforesaid categories shall be as exclusive, homogeneous, and exhaustive as possible.

3.3. Results

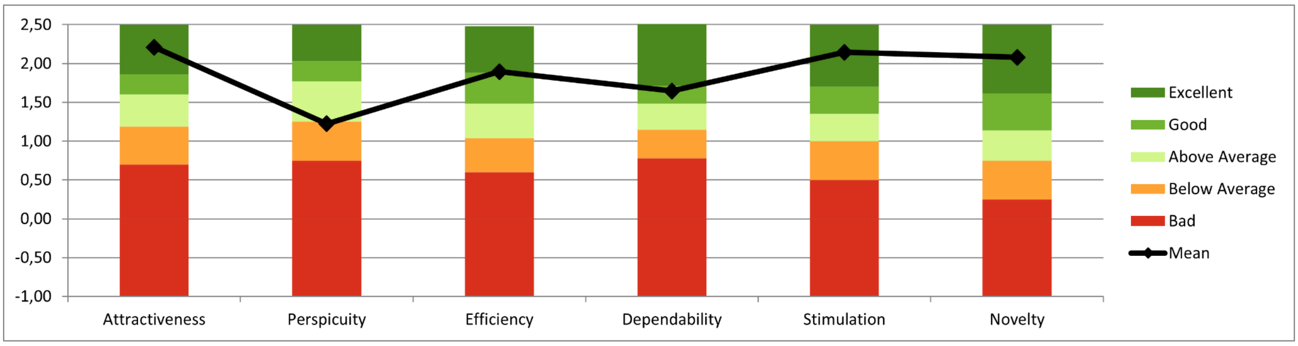
3.3.1. Quantitative approach

The UX of the programming phase was overall rated as positive (see Graph 1). The average value for attractiveness was 2.21 (SD = .59); 1,22 (SD = 1.06) for perspicuity; 1.90 (SD = .70) for efficiency; 1.64 (SD = .65) for dependability; 2.14 (SD = .82) for stimulation; and 2.08 (SD = .68) for novelty. Compared with the benchmark set by the authors (Schrepp et al., 2019), 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.

Graph 1

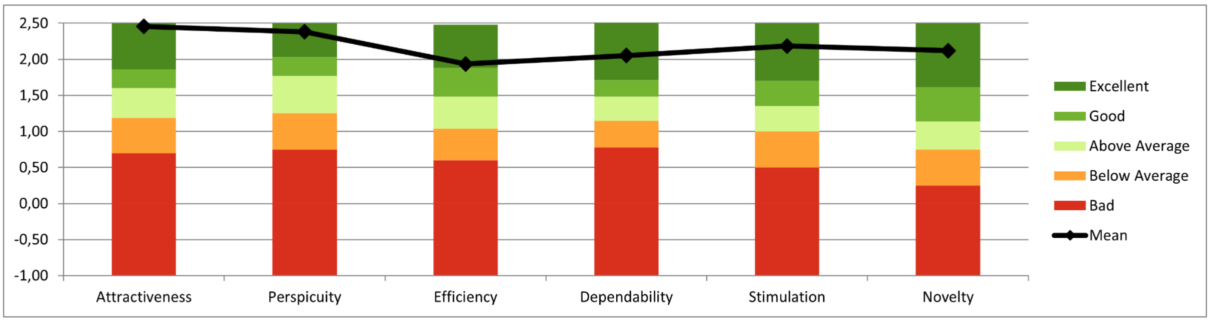
Means of UEQ scales for programming a cobot



Regarding the collaboration phase, the ratings of the UEQ were all positive as well (see Graph 2). Attractiveness had an average of 2.46 (SD = .78); perspicuity of 2.38 (SD = 1.09); efficiency of 1.93 (SD = .77); dependability of 2.05 (SD = .79); stimulation of 2.18 (SD = .89); and novelty of 2.12. (SD = .72). These six values can be interpreted as excellent (i.e., in the range of the 10% best results) when compared with the benchmark defined by the questionnaire's authors (Schrepp et al., 2019). 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.

Graph 2

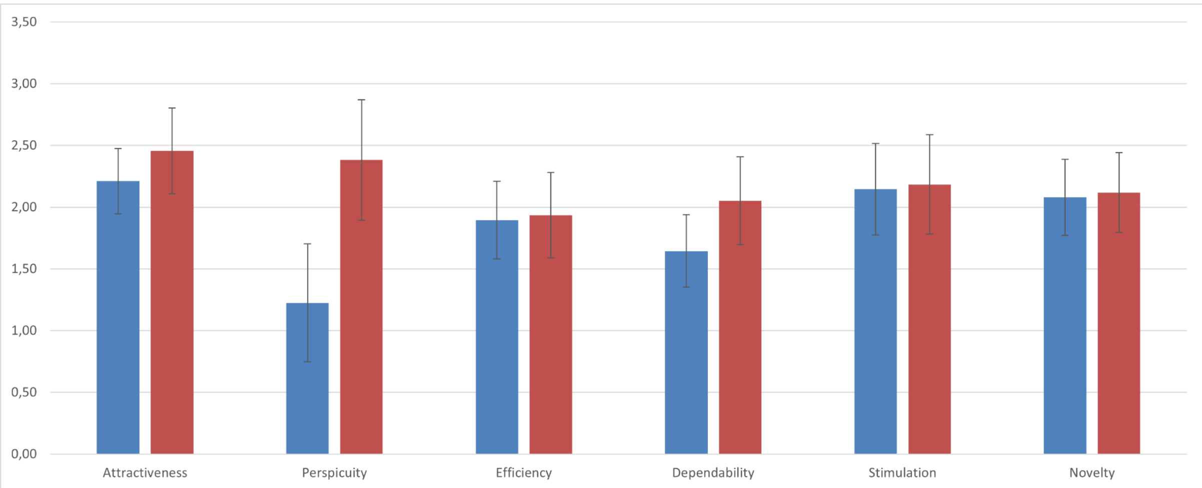
Means of UEQ scales for collaborating with a cobot



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 Graph 3). Two sample t-tests assuming unequal variances were used to assess the significance of such differences. Significant differences were observed for perspicuity ($t(18) = -4.335$, $p = .002$) only. The differences respecting attractiveness ($t(18) = -1.455$, $p = .280$), efficiency ($t(18) = -.243$, $p = .870$), dependability ($t(18) = -2.121$, $p = .091$), stimulation ($t(18) = -.220$, $p = .889$), and novelty ($t(18) = -.318$, $p = .863$) were non-significant.

Graph 3

Comparative analysis of UEQ scores for programming and collaborating with a cobot



Note. The programming score for each scale is represented by the colour blue, whereas the collaboration one is represented by the colour red.

3.3.2. 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 in the previous systematic literature review (see Table 4). No other additional goals were identified in this case study.

Each participant pointed to an average of 3 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.

Table 4

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'.

3.4. Discussion

The industry is progressively adopting cobots in its operations (ISO, 2011b). For the success of such adoption, these robots must provide a positive UX for their users (ISO, 2019), not only during the performance of a collaborative task, but also while programming the device before the collaboration (Chowdhury et al., 2020).

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, specially given the tendency to prioritize the pragmatic aspects (Chowdhury, 2020). 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 (Olsson et al., 2013).

To answer the subsequent research question, the same questionnaire was applied to the participants after collaboratively completing the assigned task with the robotic device. Similarly, the evaluation of the UX was positive, with identical values for both the hedonic and the pragmatic attributes. This result is in accordance with the perspective of Hassenzahl and Roto (2007), who defend that designers should take into consideration these two types of attributes.

When comparing these two phases with the benchmark set by Schrepp and colleagues (2019), who are the authors of the questionnaire, 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 (Pollak et al., 2020).

Combined with this quantitative approach, qualitative data was retrieved from the interviews that followed the filling of the questionnaires. Such qualitative data was then compared with the data systematically reviewed before to test the correspondence with the seven UX goals identified in that study. 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, of what UX arise during the human-cobot interaction with the Universal Robot, in general.

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 comprises 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.

3.5. Conclusion

The present study is one of the few testing the UX goals that arise during the full interaction with an industrial collaborative robot. It is the first study to empirically test the seven-goal framework mentioned in the systematic review previously conducted. This research follows the recommendations of several authors (e.g., Partala & Kallinen, 2012) to employ mixed-method approaches for UX studies, namely through the combination of questionnaires and interviews.

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., Chowdhury et al., 2020), but that could possibly be rethought. Another limitation was that the sample size was reduced, and it was entirely constituted by students, two factors which might affect the results.

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 not students, and with diverse backgrounds, could be sampled, in order to better support the conclusions.

4. General Conclusion

To conclude, the most prominent remark that derived from both studies is the necessity to continue testing and investigating the UX goals that contribute to an improved design of collaborative robots.

The systematic literature review conducted can function as a framework for future works, whereas the empirical study’s methodology can act as a guideline for the planning of related experiments. Taking into account the novelty of the topic and the specificity of the field, such recommendations do not dispense a critical analysis of each circumstance.

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6. Appendices

6.1 Appendix A

Research protocol

Title: The contribution of the user experiences (UX) goals for designing better COBOTS: A systematic literature review

Research plan (proposed by Denyer e Tranfield (2009))

1. Research question definition;
2. Papers/reports search;
3. Papers/reports selection and evaluation;
4. Analysis and synthesis; and
5. Findings.

1 – Research question (RQ) definition:

Main RQ:

- How are cobots being designed, taking into account the UX goals, in the industrial context?

Supplementary RQs:

- What are the UX goals described in the literature?
- Do those UX goals have different importance/weights?

2 – Papers/reports search: Database for papers:

2.1. **Search criteria**

Databases: Web of Science and Scopus.

Search fields:

Web of Science à Title, Keywords, Abstract

Scopus à Title, Keywords, Abstract

Publication year: 2010 – 2021

Type of document: articles, conference/proceedings papers

Language: English

Search Date: 23/07/2021

Research Areas: Consider the research areas aligned with the following:

"a multidisciplinary field with contributions from human–computer interaction, artificial intelligence, robotics, natural language understanding, design, and social sciences (e.g., engineering; robotic; computer sciences; automation control systems; operations research management science; behavioural sciences; mechanics; neurosciences neurology; science technology other topics; psychology; business economics; social issues, etc.)"

List of words with similar meaning to be used in the search expressions:

keywords	Synonymous

Cobot	Cobotic Human-robot interaction Human-interactive robot HRI Human-robot collaboration HRC Human-cobot interaction Human-collaborative robot HCI Collaborative robot Collaboration human-robot Human-robot collaborative workstation Co-robotic

Design	Plan Delineation Representation Model Proposal Method Framework Experience-driven design EDD User-centered/centred design Human-centered/centred design HCD Design thinking Interaction design Research through design RtD User experience design UXD

User	Operator Programmer Human controller Supervisor Facilitator Worker Teammate Human agent
Experience	Sense Understanding Perception Usability UX UE Emotion Feeling Event Impression

Goal	Aim Purpose Objective Target Intention Ambition Requirement Need/necessity Outcome Effect Value Task Accomplishment Safety Trust Fellowship Sympathy Inspiration Satisfying Enjoyable Fun Entertaining Helpful Motivating Aesthetically pleasing Supportive of creativity Rewarding Emotionally fulfilling

2.2. Search expressions

2.2.1. Search expressions for general purpose

(cobot* OR “human-robot interact*” OR human-interact* robot OR HRI OR human-robot collaborat* OR HRC OR human-cobot interact* OR human-collaborat* robot OR HCI OR collaborat* robot OR collaborat* human-robot OR human-robot collaborat* workstation OR co-robotic) AND (design OR plan OR delineat* OR representat* OR model OR propos* OR method OR framework OR experience-driven design OR EDD OR user-cent* design OR human-cent* design OR hdc OR design thinking OR interaction design OR research through design OR rtd OR user experience design OR uxd) AND (user OR operator OR programmer OR human controller OR supervisor OR facilitator OR worker OR teammate OR human agent) AND (experience OR sense OR understanding OR perception OR usability OR UX OR UE OR emotion OR feeling OR event OR impression) AND (goal OR aim OR purpose OR objective OR target OR intention OR ambition OR requirement OR need OR necessity OR outcome OR effect OR value OR task OR accomplishment OR safety OR trust OR fellowship OR sympathy OR inspiration OR satisfying OR enjoyable OR fun OR entertaining OR helpful OR motivating OR aesthetically pleasing OR supportive of creativity OR rewarding OR emotionally fulfilling)

2.2.1.1. Search expressions for general purpose for Scopus

TITLE-ABS-KEY (cobot* OR "human-robot interact*" OR "human-interact* robot" OR hri OR "human-robot collaborat*" OR hrc OR "human-cobot interact*" OR "human-collaborat* robot" OR hci OR "collaborat* robot" OR "collaborat* human-robot" OR "human-robot collaborat* workstation" OR co-robotic) AND TITLE-ABS-KEY (design OR plan OR delineat* OR representat* OR model OR propos* OR method OR framework OR "experience-driven design" OR edd OR "user-cent* design" OR "human-cent* design" OR hdc OR "design thinking" OR "interact* design" OR "research through design" OR rtd OR "user experience design" OR uxd) AND TITLE-ABS-KEY (user OR operator OR programmer OR "human controller" OR supervisor OR facilitator OR worker OR teammate OR "human agent") AND TITLE-ABS-KEY (experience OR sense OR understanding OR perception OR usability OR ux OR ue OR emotion OR feeling OR event OR impression) AND TITLE-ABS-KEY (goal OR aim OR purpose OR objective OR target OR intention OR ambition OR requirement OR need OR necessity OR outcome OR effect OR value OR task OR accomplishment OR safety OR trust OR fellowship OR sympathy OR inspiration OR satisfying OR enjoyable OR fun OR entertaining OR helpful OR motivating OR "aesthetically pleasing" OR "supportive of creativity" OR rewarding OR "emotionally fulfilling") AND PUBYEAR > 2009 AND PUBYEAR < 2022 AND (LIMIT-TO (LANGUAGE , "English")) AND LIMIT-TO (DOCTYPE , "ar") AND LIMIT-TO (DOCTYPE , "cp")

2.2.1.2. Search expressions for general purpose for Web of Science (Web of Science Core Collection)

((TS=(cobot* OR "human-robot interact*" OR "human-interact* robot" OR hri OR "human-robot collaborat*" OR hrc OR "human-cobot interact*" OR "human-collaborat* robot" OR hci OR "collaborat* robot" OR "collaborat* human-robot" OR "human-robot collaborat* workstation" OR co-robotic)) AND (TS=(design OR plan OR delineat* OR representat* OR model OR propos* OR method OR framework OR "experience-driven design" OR edd OR "user-cent* design" OR "human-cent* design" OR hdc OR "design thinking" OR "interact* design" OR "research through design" OR rtd OR "user experience design" OR uxd)) AND (TS=(user OR operator OR programmer OR "human controller" OR supervisor OR facilitator OR worker OR teammate OR "human agent")) AND (TS=(experience OR sense OR understanding OR perception OR usability OR ux OR ue OR emotion OR feeling OR event OR impression)) AND (TS=(goal OR aim OR purpose OR objective OR target OR intention OR ambition OR requirement OR need OR necessity OR outcome OR effect OR value OR task OR accomplishment OR safety OR trust OR fellowship OR sympathy OR inspiration OR satisfying OR enjoyable OR fun OR entertaining OR helpful OR motivating OR "aesthetically pleasing" OR "supportive of creativity" OR rewarding OR "emotionally fulfilling")))

TIMESPAN: 2010-01-01 – 2021-07-22

LANGUAGE: English

DOCUMENT TYPES: articles, proceedings papers

2.3. Search results:

2.3.1. Search results for general purpose

Search expressions	Nr. of results	
	Scopus	Web of Science
2.2.1.	3.002	2.294

3. Papers/reports selection and evaluation

After the first search stage, the papers were entered into an electronic spreadsheet and the titles, keywords and abstracts were read, knowing that this analysis focuses on the following criteria:

- Do they mention cobots?
- Are they dealing with UX goals?
- Are the studies conducted in the industrial context?
- Are the sources articles or conference papers?

Using this criterion, 105 articles were selected.

Finally, the articles were fully read and the criterion for selection was the answer to the following question:

- Do the articles help to answer the research questions?

After this step, 7 articles were selected for analysis.

Following the suggestion of other studies, and as a way to increase the reliability of the selection, the articles were evaluated simultaneously by four researchers and doubts and disagreements were discussed until consensus was reached.

The articles were only included if all reviewers agreed.

4. Analysis and synthesis

After selecting the most relevant studies for the purposes of this research, the articles were analyzed with the software Excel and synthesized.

6.2. Appendix B

Consent form

Portuguese	English
A contribuição dos objetivos da experiência do utilizador para a conceção de melhores robots colaborativos **Objetivos do estudo** O presente estudo visa aprofundar o conhecimento acerca de quais os objetivos da experiência do usuário que surgem durante as fases de programação e interação com um robot colaborativo, de modo a permitir conceber melhores cobots. **Papel dos participantes** A sua participação neste estudo é inteiramente voluntária e consiste em duas partes. Antes de iniciar,	**The contribution of the user experiences goals for designing better collaborative robots** **Study objectives** This study seeks to deepen the understanding of which user experiences goals arise during the programming and interacting phases with a collaborative robot, so as to enable the design of better cobots **Participants role** Your participation in this study is entirely voluntary and consists of two parts. Before starting, a short demographic

proceder-se-á ao preenchimento de um curto questionário demográfico. A primeira parte consiste em programar um robot colaborativo, seguida do preenchimento de um questionário para avaliar a experiência do usuário. A segunda parte envolve realizar uma tarefa colaborativa com o robot, seguida do preenchimento do mesmo questionário e de uma entrevista acerca de toda a interação. O que estará a ser avaliado é a experiência resultante dessa interação, não o seu desempenho na mesma, pelo que não existem respostas certas nem erradas. As suas respostas serão estritamente confidenciais e anónimas. Os dados recolhidos serão utilizados apenas para fins de investigação, tendo somente valor coletivo. A privacidade e a proteção dos dados estão de acordo com o Regulamento Geral de Proteção de Dados da União Europeia. A sua participação neste estudo não inclui quaisquer riscos para si, para além do incómodo que possa constituir o preenchimento dos questionários e a realização da experiência. Caso não queira participar no estudo, não haverá nenhuma penalização por isso, podendo	questionnaire will be filled. The first part consists of programming a collaborative robot, followed by filling in a questionnaire to evaluate the user experience. The second part involves performing a collaborative task with the robot, followed by filling in the same questionnaire and by an interview addressing the entire interaction. What will be evaluated is the experience resulting from that interaction, not your performance in it, so there are no right or wrong answers. Your answers will be strictly confidential and anonymous. The data collected will be used only for research purposes, having only collective value. Privacy and data protection are in accordance with the General Data Protection Regulation of the European Union. Your participation in this study does not pose any risks for you, apart from the inconvenience of completing the questionnaires and taking part in the experiment. If you do not wish to participate in the study, there will be no penalty for this, and you may withdraw from collaboration at any time and for any reason (including if you feel your privacy has been invaded), with no need

desistir de colaborar a qualquer momento e por qualquer motivo (inclusive se sentir a sua privacidade invadida), sem necessidade de justificação. A sessão durará cerca de 45 minutos. Durante a parte da entrevista, proceder-se-á à gravação de áudio. **Papel dos investigadores** Os investigadores deste projeto comprometem-se a: (1) Garantir o anonimato e total confidencialidade sobre os dados fornecidos, os quais serão identificados através de um código alfanumérico; (2) Utilizar os dados fornecidos pelos participantes somente para fins de investigação, não sendo estes alvo de qualquer negligência. **O seu contributo** A sua participação estará a contribuir para a conceção de robots colaborativos mais ajustados às necessidades humanas, melhorando assim o bem-estar dos trabalhadores no setor da indústria. Se estiver disponível para participar neste estudo solicitamos-lhe, por favor, que nos dê o seu consentimento informado,	for justification. The session will last for about 45 minutes. During the intervention's phase, audio will be recorded. **Researchers role** The researchers of this project commit to: (1) Guarantee the anonymity and total confidentiality about the provided data, which will be identified by an alphanumeric code; (2) Use the data provided by the participants for research purposes only, which will not be subject to any malpractice. **Your contribution** Your participation will contribute to the designing of collaborative robots that are better adjusted to human needs, thus improving the well-being of workers in the industrial sector. If you are available to participate in this study, please give us your informed consent by checking the box below. We thank you in advance for your time

assinalando o quadrado abaixo. Agradecemos desde já o tempo e disponibilidade manifestados para participar na presente investigação. Para questões adicionais relacionadas com esta investigação, por favor contacte as investigadoras responsáveis: inesmargaridalduarte@gmail.com | ana.pinto@dem.uc.pt | ccarvalho@fpce.uc.pt . ☐ Tomei conhecimento dos objetivos do estudo e do que tenho de fazer para participar. Fui esclarecido sobre todos os aspetos importantes e tomei conhecimento que tenho o direito de participar neste estudo e que a minha recusa em fazê-lo não terá consequências para mim. Assim, declaro que aceito participar nesta investigação.	and availability to participate in this research. For additional questions related with this research, please contact the responsible researchers: inesmargaridalduarte@gmail.com | ana.pinto@dem.uc.pt | ccarvalho@fpce.uc.pt. ☐ I have been informed about the objectives of the study and what I have to do in order to participate. I have been informed of all important aspects and I understand that I have the right to participate in this study and that my refusal to do so will have no consequences for me. Therefore, I declare that I agree to participate in this research.

6.3. Appendix C

Demographic questionnaire

Portuguese	**English**
Qual é a sua idade? _____ (anos) Qual é o seu género?	What is your age? _____ (years) What is your gender?

o Masculino o Feminino o Não binário o Outro: ________________ o Prefiro não dizer Qual é a sua ocupação? o Estudante o Outra: ________________ [Se estudante] Qual o curso que frequenta? ________________ [Se estudante] Qual a faculdade que frequenta? ________________ [Se estudante] Em que ano do curso se encontra? ________________ Teve alguma experiência anterior com robots colaborativos? o Sim o Não Teve alguma experiência anterior com outros tipos de robots? o Sim o Não Tem alguma perturbação motora ou sensorial? o Sim o Não o Prefiro não dizer	o Male o Female o Non-binary o Other: ________________ o Prefer not to disclose What is your occupation? ________________ Did you have any former experience with collaborative robots? o Yes o No Did you have any former experience with other kinds of robots? o Yes o No Do you have any motor or sensory disorders? o Yes o No o Prefer not to disclose

6.4. Appendix D

User experience questionnaire (UEQ; Schrepp, 2019)

Portuguese	**English**
Desagradável ○ ○ ○ ○ ○ ○ ○ Agradável Incompreensível ○ ○ ○ ○ ○ ○ ○ Compreensível Criativo ○ ○ ○ ○ ○ ○ ○ Sem criatividade De Fácil aprendizagem ○ ○ ○ ○ ○ ○ ○ De difícil aprendizagem Valioso ○ ○ ○ ○ ○ ○ ○ Sem valor Aborrecido ○ ○ ○ ○ ○ ○ ○ Excitante Desinteressante ○ ○ ○ ○ ○ ○ ○ Interessante Imprevisível ○ ○ ○ ○ ○ ○ ○ Previsível Rápido ○ ○ ○ ○ ○ ○ ○ Lento Original ○ ○ ○ ○ ○ ○ ○ Convencional Obstrutivo ○ ○ ○ ○ ○ ○ ○ Condutor Bom ○ ○ ○ ○ ○ ○ ○ Mau Complicado ○ ○ ○ ○ ○ ○ ○ Fácil Desinteressante ○ ○ ○ ○ ○ ○ ○ Atrativo Comum ○ ○ ○ ○ ○ ○ ○ Vanguardista Incómodo ○ ○ ○ ○ ○ ○ ○ Cómodo Seguro ○ ○ ○ ○ ○ ○ ○ Inseguro Motivante ○ ○ ○ ○ ○ ○ ○ Desmotivante Atende as expectativas ○ ○ ○ ○ ○ ○ ○ Não atende as expectativas Ineficiente ○ ○ ○ ○ ○ ○ ○ Eficiente Evidente ○ ○ ○ ○ ○ ○ ○ Confuso Impraticável ○ ○ ○ ○ ○ ○ ○ Prático Organizado ○ ○ ○ ○ ○ ○ ○ Desorganizado Atraente ○ ○ ○ ○ ○ ○ ○ Feio Simpático ○ ○ ○ ○ ○ ○ ○ Antipático Conservador ○ ○ ○ ○ ○ ○ ○ Inovador	Annoying o o o o o o o Enjoyable Not understandable o o o o o o o Understandable Dull o o o o o o o Creative Difficult to learn o o o o o o o Easy to learn Inferior o o o o o o o Valuable Boring o o o o o o o Exciting Not interesting o o o o o o o Interesting Unpredictable o o o o o o o Predictable Slow o o o o o o o Fast Conventional o o o o o o o Inventive Obstructive o o o o o o o Supportive Bad o o o o o o o Good Complicated o o o o o o o Easy Unlikable o o o o o o o Pleasing Usual o o o o o o o Leading edge Unpleasant o o o o o o o Pleasant Not secure o o o o o o o Secure Motivating o o o o o o o Demotivating Does not meet expectations o o o o o o o Meets expectations Inefficient o o o o o o o Efficient Confusing o o o o o o o Clear Impractical o o o o o o o Practical Cluttered o o o o o o o Organized Unattractive o o o o o o o Attractive Unfriendly o o o o o o o Friendly Conservative o o o o o o o Innovative

6.5. Appendix E

Interview's questions

Portuguese	**English**
No geral, como foi a sua experiência de interagir com o robot colaborativo? O que achou positivo? E negativo? Como definiria o manuseamento da interface enquanto programava? E o cobot em si, como foi de manusear? Quais as suas expectativas ao longo de toda a sessão? Como descreveria a sua experiência de aprendizagem? Sentiu alguma preocupação de segurança durante a colaboração? Há algo mais que gostaria de acrescentar?	How was your overall experience of interacting with the collaborative robot? What did you find positive about it? And negative? How would you define the operation of the interface while programming? And what about the cobot *per se*, how was it to operate? What were your expectations throughout the whole session? How would you describe your learning experience? Have you felt any safety concern during this collaboration? Is there something else you would like to add?