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Three Perspectives for Evaluating Human-Robot Interaction

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Abstract The experience of interacting with a robot has been shown to be very different in comparison to people’s interaction experience with other technologies and artifacts, and often has a strong social or emotional component – a fact that raises concerns related to evaluation. In this paper we outline how this difference is due in part to the general complexity of robots’ overall context of interaction, related to their dynamic presence in the real world and their tendency to invoke a sense of agency. A growing body of work in Human-Robot Interaction (HRI) focuses on exploring this overall context and tries to unpack what exactly is unique about interaction with robots, often through leveraging evaluation methods and frameworks designed for more-traditional HCI.

We raise the concern that, due to these differences, HCI evaluation methods should be applied to HRI with care, and we present a survey of HCI evaluation tech-

niques from the perspective of the unique challenges of robots. Further, we have developed a new set of tools to aid evaluators in targeting and unpacking the holistic human-robot interaction experience. Our technique surrounds the development of a map of interaction experience possibilities and, as part of this, we present a set of three perspectives for targeting specific components of interaction experience, and demonstrate how these tools can be practically used in evaluation.

CR Subject Classification H.1.2 [Models and principles]: user/machine systems–*software psychology*

1 Introduction

The recent and rapid advancement of robotic technology is bringing robots to assist people in their everyday environments such as homes, schools, hospitals and museums. Consequently, interaction between people and robots has become increasingly socially-situated and multi-faceted [34]. Social and emotional levels of interaction play a critical role in a person’s acceptance of and overall experience with any technology or artifact [1, 8, 12, 39], and we contend that this relationship is particularly prominent, unique and intertwined for interaction with robots.

While studies strongly support the idea that interaction with robots is complex and draws strong social and emotional responses [7, 39, 54], few researchers have directly explored how this affects the *evaluation* of interaction between people and robots. However, the question remains whether specific consideration is needed for evaluation of HRI.

In this paper we outline how robots’ social and physical presence, and their tendency to evoke a sense of agency, creates a complex interaction context very different from that of interaction with other technologies and artifacts. We argue that this wider context should

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be explicitly considered when evaluating HRI, and provide a survey of how existing HCI methods apply and relate to these particular HRI challenges.

Further, we present a new technique for *mapping* and exploring the interaction experience possibilities between a person and a robot. Our approach is built around a set of three perspectives that serve as tools to help evaluators to explicitly target various facets of interaction experience with robots and to directly consider the wider interaction context.

2 Why is Human-Robot Interaction Unique

In this section we argue that robots elicit unique, emotionally-charged interaction experiences, and that this stems from how robots integrate into everyday settings. People naturally tend to treat robots similar to how they may treat living objects, and ascribe lifelike qualities, such as names, genders and personalities, even when the robot is not explicitly designed to incur social responses [20, 49].

Exactly why this happens is a question still open to exploration. Here we consider this question in terms of what it means for interaction with robots, and focus our discussion around how robots encourage social interaction, how they elicit a unique sense of “agency”, and how they demand attention to the greater, holistic, interaction context.

2.1 Robots as Social Actors

Studies have shown that people naturally tend to respond socially and to apply social rules to technologies [38, 42]. Thus it comes as no surprise that this also happens with robots (e.g., [20, 49]). In fact, leveraging human social language and interaction patterns is perhaps becoming a standard robot design approach. Further, previous studies in non-robot cases report that social tendencies can be strengthened and harnessed through socially-evocative technology designs [42]. Likewise, robots that explicitly utilize such mediums as speech, familiar gestures, or facial expressions (e.g., exhibit *social* affordances) can be reasonably expected to further encourage social interaction from people – these social affordances suggest to people how to interact with the robot and what to expect back. This serves as general motivation for building robots that leverage social interaction.

Robots have well-defined physical manifestations, can exhibit physical movements and can autonomously interact within our personal spaces, properties that set

them apart from other artifacts such as a PC or microwave [39]. These properties can easily be construed as lifelike, encouraging social interaction even when not explicitly designed to do so. In addition, this physical, tangible nature, including such things as location and proximity to personal spaces, and the ability to somewhat autonomously move and act within these spaces [16, 28], is also considered to have an effect on the social structures surrounding interaction [32].

2.2 Agency

People have been found to anthropomorphize robots more than other technologies and to give robots qualities of living entities such as animals or other people (e.g., [2, 3, 9, 19, 22, 23, 37, 48, 49]). Arguably it is this anthropomorphism embedded within social contexts that encourages people to readily attribute intentionality to robots’ actions regardless of their actual abilities. Intentionality helps give rise to a sense of agency in the robot – the word “agency” itself refers to the capacity to act and carries the notion of intentionality [14]. While people do attribute agency to various other technologies (e.g., video game characters, movies [42]), we argue that the robot’s physical-world embeddedness and socially-situated context of interaction creates a unique and affect-charged sense of “active agency” similar to that of living entities. In a sense, then, interacting with a robot is similar to interacting with an animal or another person – the robot is an active social player in our everyday world.

Due to agency, people perceive robots to make autonomous, intelligent decisions based on a series of cognitive actions [3, 38, 42]. Considering this perspective is useful in understanding how people interact with robots because it helps explain why they readily attribute lifelike qualities. Further, agency contributes to the development of expectations of the robot’s abilities. For example, agency can imply an expected level of learning and improvement, or can create the expectation of the robot as an active social agent. In fact, it has been demonstrated that people perceive even simple robots to engage in social interaction in a reciprocal manner, and people develop affective and emotional attachment to the robot (e.g., [20, 21, 36, 49]) – while people do sometimes exhibit emotional attachment to other artifacts, robots can legitimize the relationship by responding to our affection [3]. These expectations can greatly shape how people perceive their interactions with a robot and its success in regards to particular goals [54].

2.3 Embodied Interaction Experience

Interaction is embodied within (and is itself an extension of) our social and physical worlds [16, 44, 51]. A person’s experience cannot be fully or properly understood by reductive account or limited perspectives [14], and includes difficult-to-quantify thoughts, feelings, personal and cultural values, social structures, and so forth [11, 14, 16]. From a person’s point of view, the meaning of experience cannot be separated from the wider, holistic context.

Robots’ unique “active agency” and life-like presence makes this wider context a particularly prominent part of interaction experience. That is, the meaning of human-robot interaction often reaches well beyond the simple point of interaction (particular interface and particular actions) in a much stronger and deeper way than interaction with many traditional and more-passive technologies and artifacts. We can expect social norms to manifest with robots as they may exist between people – e. g., will people be shy to change their clothes in front of an advanced household robot?

This general idea is outlined in Fig. 1. The user experience of interaction, embedded within a wide context, is greatly influenced by the robot. The robot itself is a prominent and very active social and physical player within this context, with its influence similar in many respects to a living entity. The human and robot mutually shape the experience similar to how two living agents may.

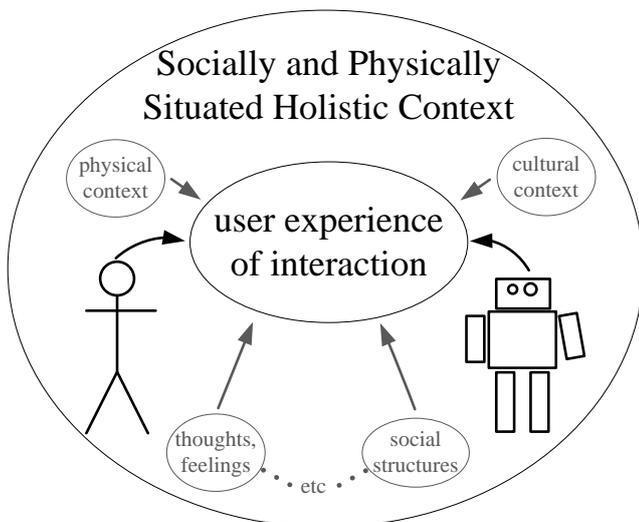


Fig. 1 robots play a very prominent role in the holistic interaction context

3 Evaluating and Unpacking Interaction With Robots

How do existing evaluation techniques from both HCI and HRI relate to the social levels of interaction between a person and a robot? How can the HRI experience be viewed as an inseparable result of its socially- and physically-situated holistic context? Our goal in this section is to provide a summary of existing methodologies, techniques, and concepts that can be useful for targeting these questions.

We approach this discussion from three perspectives on evaluation methods: task completion and efficiency, personal experience and context, and emotion and social norms. We do not intend to apply a hard-lined categorization here, we use these perspectives simply as a mechanism to add structure to our discussion.

3.1 Task Completion and Efficiency

Given the nature of most computer interfaces, traditional HCI evaluation has often taken a task completion and efficiency approach to usability evaluation, focusing directly on how an interface supports a user in their desired tasks, actions, and goals [15, 18, 40, 45].

This trend also exists in HRI where questions explored often center around control-oriented issues, performance quality, the person’s tactical awareness of the robots’ environment, error rates and action mistakes, and more (e. g., [17, 27, 43, 53]).

In addition to the obvious utilitarian importance of these measures, task and efficiency can help to stipulate context and socially-oriented qualities such as engagement and interest, boredom, distractions, or whether and how much a person understands what the robot is trying to convey. These techniques alone, however, can only provide a limited view of the holistic HRI experience.

3.2 Personal Experience and Context

Evaluations that focus on personal experience and context often aim to describe and unpack interaction experience rather than to explicitly measure it. As part of this, some argue that it is important to accept the complex, unique, and multi-faceted nature of experience (perfect understanding is perhaps impossible [47]), and evaluation should aim to find themes and in-depth description of the complexity [4, 30, 33].

This stance can be used to explicitly recognize the holistic and embodied nature of interaction with robots

and we can leverage many of the related data collection and analysis techniques toward this goal. In fact, an emerging body of work in HRI considers interaction as a holistic and contextual experience that considers such things as how a robot affects a person’s feelings or how it meshes into existing social structures (exemplified in [20, 35, 48, 49]).

This approach commonly uses qualitative-oriented techniques such as thick, detailed description based on participant feedback and interviews (e.g., [52]), collecting multiple viewpoints (perhaps across participants), or for example through more-structured approaches such as grounded theory [47], culture or technology probes [24], or contextual design [5]. Longer-term interaction or interplay with social structures and practices are often targeted with in-situ, context-based ethnographic (e.g., [10]) or longitudinal field studies (e.g., [20, 49]).

Another important consideration in relation to wider context is the idea that each person and their experiences are unique. This means that rather than trying to find an average user, context-sensitive evaluation should perhaps value that individuals have unique, culturally-grounded experiences, and evaluators should take care when generalizing any affective experience across people [6, 47]. Further, the evaluators themselves will have similar culturally-rooted personal biases towards the robots, participants, and the scenario, which, some argue, is unavoidable should be explicitly considered and disclosed with the evaluation analysis [47].

While these approaches consider the holistic and complex nature of HRI experience, we maintain that there is a need for specific structure and methodology that takes techniques such as these and applies them to exploring the HRI experience.

3.3 Emotion and Social Norms

Some research in HCI specifically targets socially-situated interactions between people and computing technologies. One such area is affective computing, which explores how interaction with an interface influences the emotional state, feelings, and satisfaction of the person [41], whether through deliberate design (e.g., [4]) or as an incidental artifact of interaction (e.g., [33, 41]).

One approach to evaluation of affective interaction, for example, monitors heart rate, blood pressure or brain activity, or measures the number of laughs, number and duration of smiles, and so forth [13]. These methods can serve to quantify the difficult-to-quantify social-oriented aspects of interaction such as types and

amounts of emotion, affect, or social involvement. However, evaluators should note the limitations incurred when using such methods. Arguably, ability to understand the rich and multi-faceted nature of social interaction will be limited when they are simplified and reduced to a set of external quantities and discrete categories [33, 47].

Other affective-computing approaches attempt to focus on participant self-reflection, where people directly report on their experience with an interface and how it makes them feel (e.g., see [4, 6, 30, 31]), for example, via interviews or questionnaires. This has the added benefit of accepting participants as expert evaluators of emotion, social interaction, and more. Sometimes, creative or artistic techniques are used to help people reflect on aspects that are difficult to express with words. One such example is the sensual evaluation instrument [33, 44]: during interaction, people handle a set of abstract, molded props that represent emotional states, and are later asked use the props as memory aids and descriptive tools for their experience. Self-reporting, however, has the complication of often being done in retrospect (after, not during, an experience) and relies on people understanding their own emotions and being confident enough (i. e., not shy) to discuss them.

Finally, when dealing with social norms the observer effect can be particularly powerful when interacting with robots: when evaluating interaction between a person and a robot, consider how observation would influence the same interaction between people. For example, interaction between a boss and a worker may change when they are being videotaped – the same change may happen between a person and a robot.

3.4 Frameworks for Unpacking the Interaction Experience

So far in this section we discussed how existing evaluation methods and techniques are used to help target the holistic and contextual nature of HRI, and highlighted some of their current limitations within the HRI context. Complementary to this, evaluators can use frameworks as a means of dissecting this holistic, complex whole into more-targeted and focused units, or perspectives. Further, frameworks can provide vocabulary as a comparison tool, and can serve as sensitizing tools to help evaluators focus on particular concepts. In terms of HRI, then, we need frameworks to help consider such concepts as personal comfort, internal emotional experience, and social integration.

One common (and relevant) example in HCI is Norman’s three-level framework for analyzing how people

interact with and understand everyday objects (products, in this case), with an explicit concern for emotion [40]. This highlights the stages a person may go through when dealing with a product over time. Closer to HRI is the social considerations of human-robot awareness, specifically, the awareness (understanding) that both the people and robots have of the social structures and activities within a group [17]. Perhaps the most explicit social interaction framework for robots is the classification of robots based on their socially-charged design characteristics and capabilities [7], although this does not explicitly consider the wider context or the more-general social interaction that may occur.

In our research we have found very little work that explicitly attempts to target the holistic, socially- and physically-embedded nature of interaction with robots. We call for new tools and frameworks to explicitly target these concerns and to aid designers and evaluators alike in their creations, evaluations, and discussions. As one attempt at this problem, in the following section we present a new framework for considering the social interactions between people and robots, and the wider context within which it happens.

4 Three Perspectives on Social Interaction with Robots

Here we present a new set of perspectives, or lenses, on social interaction with a robot which can provide a means to shape thinking toward a more holistic, socially-oriented view of interaction experience with a robot. These perspectives serve as sensitizing concepts and form a new vocabulary that encourages investigators to focus more on unpacking the emotional and social aspects of the interaction.

4.1 Introducing the Perspectives

We categorize social interaction into three perspectives: visceral factors of interaction (e. g., the immediate, automatic human responses), social mechanics (e. g., the application of social languages and norms), and the more macro-level social structures and work practices related to interaction.

Perspective One (P1), visceral factors of interaction, focuses on a person’s biological, visceral, and instinctual emotional involvement in interaction. This includes such things as instinctual frustration, fear, joy, happiness, and so on, on a reactionary level where they are difficult to control.

Perspective Two (P2), social mechanics, focuses on the higher-level communication and social techniques, mechanics, and signals used in interaction. This includes both the social mechanics that a person uses in communication as well as what they interpret from the robot throughout meaning-building during interaction. Examples range from gestures such as facial expressions and body language, to spoken language, to cultural norms such as personal space and eye-contact rules.

Perspective Three (P3), social structures and work practices, covers the development of and changes in the social relationships and interaction between two entities, perhaps over a relatively long (in comparison to P1, P2) period of time. This considers the changes in or trajectory of P1, P2, as well as how a robot interacts with, understands, and even modifies social structures such as family cleaning practices.

These three perspectives are not a hard-line categorization of the various components of interaction, or a linear progression of interaction over time. Rather, interaction happens simultaneously and continuously from all three perspectives, and there is crosstalk between the perspectives for any given interaction – these categorizations provide perspectives on this complex relationship.

Given a particular robot, interface, scenario, or research question, certain perspectives may be of greater interest than others. However, we contend that components of all three perspectives exist in any interaction between a human and a robot. This means that not explicitly considering a particular perspective will limit the view of the interaction scenario and should be done with care.

4.1.1 Perspective 1 – Visceral Factors of Interaction

People have many visceral-level, perhaps largely instinctual, reactions to the world around them. These reactions are often difficult, if not impossible, to quell or restrict. Some of these reactions are nearly universal to all humans, such as smiling when happy, while others are cultural or individual-oriented such fear of insects or particular associations such as having a positive response to a Christmas theme. Many of these reactions are entirely internal, with very little or no outwardly noticeable effect, while others such as recoiling from a spider are very externalized in their expression. Interaction continues to occur on this level even for continued, engaged or long-term interaction.

This perspective of human reaction to the world is a very powerful and important part of the user experience of interaction: fear, happiness, excitement, dread,

and so forth, can have a large impact on the overall interaction experience. This is particularly relevant when considering social interaction with robots, given the active agency and unique situated and contextual nature. One example of robots that have a strong P1 component are those that focus primarily on eliciting emotional reactions as an important component of interaction (e.g., [1, 2, 29, 37, 55]).

4.1.2 Perspective 2 – Social Mechanics

Social interaction, whether it be with another person, an animal, or a robot, consists of an extremely diverse set of explicit social signals, responses, and other communication techniques. People are very good at interpreting social-level communication, and as such, robots are often designed to explicitly communicate using these techniques, such as by using programmed voices, facial expressions, and so forth. Further, people often see social communication where there is none intended, particularly with robots that elicit a sense of agency, and often attribute human-like gestures, expression, and so forth. For example, people may say that a slow robot is not interested or is lazy, interpret a robot that moves erratically as trying to show its anger, or a robot that avoids people to be shy.

The tone and inflection of robot interaction techniques, whether explicitly intended to be social or not, play a crucial role in how people form their overall opinions about a robot and about their interaction experience with it. This layer of interaction provides an important and fundamental part of the overall social interaction experience, where seemingly localized design decisions can taint the overall impression. For example, one robot that debates using jerky (perhaps violent) hand gestures may be received quite differently from another that uses smooth (perhaps docile) ones, or if the robots used a monotonous or bored versus excited voice in their statements.

Examples of robots that leverage P2 interaction are those that both try to use and understand human-oriented and perhaps culturally grounded interaction techniques to communicate with people (e.g., [25, 26, 46]).

4.1.3 Perspective 3 – Social Structures and Work Practices

Social interaction with a robot extends well beyond an easily definable “interaction session.” Over a period of time, attitudes toward a robot, responses to given interaction scenarios, and the overall interaction experience itself will vary and evolve. One Example of this is a

novelty factor, where interaction can become less interesting and we become less tolerant of mistakes with time. Others include a learning curve, where perception of difficulty may fall over time, bonding, where people may become more intimate with experience, or an acquired taste, where something which is initially disliked may become more appealing, and eventually liked, with time.

This perspective also considers the role that the robot plays in the social structures of the home. The simple existence of the robot, in addition to its design and behavioral characteristics, have an impact on the greater structures of the home [54]. For example, adopting cleaning-robot technology may shift who is responsible for the cleaning duties [20], a personal-assistance robot can be very empowering, and there is also the possibility of the robot being attributed moral rights and responsibilities of its own [21]. This effect can happen whether explicitly designed for or not [54].

Robots that explicitly leverage P3 interaction are rare, perhaps due to the complexity of attempting to interpret and interact within such a wide, complex context. However, it is becoming common to study P3 as these effects still exist regardless of a robot’s ability to interpret or interact on this level (e.g., [19–21, 49, 50]).

4.2 Applying the Three Perspectives

In this section we give an example of how the new perspectives can integrate into a simple, complete evaluation process. The three perspectives form a component of evaluation design and serve as a set of tools, or lenses, that can help to explore, unpack, and analyze the social components of interaction between a person and a robot.

The core of our application revolves around a preliminary effort of using the three perspectives to map out the experimenter’s expectations of the interaction possibilities. This approach is reminiscent of cognitive walkthroughs from HCI, and such a map helps an experimenter to consider alternative participant interpretations, reactions, and perceptions of a robot, and how they relate to the design of the robot. All of these considerations are in relation to the social components and context of interaction. This exploration then provides a base from which the evaluation itself can be designed, and a resource to be used when analyzing the collected data.

4.2.1 Mapping Interaction Experience Possibilities

As a base for this exploration, we present a view on HRI as outlined in Fig. 2. This is a simplification of

Fig. 1's holistic view on interaction experience, with the three perspectives added as a structural framework. All three perspectives on interaction experience, then, can be viewed from the human or the robot. The human-centric view considers how the person feels about, approaches, and interprets the interaction experience. The robot-centric view considers how the robot itself, in-

cluding its design, behavior and actions, influences the experience.

Following, in Fig. 3 we present a process that can help develop and create a map of experience possibilities in relation to the design of the robot. The key points of this process are that a) both the human- and robot-centric views are explicitly and simultaneously considered, and b) the three perspectives serve as direct brainstorming and sensitizing tools.

The map-building happens in an iterative and exploratory manner, where the three perspectives prod the experimenter to consider the targeted facets of interaction. For the human-centered view, we start by brainstorming possible interaction scenarios which may happen in regards to the particular robot or interface. Then, we begin an iterative process where we encourage the experimenter to consider experience possibilities within the given scenarios, focusing on the three perspectives. This is followed by an explicit consideration of alternate experience possibilities, and finally by building the alternate experience possibilities back into new interaction scenario possibilities.

Simultaneously, a similar process is followed for the robot-centered view. First, the experimenter brain-

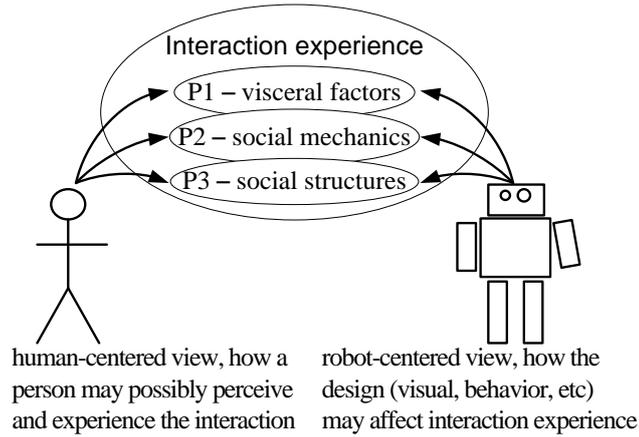


Fig. 2 interaction experience, mutually shaped by two active agents: human and robots

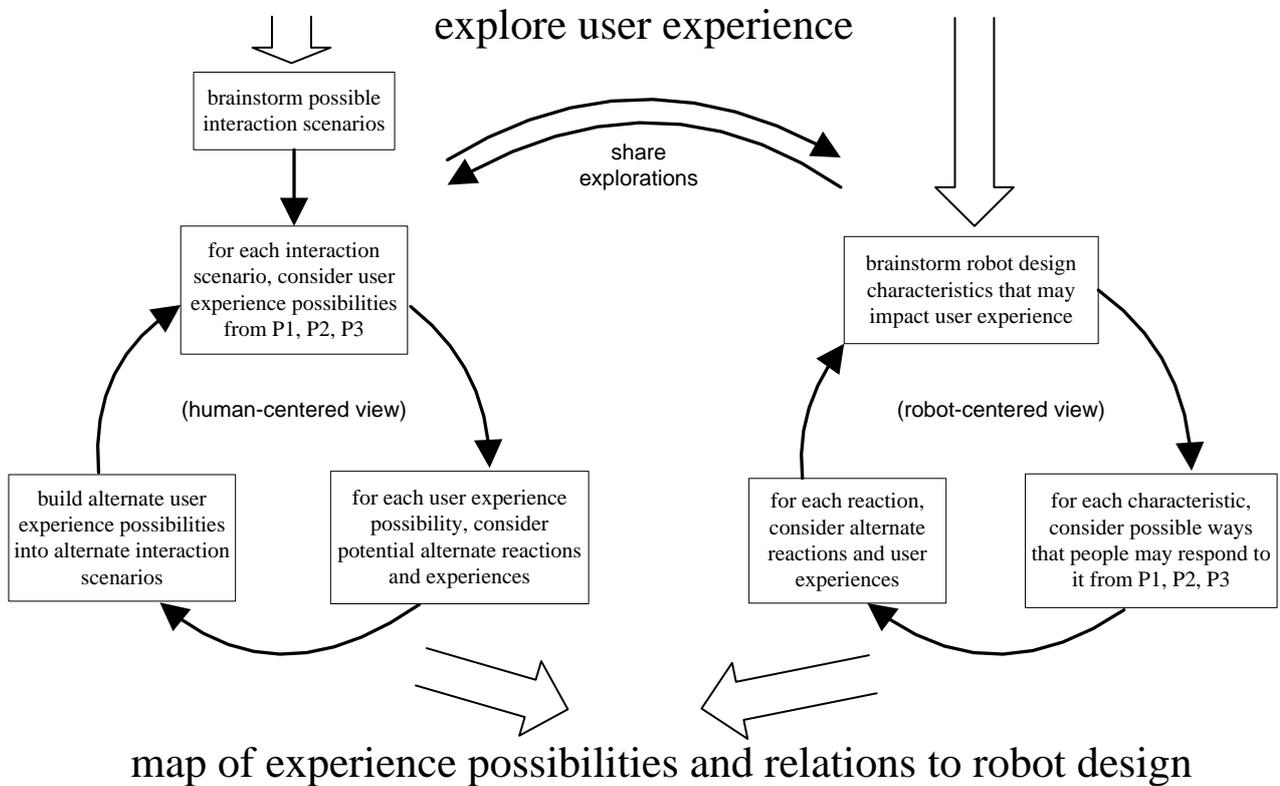


Fig. 3 example process of using the three levels to fuel an exploration into experience possibilities

storms robot design characteristics that they expect may influence the interaction experience. Then, for each characteristic, the experimenter considers how people may react to it (and thus, how it may influence the interaction experience) explicitly from the three perspectives. Finally, for each reaction possibility discovered above consider alternate ways that the interaction experience may be affected. Finally, use the alternate experience possibilities to re-think and re-brainstorm which characteristics of the robot may impact experience.

As both processes should happen simultaneously, then new discoveries and ideas from one process will be used in the other process, and vice versa. Further, this process could conceivably yield a very large map and become unwieldy, and it is up to the judgment of the experimenter to decide which possibility trees to cut. Further, it is important to remember that the resulting map is grounding only within the experimenter’s own sense of judgment, a fact that must be considered honestly.

The overall result of this process is a very comprehensive set of socially-focused and context-aware considerations on interaction experience possibilities, how they relate to interaction scenario possibilities, and how they potentially relate to robot design and a robot’s social affordances.

4.2.2 The Wider Interaction Picture

In Tab. 1 we outline how the experience possibilities map, and the three perspectives themselves, can be incorporated into a complete evaluation. The table is organized into rough phases of evaluation (columns) and components within each phase (rows). The first phase (explore) is taken care of by the creation of our experience map (process given in Fig. 3), and serves as a resource from which to start designing and conducting the study itself.

The experience map and the three perspectives can be directly used in the design of the evaluation itself (Tab.1, “evaluate” column). The map can be leveraged

in hypothesis building, where the perspectives can be used to build socially-targeted questions and experiment tasks.

For the analysis of the evaluation results, the three perspectives form a powerful vocabulary that can be used to dissect and discuss the observations (Tab.1, “analysis” column). Further, the experience map can be used to hypothesize about perhaps unexpected results, and can be also used as, for example, a start for a coding scheme.

Overall, we have shown how the three perspectives can be applied to explore the interaction experience possibilities from a holistic and social standpoint, and, how the resulting map and the levels themselves can prove to be useful tools for design of an evaluation and the analysis of the results.

5 Future Work

Our new set of perspectives is but one tool for exploring HRI, and there are still yet many concerns not covered here. For one, given the environments within which robots will work, there is a need for tools to help with the explicit consideration of robot-group interaction (or groups of robots – human interaction), including the underlying social activities – perhaps our three perspectives could be extended for explicit group consideration. Similarly, it may be useful to explicitly consider the impact that a robot will have on an environment beyond the social structures, for example, as with roombarization [49] where homes may be physically modified to accommodate the robot.

Our current three levels focus on a person’s interaction experience, but it can be interesting to consider how a robot could use a similar approach in its evaluation of a social expectations and social impact.

6 Conclusion

Robots, by their very nature, encourage social interaction and create a very unique interaction experience for

	explore (pre-study)	evaluate (conduct the study)	analysis (post-study)
phase	explore the experience possibilities in relation to design of robot	design evaluations that target user experience	analyze study data with a focus on user experience
process	leverage P1-3 to consider experience alternatives and possibilities	use experience possibilities map in hypothesis building, leverage P1-3 in developing targeted evaluation	use experience possibilities map to develop coding system and exploration hypotheses, leverage P1-3 as vocabulary to dissect as well as explain data
results	map of user experience possibilities and how they may relate to design of robot	evaluation task, questionnaires and interviews, experience hypotheses	study results grounded in user experience, with explicit focus on interaction through P1-3

Table 1 integration of P1, P2, P3 into an evaluation framework

people. The exact mechanics behind this phenomenon are perhaps yet unknown, but we argue that it is related to how robots encourage anthropomorphism and create a unique sense of active agency.

While the fields of HCI and HRI provide many well-tested evaluation techniques, we are concerned about how these should be applied to HRI in a way that acknowledges and targets its holistic and contextual nature. As such, we call for this question to be explored and for researchers to devise techniques and methods that explicitly target the unique properties of HRI.

In this paper, we have presented one such tool in the form of a new set of perspectives that evaluators can use to help target the social and contextual nature of HRI. Further, we have demonstrated how this tool can be integrated into an evaluation framework to be used directly in the process of designing and conducting an evaluation.

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