From Beeping Machines to Caring Companions: Redesigning Social Robots Through Reflective Ethnography in Elderly Care Work

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Roboticists have long focused on areas far removed from everyday human work practices, raising questions about the usefulness of robots in various domains. An ethnographic study can help bridge this gap, but while there are some studies on human-robot interaction (HRI), many of them explore the relationship between ethnographic work and robot development without considering ethnographic reflexivity. This paper reports on a heterogeneous team involved in an elderly care project utilizing a pre-programmed social robot. Through a pragmatic inquiry lens, we iteratively improved the design of the robot systems as part of the research process. Our surprising findings reveal that the robot alone cannot fully support care work, and the design of the 'robotic' must extend beyond the robot itself and human-robot interaction. Instead, robot-assisted care work should focus on the design of the entire information technology system, of which the robot is only one component. This study highlights the need for real-life, user-centered, and pragmatic research, offering an exemplary account of how pragmatism can serve as a sensitizing framework for the HRI field.

CCS Concepts: • **Human-centered computing → HCI theory, concepts and models**;

Additional Key Words and Phrases: Pragmatic social robot, Wizard of Oz, Ethnographic reflexivity, Heterogeneous team

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1 Introduction

Contemporary CSCW research faces a fundamental challenge: how to reconceptualize "collaboration" itself in increasingly complex socio-technical systems. As social robots quickly integrate into collaborative environments such as elderly care [6, 14], the gap between CSCW theoretical insights and practical design implementation is becoming more apparent.

This gap reveals the knowledge divide between CSCW and HRI research, reflecting the fundamental differences in research methodologies: HRI tends to adopt a laboratory-centered design

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paradigm, focusing on the interaction evaluation of controllable variables [62, 77, 89, 92]; whereas CSCW emphasizes the social embedding of work practices, focusing on how technology coordinates distributed cognition and collective action [3, 40, 72, 84]. Although CSCW has made significant contributions to understanding the socio-technical nature of collaboration, these theoretical insights have yet to be effectively translated into actionable design principles [22, 79], leading to a disconnect between technology design and real work practices.

The research by Moharana et al. [49, 57] highlights a specific manifestation of this problem: advanced technologies developed for dementia patients, although performing well in laboratory environments, become "island technologies" that fail to integrate into the complex care ecosystem in real caregiving practices. We conceptualize this phenomenon as a "failure of collaborative knowledge translation," resulting from the inability to effectively preserve, translate, and integrate contextual knowledge from work practices during cross-disciplinary design processes. Meanwhile, emotional expression, as a core element of human collaboration, is particularly important in cross-boundary collaborations, yet it has not received sufficient attention in current research [78]. Takayama [83] points out that robotics research must shift towards a "transformative science" paradigm, which first requires addressing the crisis of transformation within CSCW: how to translate collaborative knowledge from observation to design, from theory to practice?

This study focuses on the design of emotional expression in social robots, exploring how to coordinate knowledge transformation and collaboration between heterogeneous teams (HRI researchers, roboticists, elderly people, and caregivers) through a reflective ethnographic approach. Thus, our core question becomes: How can we effectively bridge knowledge gaps when designing caregiving robots for heterogeneous teams, and what can we do to support meaningful human collaboration? To unfold the research questions, we explore two interrelated sub research questions:

- How can knowledge gaps between different professional fields be effectively bridged through ethnographic methods of reflection when designing care robots with heterogeneous teams (i.e., HRI researchers, older people, robotics experts, and care workers) to avoid the problem of "island technology"?
- How can care robots be designed to support meaningful human collaboration by integrating the different needs of stakeholders, addressing privacy concerns, and fostering trust?

To explore these issues, this study examines the "Maru" robot project as our research object [46, 70]. Maru, originally designed in Japan in 2015, reflects and conveys human emotions through multimodal channels such as sound, color, and vibration. In this study, Maru functions not only as a technological entity but also as an epistemological tool that enables a reevaluation of traditional collaboration concepts in CSCW through multimodal emotional expression practices [81]. Maru facilitates the knowledge transformation process between designers and users. We observe that assistive technologies need to adapt to users' existing flow of work[68] rather than requiring reconfiguration of work practices around the technology, which is particularly critical in sensitive environments such as healthcare [4, 20, 43].

This study integrates Dewey's (1938) pragmatist epistemology with coordination mechanisms theory to construct the "practice-transformative coordination" analysis framework [30]. This framework emphasizes that technology should be evaluated based on actual usage environments and designed to meet real needs rather than technological possibilities. The design process should focus on how technology changes existing practices. Unlike traditional HRI approaches, we adopt a "reverse engineering[34]" method from CSCW perspective, deriving technical requirements from users' actual work practices. Given that, we employ an "interventional ethnography" research approach [23, 24], positioning the researcher as a knowledge negotiator, actively participating in and recording the transformation of knowledge between different professional domains. In collaboration with the "Wizard of Oz" (WoZ) team, the technical prototype becomes a knowledge transformation object, prompting different participants to reassess and adjust their professional practices through interactions with the technology [4, 20, 36, 50].

Based on this theoretical framework, this study makes three fundamental contributions:

(1) It proposes a systematic approach to translating users' natural work practices into system design elements. This ensures that technology truly serves and supports the flow of work of elderly care, providing an actionable framework for incorporating work practices into the early stages of design.
(2) It offers a "pragmatic" perspective, with a particular emphasis on maintaining the continuity and naturalness of flow of work in care work environments.
(3) The case of the Maru robot illustrates the generalizability of the present work and its potential impact on actual design processes, offering a methodological demonstration for future research.

The paper is structured as follows: Section 2 introduces related works; Section 3 presents our pragmatic inquiry framework. This framework should not be read as a prescriptive guide for this project; instead, it is a philosophical presentation to help readers better understand our theoretical analysis of robot design. Section 4 presents the case of Maru and its emotional expression capabilities for interacting with elderly people and caregivers through three rounds of WoZ studies and design workshops. Section 5 details our methodology, including data collection and analysis approaches. In Section 6, we present our findings. Section 7 discusses the implications of our research for CSCW and HRI fields. Section 8 concludes by summarizing key contributions and suggesting directions for future research.

2 RELATED WORK

This study focuses on the design of emotional expression in social robots, particularly how to coordinate collaboration and knowledge translation between heterogeneous teams in elderly care environments. The following related work builds our research foundation from four interrelated perspectives: the differences between CSCW and HRI research paradigms, the application of pragmatism in collaborative design, the value of the WoZ method in interaction design, and the central role of emotional expression in coordination mechanisms.

2.1 From Laboratory to Practice: Differences Between HRI and CSCW Research Paradigms

There is a fundamental difference between contemporary CSCW and HRI research, which directly affects the design and application of social robots. HRI research traditionally adopts a laboratory-centered paradigm, focusing on a binary interaction model between humans and robots. Although this approach has advantages in controlling variables, it struggles to capture the dynamics of collaboration in complex social environments. A review by Lee et al. [50] of ACM/IEEE HRI papers from 2006 to 2021 found that humans often play limited and interchangeable roles in robot design processes, reflecting insufficient attention to the social dimensions in HRI research.

In contrast, CSCW research emphasizes the social embedding of technology in work practices. The pioneering work of Schmidt and Bannon [75] highlighted that understanding the social complexity of collaborative work is crucial for designing supportive technologies. This view provides a more comprehensive framework for understanding the role of social robots in care environments, seeing robots as technologies embedded in complex social networks rather than simple one-on-one interaction tools.

In recent years, some researchers have attempted to bridge this gap. Carros et al. [18] used the WoZ method to study the application of the Pepper robot in elderly care, focusing on how robots integrate into existing caregiving practices. Blond [8] positioned HRI as an ethnographic approach, studying robots' application in elderly care in Denmark, finding that combining empirical research with ethnographic methods deepens the understanding of robots' adaptability. These studies offer important insights: the practical value of robots depends on how they integrate into specific social environments and work practices.

However, current research still has significant limitations: first, most studies focus on a single stakeholder group (e.g., engineers or users) and rarely explore the collaboration dynamics between heterogeneous groups; second, key factors such as privacy protection, trust-building, and diversity considerations are often overlooked in the design process; and most importantly, there is a lack of effective mechanisms to translate CSCW's theoretical insights into HRI design practices. As Breazeal [12] pointed out, advanced technologies developed for dementia patients, while performing well in laboratory environments, become "island technologies" that fail to integrate into the complex caregiving ecosystem in real practice. This "failure of collaborative knowledge translation" directly inspired our research question: How can we establish effective translation mechanisms between heterogeneous knowledge systems to avoid the "island technology" problem?

2.2 Pragmatist Perspective and Collaborative Design

To address the above challenges, we turn to pragmatist philosophy for theoretical guidance. Dewey's pragmatist philosophy emphasizes the central role of experience, interaction, and continuous reflection in knowledge construction, which aligns closely with the CSCW theoretical orientation focusing on collaborative knowledge construction. Hickman [37] extended Dewey's ideas by defining technology as "all intelligent technologies, through which natural and human energies are guided and used to meet human needs." This definition provides important insights: robots should not be viewed as technological artifacts independent of the social environment, but as tools embedded in specific social practices, whose value depends on how they support human activities.

This pragmatist perspective provides three concrete guidelines for the design of social robots: first, design should start from meeting actual needs rather than technological possibilities; second, technology evaluation should be based on performance in the real usage environment rather than laboratory tests; and third, the design process should focus on how technology transforms existing practices, not simply automating existing workflows. These principles are highly consistent with CSCW's emphasis on technology adapting to and improving work practices, providing the theoretical foundation for our proposed "practice-transformative coordination" analysis framework.

In CSCW, pragmatism has been applied in various design contexts. Pitsch et al. [66] applied Dewey's concept of "inquiry" to museum interaction design, viewing interactive exhibits as tools that promote visitor inquiry rather than merely conveying information. Ljungblad et al. [52] and Ljungblad et al. [52], based on Dewey's pragmatic aesthetics, proposed the "technology as experience" framework, emphasizing that the use of technology is a holistic experience that includes emotions, sensations, and meaning construction. These studies offer new perspectives on understanding the role of social robots in care environments: robots are not just service providers but also tools that support collaborative inquiry.

However, as Wulf et al. [91] noted, translating pragmatist principles into specific design requirements remains a challenge, particularly in cases involving heterogeneous team collaboration. This challenge is directly related to our second research question: How can we design caregiving robots that integrate the needs of different stakeholders, address privacy issues, and build trust, thereby supporting meaningful human collaboration?

2.3 The WoZ Method and Heterogeneous Team Collaboration

In exploring the above issues, the WoZ method becomes an important bridge between theory and practice. The WoZ method allows designers to evaluate design concepts before committing substantial development time, making it particularly suitable for exploring designs that combine complex social environments and intelligent control. Frennert et al. [33] proposed three requirements for effective WoZ: the ability to simulate future systems under constraints, specify the behavior of future systems, and make the simulation convincing. These principles provide guidance for using the WoZ method to design social robots.

From a pragmatist perspective, the WoZ method embodies Dewey's "learning by doing" philosophy by testing and refining design hypotheses through simulated interaction scenarios. Dourish and Button [28] viewed WoZ as a tool in iterative design processes rather than just a research method. In our study, WoZ was not only used to test interaction design but also as a medium to facilitate collaboration among heterogeneous teams, helping members from different backgrounds reach consensus around specific interaction scenarios.

This use directly relates to the concept of "boundary objects" proposed by Sokolova and Fernández-Caballero [80]. Boundary objects are artifacts that help establish consensus between different social worlds; they are flexible enough to meet the needs of different communities while maintaining enough consistency to preserve identity. In our research, the WoZ-controlled Maru prototype serves as a boundary object, facilitating knowledge sharing and negotiation between robot experts, HRI researchers, elderly people, and caregivers.

This method is particularly effective in addressing the challenge observed by Pan [64]: that CSCW researchers and maritime engineering researchers have different understandings of interacting with machines—engineers tend to view users as system components, while CSCW researchers focus on the social dimension of interaction. By using the prototype in the present work, we facilitate "dialogue[67]" between participants with different professional backgrounds, establishing consensus on design goals and methods.

2.4 Emotional Expression as a Coordination Mechanism

A key practical contribution of our study is to reconceptualize emotional expression as a core element of coordination mechanisms rather than a peripheral factor. Traditional CSCW research tends to view emotions as background elements of collaboration, focusing on information exchange and task coordination. However, recent studies suggest that emotions play a more central role in collaborative knowledge building.

In elderly care environments, emotional communication is particularly important. Caregiving practices inherently involve emotional labor, including emotional expression, recognition, and response. When social robots enter this environment, they must be able to participate in this emotional exchange, not just perform functional tasks. However, as shown by Šabanović [71], emotional expression has different meanings and functions in different cultural and social contexts. For example, Japanese users tend to accept more subtle emotional expressions, while Western users expect clearer emotional signals.

Our Maru robot study particularly focuses on the multimodal practice of emotional expression—expressing and perceiving emotions through visual, auditory, and tactile channels. This multimodal emotional expression not only enriches the human-robot interaction experience but more importantly, it becomes a mechanism for coordinating different activities and roles. Emotional expression becomes an important medium for building consensus and coordinating actions between robots, elderly people, and caregivers.

Closely related to emotional expression are trust and privacy issues. In elderly care environments, building trust requires considering multiple layers: trust in technological reliability, trust in data processing, trust in social roles, and moral trust. Hyland et al. [41] demonstrated that trust is based on perceptions of a technology's ability, honesty, and kindness. For social robots, ability refers to the capability to perform expected functions; honesty refers to transparency in data processing; kindness refers to whether the design prioritizes user welfare. Similarly, privacy is not just an individual concept but a socially constructed result. Norman [58]'s "contextual integrity" theory argues that privacy expectations depend on the norms governing information flow in a given social context. In elderly care environments, this means privacy design must consider the expectations and needs of multiple parties (including elderly people, caregivers, family members, and institutions).

Finally, the design process itself must consider diversity and inclusivity. The "feminist HCI" framework proposed by Beneteau et al. [7] emphasizes that the design process should challenge power inequalities and promote diversity. In our study, we particularly focus on ensuring that robot designs reflect the needs and preferences of different stakeholders in caregiving work, including those who traditionally lack technical voice, such as elderly people and caregivers.

2.5 Recap of Related Work

Through the above related work, we decide to combine CSCW's emphasis on social embedding with HRI's focus on interaction design, grounded in Dewey's pragmatism, using the WoZ method as a bridge between theory and practice, and conceptualizing emotional expression as a core element of coordination mechanisms. In the next section, we will detail our research framework and explain how we applied this framework to the design practice of the social robot.

3 PRAGMATIC FRAMEWORK AS THEORETICAL LENS

3.1 Ethnographic reflexivity as pragmatic inquiry

In the article When Second Wave HCI Meets Third Wave Challenges, Susanne Bødker [9] argues that the emotion concerning design and HCI has been promoted, for example, by Norman as the next wave emerging from the traditional cognition, short-circuiting the second-generation Human-Computer Interaction. However, Norman's research seems to limited by his cognitivist paradigm, which means that he sees emotions as mere add-ons to cognition [58]. Boehner et al. [10] tackle the topic of emotion from a social, interactionist point of view, arguing that the meaning in emotion is generated by the interaction of people. Therefore, emotion is understood and often modified by interactions with others rather than presents individually developed experience. This understanding has existed for a long time. A decade ago, Chris Johnson [44] showed that HCI had to blend the traditional techniques of scientific empiricism with the increasing amount of pragmatism. He foresaw that HCI practitioners would have to abandon their usability labs and follow users from their offices in pubs, clubs, and streets. Anthropological and ethnographic qualifications are likely to remain common requirements until it becomes possible to derive pragmatic design requirements from the studied domains. However, it is not sufficient to provide increasingly detailed analyses of previous failures [64, 69]. To make the design of robotics useful, pragmatism must play a role in the HRI field.

By definition, pragmatism looks at science and philosophy for the opportunities to offer individuals and enable them to find meaning in their lives—pragmatism's disavowal of metaphysical levels excludes absolutes and certainties. John Dewey [26] states:

"'Technology' signifies all the intelligent techniques by which the energies of nature and man are directed and used in satisfaction of human needs; it cannot be limited to a few outer and comparatively mechanical forms. In the face of its possibilities, the traditional conception of experience is obsolete."

Thus, technology is related to invention, development, and cognitive deployment of tools and artefacts to bear on raw materials and intermediate stock parts with a view to resolve perceived problems [37]. In this light, robot design and robot use are evolutionary products: they are evolved from non-instrumental, non-artifactual behavior in ways that appear continuous when seen in retrospect, even though they are probably cases along with the way [54]. Experience resides in neither the person nor the situation but in the interaction between them; therefore, experience is not the mind or a product of subjective perception, and metaphysical dualisms are not applicable here.

When discussing robot design, our purpose is not to evaluate whether elderly people can confirm our proposed interactive patterns; rather, they are expected to express their needs as part of their experience of interaction with Maru. Moreover, the social robots in use are a phase of experience for HRI researchers, as well as elderly people, roboticists, and caregivers. Social robots can be used by a heterogeneous team to enhance their perception of elderly care work as the way heterogeneous teams experience the world is increasingly technical [37, 54]. This understanding of experience is in line with the ethnographic fieldwork, where ethnographic reflexivity as an inquiry was used to outspeak the practice actions and reasoning of the participants in relation to the use of technology. The purpose is to make the invisible work practices of technology use visible to all members of heterogeneous teams, which is likely to be within the expectation of Schön [76], who, acknowledging Dewey's influence, stated that no design theories had incorporated pragmatism as a foundation, especially not with respect to interaction design:

"When someone reflects in action, he becomes a researcher in the practice context. He is not dependent on the categories of established theory and technique but constructs a new theory of the unique case. His inquiry is not limited to a deliberation about means, which depend on a prior agreement about ends. He does not keep means and ends separate but defines them as interactivity as he frames a problematic situation. He does not separate thinking from doing, ratiocinating his way to a decision, which he must later convert to action. Because his experimenting is a kind of action, implementation is built into his inquiry" (p. 69).

Thus, our way of utilizing pragmatism is in line with most ethnographic studies conducted throughout the design work, providing crucial details about specific situations and practices, yielding both design artefacts and systems that are a better fit and more sustainable within their own context [68], and creating new knowledge about interaction design [39, 86]. In light of this, HRI researchers who have interests in HRI studies are an inquiry, experimentalism judgments, and interpretation. Prior researchers, for example, Chris Johnson [44], warned that blending the traditional techniques of scientific empiricism with increasing pragmatism.

In the present work, we focus on when, how, and what should be considered in the design process of HRI, applying pragmatism to facilitate the collaboration of all stakeholders on practical reasoning and actions in elderly care work. Therefore, we followed three layers of the pragmatic framework (the experience layer, the inquiry layer, and the action layer), which are similar to pragmatism in the interaction design research [23]. However, we diverge from Dalsgaard in the sense that we have no intention to classify the principle of design based on democracy, psychology, moral, ethics, logic, experience, and art, as Dalsgaard did. Instead, inspired by Höök and Löwgren's strong concepts [39], our ideas on HRI study in elderly care started from a knowledge-construction process. Thus, the goal of the experience layer was to analyze interaction as performance that complements other approaches to yield techniques which can be useful in designing sociotechnical materials. Most importantly, this analysis produces what Höök and Löwgren called "intermediate-level knowledge," or generative knowledge, for reflective practices. It is of little importance whether our work can be generatable; the essential point is that the experience of researchers shed light on the need for the pragmatic inquiry layer to propel the design process in and across the design groups of our project, i.e., the HRI researchers, roboticists, elderly people, and caregivers. To facilitate collaboration among the stakeholders, the inquiry layer must make the accounts of actions and reasoning of the participants using Maru visible to all, especially roboticists. That is why we implemented ethnographic reflexivity in the executive stage, making a step toward robotic system design using the WoZ-supported iterative design process [29].

This strategy is in line with the work of HRI studies, in particular in Europe, which have been able to articulate and analyze performative knowledge gained through the experience in the researched context. Inspired by the previous insights, we believe this effort makes it possible to iterate the use of Maru in elderly care work and develop Maru through design development as a complete reverse engineering process to explore new design spaces for the use and reuse of existing systems to better support elderly people and caregivers. Reporting and discussing the challenges of interpretive empirical research related to everyday life can provide a bridge to address the core of designing robotics systems through fieldwork materials. The profound relationship between ethnography and design is not only at the analytic level [27]; rather, it rules out the relevance of corresponding responsibility of roboticists based on what has happened, the constitutive features of what has happened, and what is available in the form of clear accounts. This insight is in line with the research question for this paper. A heterogeneous team's actions can be visible throughout the use of Maru, and such actions must be interpreted through dialogues on the evidence in a pan-social setting across the care giving and care receiving [90] that surrounds the development of Maru. Such dialogues go beyond the purely mental process of the heterogeneous team when designing social robotic systems.

3.2 Wizard of Oz-supported iterative design process

The WoZ prototyping approach is particularly practical in exploring the utility of the design ideas that combine complex social environments and intelligent control logic. Moreover, the WoZ method helps designers to avoid getting locked into a particular design or working under an incorrect set of assumptions about user preferences because it lets them explore and evaluate designs before investing considerable development time that it takes to build a complete prototype. In the HRI community, WoZ is usually used as a purely experimental, or empirical, technique. However, there are methodological concerns over its use and some comprehensive criteria on how to best employ it. As robots tend to move toward being "in the loop" and have increased autonomy in their interactions with humans, it is important that researchers who have interests in HRI studies scientifically employ rigorous practices during the robot design lifecycle.

In HRI research, scholars who employ WoZ argue that because robots are not sufficiently advanced to interact autonomously with people in socially appropriate or physically safe ways, this kind of puppeteering allows participants to envision the nature of future interactions and, as part of the iterative design process, can be used to test early aspects of robots' design that are to be implemented [18]. However, some researchers raise methodological concerns regarding the use of this technique. For social interaction, Weiss [87, 88] suggests that a WoZ-controlled root serves more as a proxy for a human than an independent entity, which makes the interaction human–human–robot rather than just human–robot (personal communication with Professor Dave Randall, March 2, 2022). In the field of HRI, researchers do not have explicit criteria that would guide them in the design of HRI when using WoZ, so many follow Fraser and Gilbert's suggestion [32], according to which for a valid WoZ, at least three requirements must be met: 1) it must be possible to simulate the future system given human limitations; 2) it must be possible to specify the future system's behavior; and 3) it must be possible to make the simulation convincing. From the engineering perspective, Breazeal et al [13] suggest relying on WoZ as an experimental technique, which can make further complicate building robots that would be capable of successfully mitigating errors on their own. Thus, roboticists are consider employing WoZ in a rigorous and repeatable manner, allowing for a smoother transition to warrant a more autonomous and capable system in the future.

Despite the controversy, scholars and scientists seem to have an agreement on the use of WoZ in HRI research. For example, there are discussions on controlling for various aspects of the Wizard's behaviors, such as Wizard recognition variables (Is the Wizard perfect? How is error controlled for?), how fast the Wizard should respond, and whether the Wizard has enough study time to adjust to the envisioned autonomous systems. Although there is general agreement on the use of WoZ in HRI study, there are also some differences. For instance, there are debates on how the level of the robot's autonomy can affect the way humans control the robot, or, in some cases, how to model, simulate, and otherwise account for the actions of the Wizard. Some argue that there is a need to design studies that employ one or more human- or robot-centric experimental techniques throughout the design lifecycle, including not only Wizard of Oz but also Wizard with Oz (a human-centric method that uses real technology in a simulated environment), Wizard and Oz (a human-centric method that uses real technology in a real environment), Oz with Wizard (a robot-centric method that includes humans but does not measure them), Oz of Wizard (a robot-centric method where humans are either simulated or minimally involved), and Wizard nor Oz (all aspects of the system are simulated). However, it seems that HRI research that involves WoZ uses it as a vague term rather than distinguishes it from other methods.

For the present work, WoZ is a natural choice because we needed a low-cost version of a robot that must be flexible enough and can be redesigned quickly. Maru is a fast prototype that was adjusted quickly after placing it into the elderly care work environment. We also wanted to use Maru to facilitate collaboration among the HRI researchers, roboticists, elderly people, and caregivers, simulating possible future systems that could convince not only elderly people but also caregivers and get them to use it. Most importantly, we want to reflect on what we can learn from this HRI study to investigate how HRI insights can be used for HRI research. Therefore, we used Maru as a real technology in a real environment instead of employing a lab-based scenario. Even though our WoZ application can be similar to Wizard and Oz, our purpose is straightforward, focusing on the design process iteratively until we have learned a clear result on how to use emotional expressions in elderly care and established a sense-making process. Thus, our use of WoZ is in line with Dow's application through an iterative design process. Our aim was to incorporate identified the heterogeneous team's practical actions and reasonings, which we learned from ethnographic reflexivity gained by the HRI researchers from the use of Maru in everyday elderly care work, into the improvement of Maru's system. Thus, for us, the Wizard meant mediating the coordination between HRI research and robotics design, and it helped us to pinpoint the problematic areas of Maru's use and translate the possible design space for supporting elderly care and caregiving work. This is important as not all studies on the HRI perspectives intervene in the design of HRI, making sense of HRI studies in-situ. We consider our work a step forward to investigating the usefulness of HRI design that can be perceived as a response to the call of the HRI field, engaging the social perspective of HRI research [83].

4 THE CASE

4.1 Robot Design

The roboticists designed and built a robot prototype for elderly care content based on previous robot Maru [81], as shown in Fig. 1. The roboticists used three visual, auditory and haptic modalities for emotion expression. They chose stimuli parameters based on the following mapping for each modality, as shown in Tab.1. Specifically, for the visual stimuli, different colors represented different emotions, white, green blue and red corresponding to relaxed, happy, sad and angry. For sound stimuli, the roboticists adopted different intensities of flat beep sound for relaxed and happy, and falling and rising beep sound for sad and angry, respectively. For the vibration stimuli, they used different intensities of vibrational stimuli to represent sad, relaxed, happy and angry, from low to high, respectively.

Although the roboticists all agreed on the mappings, they mentioned the possibility that some participants might not ask for these basic expressions as a ground truth. Thus, they decided to treat the basic expressions as assumptions rather than true relationships that are accepted by everyone. Noted that the roboticists suggested using a flat beep sound to express both relaxed and happy emotions as a flat beep sound is unlikely to cause elderly people to act differently in specific contexts. Therefore, to differentiate between the two emotions, the beep sound associated with happiness was made louder as happiness is perceived as being of higher arousal than relaxation [16, 21].

We used a set of labeled codes to represent multi-modality samples.

Tab. 1 shows 12 basic expressions with a unique assigned code: for example, white-color expression was designated as C1, and a falling beep sound was designated as S3. Based on prior literature exploring the relationship between emotions and modalities [15, 48, 74], as well as the study on Mura by Song and Yamada [81], the roboticists identified several key insights regarding emotional expression through different sensory channels: 1) Color was found to be the most effective modality for expressing affection. 2) Auditory cues such as rising and falling tones were relatively easy to associate with emotions like anger and sadness, whereas flat tones were more ambiguous and difficult to interpret. 3) Vibration tended to convey negative emotions; for instance, strong or intense vibrations were often interpreted as anger. 4) Multimodal expression, which combines multiple modalities, was generally more effective and understandable than relying on a single modality alone. In addition, Song and Yamada [81] also indicated possible emotional expressions that could be useful for future research, including C1 (relax), CVS (sad), VS3 (sad), S3 (sad), CV4 (angry), CVS4 (angry), VS4 (angry), and CS4 (angry). However, although the roboticists rebuilt the robot, whether those emotional expressions could be used in elderly care was unclear. Therefore, the HRI researchers were invited to collaborate with the roboticists to redesign the modalities information presented by Mura. Finally, considering to the effectiveness of modality presentation and the size of design space, they determined 28 types of candidate expressions, 12 for basic expression and 16 for mmulti-modality expressions (Tab. 2)

Emotion	**Colour (c)**	**Sound (s)**	**Vibration (v)**
Relaxed	White (C1)	Flat beep sound (S1)	Mildly intense vibration (V1)
Happy	Green (C2)	Flat beep sound (louder than S1) (S2)	Highly intense vibration (lower than V4) (V2)
Sad	Blue (C3)	Falling beep sound (S3)	Low intense vibration (V3)
Angry	Red (C4)	Rising beep sound (S4)	Highly intense vibration (V4)

Table 1. Mappings between single modality and emotion, forming 12 basic expressions

For the hardware design of Mura, the roboticists created a social robot prototype that consisits of two pieces of hollow, semi-spherical styrofoam, with four different colors LEDs (i.e., white, green, blue, and red) as the robot's eyes, a speaker used to generate beep sound cues, and an ERM vibration motor attached to its inner body to generate vibration stimuli. An Arduino UNO board was deployed to control these different modality information. Fig. 1 shows the appearance of developed Maru and the expressed emotions through the three types modalities, including colors, sounds, and vibrations.

1	C1	5	S1	9	V1	13	CS1	17	CV1	21	VS1	25	CVS1
2	C2	6	S2	10	V2	14	CS2	18	CV2	22	VS2	26	CVS2
3	C3	7	S3	11	V3	15	CS3	19	CV3	23	VS3	27	CVS3
4	C4	8	S4	12	V4	16	CS4	20	CV4	24	VS4	28	CVS4

Table 2. A list of 28 candidate expressions: 1–12 are basic expressions, 13–28 are mixed-modality expressions

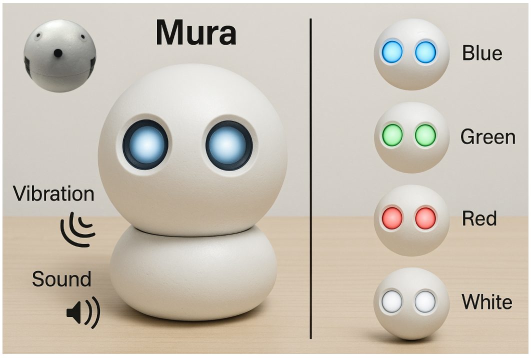

Fig. 1. Maru and its expressions made through color, sound, and vibration

4.2 WoZ iteration in Maru

In this section, we describe the iterative WoZ studies conducted to develop and refine Maru, a social robotic system designed to support elderly care. Through these iterations, we illustrate how ethnographic reflexivity can inform HRI research, particularly when integrated with feedback from diverse stakeholders.

China, like other aging societies, faces challenges in caregiving due to a shortage of young caregivers. Cultural preferences and low wages have made caregiving jobs unattractive to younger individuals, while the task typically falls to middle-aged workers (45–60 years old) with limited formal education. The former one-child policy, along with demographic aging, exacerbates the caregiving crisis, necessitating innovations such as intelligent digital technologies. If widely adopted, Maru could support caregiving not only within specialized elderly care apartments but also broadly in urban and rural communities, significantly enhancing care infrastructure.

Our study involved deploying Maru within an elderly care apartment complex, specifically within communal dining areas where residents frequently gathered for socialization and leisure. Typically, apartments lack comprehensive kitchen facilities, relying instead on shared dining halls and caregiver workstations. Although caregivers provide assistance upon request, elderly tenants, predominantly living alone, often seek companionship and emotional support, highlighting a critical role for social robotic interventions. Between June 2019 and July 2020, twelve elderly residents (six males, six females; ages 73–92) participated in our WoZ studies, conducted exclusively in Chinese. Ethical considerations were paramount; participants provided informed consent and were advised they could withdraw at any time. Indeed, three participants chose to withdraw due to discomfort with robotic presence and surveillance practices, resulting in nine fully participating individuals (see Table 3 for their information).

The iterative process began with extensive ethnographic observations and relationship-building. Researchers spent approximately 20 days interacting daily with participants to establish trust and familiarity. Once participants accepted researchers' presence, we initiated the first WoZ iteration.

Gender	Age	Participated (P) / Withdrawn (W)	Gender	Age	Participated (P) / Withdrawn (W)
M1	87	P	**M4**	87	P
M2	88	W	**M5**	87	W
M3	73	P	**M6**	85	P
F1	85	W	**F4**	81	P
F2	87	P	**F5**	89	P
F3	77	P	**F6**	92	P

Table 3. The elderly participants in the second study

Researchers unobtrusively monitored and categorized emotional expressions (relaxed, happy, angry, sad), subsequently validating these categorizations through structured interviews and feedback sessions. This collaborative sorting allowed researchers to determine which emotional expressions could be reliably interpreted and operationalized through Maru. At first, the elderly peoples' relaxed mood, such as when drinking tea, watching TV, or singing songs, was recognized. Then, the HRI researchers set up an interview to discuss recognized modalities (C1 (relax), CVS (sad), VS3 (sad), S3 (sad), CV4 (angry), CVS4 (angry), VS4 (angry), and CS4 (angry)) with the elderly people to confirm a common understanding of their emotion changes and Maru's responses. After that, the first WoZ was organized to work with the elderly people to distinguish the degrees of their emotions, such as anger and sadness. In this WoZ, the HRI researchers worked with the elderly people to categorize and sort different expressions of Maru to set those expressions as automatically operational.

After the first WoZ study, the researchers identified only three expressions were clearly distinguishable by participants: anger (e.g., late meal service), Maru expressed anger (CV4); sadness (e.g., missing their family phone calls), Maru indicated sadness (S3); and relaxation (general contentment), Maru expressed C1 (write color).

Other expressions were denied by the participants because they were too complex to distinguish. Apart from categorizing and sorting Maru's various expressions, the researchers also discussed with the participants the meaning of Maru's indications (workshop 1). The elderly participants were asked to what degree of accuracy they thought Maru had mirrored their expressions. In reply, the HRI researchers were inquired whether it mattered that the modalities of Maru's emotional expressions represented their feelings. The researchers were not prepared to this question. When Maru was developed by the roboticists, we did not question ourselves how Maru's indications could be used. The roboticists believed these Maru's indications could distinguish different degrees of emotions and help the elderly understand their moods better. Although the roboticists confirmed their intentions at the beginning of the project, the question raised by the elderly people surprised the HRI researchers and led them to realize that Maru was not the end of the interaction. For example, participant F2 said, "It is difficult to say that a blue light with a vibration or sound can express my sad mood. I believe all of them can mirror my feelings to some extent; however, I would hope that someone could help me out by talking to me, chatting with me, or sitting beside me when they see the expressions of the robot." Participant M6 noted, "It is a toy like my grandson has. For example, I dislike the food because it is not tasty, and I am angry, but how can this toy help me?" Referring to vibration, participant M5 said, "Vibration might mirror that I urgently need help to solve some problem, but it seems that Maru does not do anything. Can anyone help?" Both participants M1 and F6 pointed out, "Rising/falling sounds made me mad because I felt I was alone with that robot, waiting for someone to help me." Based on this feedback, elderly people can want someone to help them do something rather simply confirm that the HRI researchers helped them to find a reasonable emotional expression.

4.3 The workshops with caregivers and elderly people

To address participant feedback, a second WoZ study was conducted between June and September 2020, involving five caregivers aged between 46 and 58, all native Chinese speakers without English proficiency. This study examined caregiver responses to Maru's emotional expressions (C1 (relax), S3 (sad), CV4 (angry)). Caregivers observed elderly participants interacting with Maru and subsequently participated in a workshop (Workshop 2) discussing their recognition of these expressions and potential support in their caregiving tasks.

The workshop revealed critical usability concerns: caregivers found Maru's emotional indicators too complex and impractical given their demanding schedules. Instead of continuous monitoring, caregivers suggested simplifying Maru's signals into actionable information, recommending transmitting prioritized alerts to their central workstation. Based on these insights, Workshop 2 evolved into a collaborative discussion involving researchers, roboticists, elderly, and caregivers, ultimately deciding on a simplified traffic-light system (green, yellow, red) representing care urgency levels (see Table 4). A dedicated interface displaying essential information—elderly individual's name, age, gender, room number, health status, and caregiver assignment—was implemented on the caregivers' workstation and mobile tablets (see Figure 2 for an English translation of the interface)[47].

Expression	Indications from Maru	Action from caregivers	Color on the screen
C1 (relax)	White light	No attention is required.	Green
S3 (sad)	Blue light	Attention is required. Action might be needed.	Yellow
CV4 (angry)	Red light, highly intense vibration	Attention is required. Action with high priority.	Red

Table 4. Expressions and their assigned meanings

Following these design modifications, researchers initiated a third WoZ iteration to monitor practical use, refine functionality, and integrate minor improvements based on caregiver feedback. For instance, caregivers expressed a need to review historical data (e.g., daily activities and special dietary requirements). Therefore, during Workshop 3, a calendar feature was added, enhancing caregivers' capacity for scheduling and retrospective management. Upon finalizing the system, researchers exited the field site yet continued remote interviews to track user experiences, given COVID-19 restrictions limiting in-person visits. Considering the age of the elderly participants, these interviews lasted one hour maximum per person. As we had worked closely with the elderly people and caregivers for a rather long time, they were excited to speak with us after the year-long project.

The further study showed that the use of Maru in elderly care work was successful.Participants expressed positive sentiments; one elderly user noted, "Your work makes me feel loved," and caregivers acknowledged improved efficiency in managing tasks. We realized that during our work in the apartments, we did not merely use the participants as research subjects; rather, we stayed there, observing, talked to and listening to them to revise and redesign our product to support their daily life. As a result, both the elderly and the caregiving participants gladly shared many

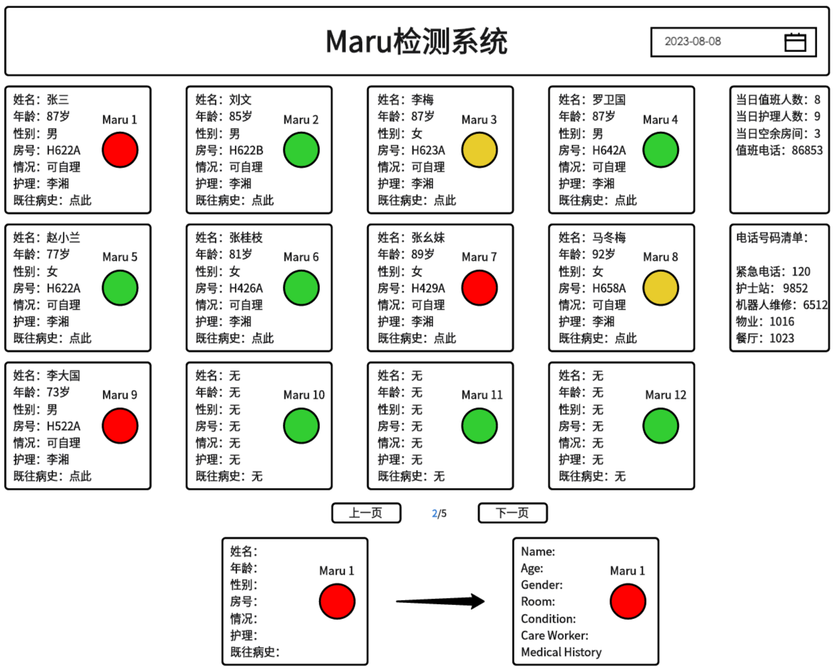

Fig. 2. The monitoring system at caregivers' workstation and tablets in Chinese language. *A translated version of the original monitoring system is attached for English-speakers (Translation: Elderly's name, age, apartment number, health status, caregiver's name, and medicine journal are listed on the left of each box. The boxes on the right upper side are information for caregivers, including the numbers of caregivers on duty, the total number of elderly people, the number of empty apartments, the telephone numbers for emergency, workstation, Maru's maintenance, apartments' management office, and canteen)

stories related to Maru's use, which complimented our project far more than we had expected, and expressed their hope that we would continue providing support to enrich Maru-assisted care work, introducing more daily care work tasks such as scheduling.

5 METHODOLOGY

5.1 Participants

The participants consisted of older adults, care staff, and robotics experts. The development team remained stable between 2023 and 2024, with no staff changes. The older adults involved in the study were between 73 and 92 years old, with an average age of 83. They were healthy and active, typically not requiring additional assistance with everyday tasks.

5.2 Data Collection

5.2.1 Interview. During the research period, HRI researchers conducted Individual meetings and seminars with elderly individuals and their caregivers, utilizing both individual sessions and workshops. To ensure that robot experts could freely express their ideas and to prevent reinforcing existing stereotypes about technological design, these experts were interviewed individually rather than in groups. Face-to-face meetings were organized to gather insights into:

- The elderly's perspectives and experiences interacting with Maru, as well as their daily lives;

- The caregivers' viewpoints on using Maru in their professional routines;
- The robot experts' suggestions for enhancing Maru's system within elderly care.

Each interview was held in Mandarin, lasting between one to one and a half hours. HRI researchers documented these observations in notebooks. These notes were subsequently transcribed, analyzed, and synthesized to form a cohesive understanding.

5.2.2 Observation. Direct observation was employed as the second method of data collection, involving the unobtrusive monitoring of behaviors in the natural environment to minimize bias. While participants were aware they were being observed, this approach was deemed most appropriate given the exploratory nature of the research. Observations commenced in 2023 and continued through 2024, capturing a wide array of activities, including:

- Interactions between older adults and Maru in various contexts;
- The process of redesigning Maru by robotics experts;
- Collaboration between care staff and robotics experts in sharing daily care routines;
- The use of Maru by care staff to complete daily tasks.

Video recordings were made solely of older adults and care staff interacting with Maru and its support systems, aiming to document any instances of failure when using Maru in real-world scenarios. Only project-relevant videos, particularly those focusing on interaction processes, were transcribed. This was essential for understanding the dynamics between the elderly and Maru, the relationship between robotics experts and Maru, and the differences in interactions between caregivers and the elderly. In addition to video recordings, detailed field notes were taken during daily observations. At the end of each day, HRI researchers integrated the newly collected data with previously gathered information to cross-reference it with prior interview and observation results. Key themes identified during the initial days of observation were used to formulate questions and pinpoint subsequent activities to be observed.

5.2.3 Online Platform Communication. We established an online platform on the university server designed for robot experts and caregivers to facilitate information sharing. This platform allows users to communicate via email, collaborate on online documents, participate in chat discussions, and leave comments, while also providing a space for feedback through interview and observation notes.

Given that many elderly users are unfamiliar with online platforms, their feedback is often relayed by caregivers or gathered during personal meetings. Consequently, one of the caregivers' additional responsibilities involves reading notes aloud to the elderly, which indirectly fosters a trusting relationship between the HRI researchers and the elderly participants. To enhance accessibility, information on the platform is organized into folders, allowing stakeholders to easily access their interview and observation notes. HRI researchers actively engage with stakeholders by posting questions for clarification and inviting elaborations to validate the notes from previous interviews. Additionally, notes are added to transcripts immediately during the interview process to ensure accuracy and timely documentation.

5.3 Analytical approach

HRI researchers employed thematic analysis [59] to examine data from interviews and observations, focusing on detailed practice specifics rather than deriving theoretical insights from empirical data. They meticulously coded the handwritten transcripts of interviews and observational notes, ensuring all personal identifiers were anonymized. Video data was selectively utilized for in-depth examination to construct analytical narratives, employing Adobe Premiere Pro to anonymize participants' identities by obfuscating faces and altering voice recordings for public dissemination [35].

Setting	Participants	Number of Interviews	Hours of Observation	Date
Robot Design Studio	Roboticists	14	32	June 2023
Elderly care apartments	Elderly people, caregivers	23	209	May 2023 – August 2024
Workshops and WoZ at elderly care apartments	Elderly people, caregivers, roboticists	18	189	2023.06.10 – 2023.06.14 (WoZ 1) 2023.06.15 (Workshop 1) 2023.06.20 – 2023.07.15 (WoZ 2) 2023.07.16 (Workshop 2) 2024.06.19 – 2024.07.29 (WoZ 3) 2024.08.02 (Workshop 3)
Emails, online documents, online chats, and comments	Caregivers, roboticists	32	–	May 2023 – August 2024

Table 5. Research activity between 2023 and 2024

Furthermore, elements potentially revealing locations or personal items (e.g., windows, personal items, signage) were deliberately blurred to maintain participant confidentiality. Consequently, the public could only view interactions involving Maru and the interactions of care staff with Maru's monitoring systems.

The selected data collection methods necessitated thematic analysis as the optimal analytical approach. This process involved meticulous sentence-by-sentence analysis of interviews, videos, and observational notes, with data subsequently coded into themes and aggregated into broader thematic categories. Researchers engaged in iterative comparisons and clarifications of the data against previously analyzed materials to develop a robust categorization of the data. The emergent themes identified from the elderly participants' responses to Maru's color, sounds, and vibrations are detailed in Table 6.

(1) Maru's assistance in the daily activities of elderly individuals.
(2) Reactions of the care staff to Maru and their collaborative efforts in elderly care.
(3) The technical and engineering aspects of the interaction between Maru and the elderly participants.

These thematic categories elucidated not only the interactions, design, and usage of Maru but also the broader collaborative efforts of the project team. The themes were heavily emphasized throughout the project's investigative and design phases, aiming to refine Maru's functionality throughout its lifecycle. The primary objective of the analysis was to provide an ethnographic examination of the practices linking the residential setting and the design studio, particularly focusing on Maru's utility in elderly care. This analysis also sought to highlight the role of ethnographic reflection and the WoZ technique within the diverse HRI project team. Ultimately, the analysis aims not merely to elucidate interaction failures but to bridge the socio-technical divide in contemporary HRI research, thereby driving improvements in Maru's design and application [27].

5.4 Ethic

This study was rigorously conducted in adherence to academic ethics and received formal approval from the university's ethics review committee. Before initiating the study, we thoroughly addressed the protection of participants' rights and interests. Each participant was provided with a comprehensive overview of the study, detailing its purpose, methods, and potential impacts. We highlighted their rights, particularly the option to withdraw from the study at any time without

Parent theme	Definition	Sub-themes
Elderly people's responses to color, sound and vibration	Interacting with Maru, elderly people act and react to their life routines in line with Maru's color, sound and vibration changes.	**Color changes:** blue, red, green, and white. **Sound changes:** (1) flat beep sound (2) flat beep (louder than 1) (3) falling beep (4) rising beep **Vibration changes:** (1) mildly intense (2) highly intense (lower than 4) (3) low intense (4) highly intense
Collaboration between Maru and caregivers	Caregivers' work is supported by Maru through different modalities, including how cooperative work is done in and outside of the apartments.	Care work, collaboration, and interacting with Maru
Engineering Maru's design, focusing on the interaction between Maru and the elderly	Maru and seniors' interaction and cooperation. Design relates to the engineering designs for Maru's modalities.	Robotics principles, decision making, interaction means.

Table 6. Themes of the interviews and observation data

providing a reason. To respect the genuine wishes of the participants, we utilized various consent methods. The majority consented by signing a written informed consent form. For those unable to write, due to age or other reasons, we facilitated oral consent, verified by an independent witness to ensure the process's integrity and fairness.

During data collection, we implemented stringent confidentiality measures. All interviews were audio-recorded only with explicit participant consent. Aware of the potential sensitivity of the discussions, we ensured participants could halt recordings or omit questions at their discretion. Privacy was also a priority during data handling; all recordings were destroyed post-transcription, and any identifying information was removed from notes and electronic files. Additionally, we adhered to strict data storage protocols to securely maintain all research materials.

Our approach was guided by a commitment to respect the trust participants placed in our team. Although we cannot promise immediate impactful changes from our findings, we are dedicated to influencing policy development to better the conditions of delivery platform workers. We maintained transparency throughout the study, inviting participants to voice any questions or concerns. Regular ethical reviews within our team ensured that we consistently upheld the highest ethical standards. Through these efforts, we aimed to balance advancing research goals with safeguarding participant rights, thereby conducting this significant research responsibly.

6 FINDINGS

Our findings were organized around three key themes that emerged from our ethnographic analysis: (1) Human-Human-Robot Interaction, (2) Reconceptualizing Robots in HRI & CSCW, and (3) Methodological Insights from WoZ Iterations. These themes directly address our research questions about bridging knowledge gaps between different professional fields and designing robots that support meaningful human collaboration from CSCW perspectives.

6.1 Human-human robot interaction

Human–human–robot interaction (HHRI) represents a relatively novel area within human–robot interaction (HRI) research. Our findings suggest that HHRI dynamics cannot be fully predefined by roboticists in laboratory settings. Initially, roboticists in our earlier studies hypothesized that systematic experimentation with various modalities—such as color, sound, vibration, and their combinations—would reveal practical insights to guide robot design. However, when robots like Maru were introduced into real-world settings, this assumption did not hold, failing to generate actionable insights to meaningfully improve the robot's design. This discrepancy could be explained by the fact that the accountability and interactions of heterogeneous teams (involving both robots and multiple human stakeholders) have largely been overlooked in traditional HRI research.

Conventional HRI studies typically rely on controlled experiments to evaluate the trustworthiness, acceptability, and emotional expressions of robots, often categorizing user feedback simply as positive or negative. Although biologically oriented research on emotions provides certain insights, such approaches fall short in capturing the complexities of emotional interactions that are largely influenced by social contexts [11]. Our study emphasizes the importance of contextual, field-based verification that transcends experimental boundaries to genuinely assess the practical utility and communicative efficacy of robot emotions in everyday use.

While the call for HRI research to move "into the wild" is increasingly urgent, exactly what should be studied in real-world contexts and how such studies should be conducted remain unclear. Many HRI scholars have explored technological approaches primarily aimed at enhancing robot functionality or emotional expressiveness. Although these engineering-centric methods have their merits, they often miss the critical perspective of end-users—in our case, elderly individuals and caregivers—who may prioritize practical considerations over mere emotional mimicry. Specifically, end-users may be less concerned with robots reflecting their own emotional states and more interested in how robotic emotional expressions effectively convey critical messages aligning with their internal feelings, sentiments, or practical needs, to facilitate actionable support among human caregivers.

This emphasis is related to current trends in HRI that increasingly focus on teleoperation scenarios. Yet, our work highlights a distinct difference in how communication through robots such as Maru was managed. Our findings suggest that roboticists themselves, serving as both researchers and users, need to better understand participants' real-world practices and contextual reasoning. Such understanding is essential for effectively bridging the communication gap between elderly individuals and their caregivers in daily interactions. Reflecting this insight, one roboticist remarked:

"This is the first time we can use the knowledge of the participants (the elderly people and caregivers). If we redesign Maru for remote control purposes, we know the caregivers will be the most important collaborator for us."

Caregiver 3 confirmed the effect on their basic everyday work practice:

"The color of the system and the information delivered by Maru give me a clearer understanding of when and how I should respond to the elderly people. Our schedule is very busy, and sometimes we are not able to attend to each elderly person on time. This has been a problematic area for years due to a lack of labor. If it could be altered by the system, it would help a lot in offering care; I would know whom I should go to first and who can wait a bit."

These observations provide roboticists with critical insights into real-world challenges and user needs within the context of HHRI. Importantly, our study highlights accountability in heterogeneous teams as a central concern—not only within specific HRI studies but as a fundamental issue across the broader HRI community. To address this, our work proposes an epistemological framework that underscores the necessity of specialized training for researchers to effectively observe, understand, and document design challenges arising from interactions in diverse, multidisciplinary teams. Thus, we argue that the initial "human" component within human–human–robot interactions must be the researcher, equipped with sufficient experience and training to navigate complex collaborative environments.

6.2 Robots in HRI And CSCW

While many scholars advocate for robots to exhibit human-like features in certain research contexts, practical implementations of robotic technologies—particularly in homes, hospitals, and caregiving environments—remain considerably distant from this ideal [65]. In elderly care work, looking after individuals is the most resource-intensive work, which necessitates fast development of automated support. Although robots can perform valuable tasks such as singing, cleaning, and guiding elderly people through basic physical exercises [18], their primary role in elderly care should be to augment human awareness and support caregiving activities. Robots can effectively fill gaps left by human limitations, thereby bringing meaningful benefits to caregiving practices.

It is clear that a robot means different things to different people. Even roboticists themselves have different notions about what a robot is or is not. The perception of a robot must not be influenced by science fiction, based on which we expect a robot to look in a certain way and be able to perform certain functions. For the present work, the initial failure of Maru's deployment in the elderly setting is caused by the impractical practice of robot design. Emotional expressions can be an important study area in HRI, and we agree that this study must remain at the center of HRI. However, it is crucial to recognize that robots, fundamentally, are autonomous systems capable of sensing their environments, performing computations to facilitate collaboration, and responding appropriately to real-world conditions. Just as in the present study, the redesign of Maru went beyond the purely cognitive inquiry to verify the meaning of the modalities between the elderly and robots; rather it focused on the real needs, supporting both the elderly people and the caregivers' trajectory of technology-supported care work. One of the roboticists added:

"Our previous vision on robots was probably too narrow. We had never thought a tablet system or a web system could be associated with Maru to boost its features as we did not consider it part of a robot. Now we see that a robot can be a holistic system that consists of Maru as well as any tools that make Maru useful. We admit that interaction is the keyword in HRI study"

So, does our research still stand within the scope of social robotics? We argue that it does. Strict roboticists can deem our work is outrageous and betrays robotic research. However, we must keep in mind that robots can typically do three things: sense, compute, and act in any context. These three components vary widely from robot to robot, but they are the basic components of any robot. All robots keep repeating the sensing-computing-acting cycle, the phenomena that roboticists called the "feedback loop" [56], and social interactions make robots smart. It is important to evaluate robots' autonomy and whether they provide meaningful acts in the domain humans assign to them. The level of autonomy can differ from robot to robot for each specific setting; however, it is important to understand the best possible solution for the given setting. In this work, we show that the elderly people who live in elderly care apartments do not care much about the emotional expressions (whether Maru can correctly respond to them); rather, they wanted the robot to act when they wanted caregivers' attention, which they can do by showing Maru a different mode to make Maru inform the caregivers about their needs.

So, what would a robot for elderly care be like? Are emotional expressions that important for designing a robot? Unlike many HRI studies of robots that emphasize cognitive models of emotional recognition, the meaning of emotion use and the messages delivered to the respondents prove to be more useful for interaction. From a pragmatic point of view, technology determination should extend its scope to include wider social interactional environments. There are no dichotomy answers. A social robot is an artefact that falls within the boundaries of the sciences of the artificial. A social robot is synthesized by roboticists, HRI researchers, and the end user, and these synthesized attributes must imitate appearances in a natural setting to involve a holistic approach to robotic use, which is the key character of the robots' functions, goals, and adaptation, as agreed upon by the stakeholders in their design and implementation. Design of social robots must come from a constructive sense, according to which we must synthesize and ask whether new forms of reasoning of a heterogeneous team's actions are involved in considerations, then, seeking a satisfactory solution for robot design, we can gain knowledge from the experiences of the users, which is one of the most important design criteria.

6.3 Research methodology

The third finding of this study is the use of the WoZ methodology in HRI study. We have no intention to criticize the HRI studies that focus on single-use of WoZ; however, we want to pinpoint that WoZ is an efficient way of exploring the development of HRI. In our case, for example, the HRI researchers' fieldwork offered novel design space, in which iterative use of WoZ improved Maru design in terms of its usefulness in elderly care work [45, 83]. Therefore, WoZ can be applied throughout the iterative design process, which is widely used in designing useful robot systems. WoZ helped us avoid getting locked in a particular design or working under an increased set of assumptions about user perceptions. The WoZ approach let us explore and evaluate designs before investing considerable development time to build the complete product.

"I did not realize that I was getting stuck in an endless, expensive process of robotic systems design. I suppose WoZ will direct me to a future solution; however, I definitely do not know if that future solution is doable. So, we will probably stay in endless experimental work until we convince ourselves that our design is reasonable. Well, in most cases it is not [smiles]."

To respond to the iterative design process, researchers should take advantage of WoZ to simulate the vision of the robot in line with the needs of its users (in our work, elderly people and caregivers) during the development process. This not only made it possible to account for the actions and reasoning of the elderly people but also allowed us to translate our findings related to Maru's use as an aid into sophisticated applications that enabled the roboticists to redesign the interaction between the elderly people and Maru without spending time on over-engineering a complex underlying system that may not have been needed. In addition, WoZ played a supervisor role in our case as it helped the participants through their experiences on a case-by-case basis, iterating the design back and forth until a solid solution was achieved in three workshops. WoZ also plays a dedicated role, aiding intelligence beyond the current possibilities of computing or simply monitoring experiences to provide help when we were not able to identify the meaningful combination of three modalities. We benefitted greatly by becoming wizard operators and saw that formal models for Maru's behavior were necessary to keep our design for the elderly care transparent. This approach can be considered explicit support for the WoZ simulation method in prototyping robots [75]. By providing a realistic solution for the wizard interface creation and data visualization, such as connection between Maru and the systems used by a caregiver, we created collaboration between the HRI researchers and roboticists to explore a variety of potential uses of WoZ simulation throughout the design cycle. Our ethnographic reflexivity and WoZ-supported iterative design that gave the HRI study in this project a more comprehensive framework of possible wizard roles. One of the roboticists stated:

"We thought that we needed to develop useful emotional expressions of Maru, but it is truly problematic, so much so that most research studies pay attention to verification. So, when we first use

experiments, they cannot help us to gain valuable insights to implement our work further. It seems the problem is not in verification or confirmation of emotions; the problem can be the epistemology in our mind."

Therefore, we acknowledge that over the past fifteen years of HRI research, there have been many significant considerations that scholars are prompted to be more conscious of when designing WoZ experiments. Specifically, just as with any human–robot interfaces, the wizard interfaces should carefully account for the perceptual, cognitive, and motor capabilities of the wizard operators. Nevertheless, our research differs notably from traditional robot-centric methodologies commonly adopted in HRI studies, which typically include human users without explicitly evaluating human practices. In our context, both elderly individuals and caregivers required robots and their algorithms to transparently support established caregiving practices. Although end-users may perceive robots as complex technical systems, these robots must remain comprehensible, controllable, and accountable according to simple, user-defined principles. The robot Maru, within our study, functioned explicitly as a mediator, actively facilitating interactions between elderly people and caregivers. Importantly, this role extends beyond mere human–human communication mediated by robotic platforms; it encompasses a more comprehensive notion of robots as active participants in heterogeneous teams involving caregivers, elderly individuals, HRI researchers, and roboticists, each playing distinct yet interconnected roles.

7 DISCUSSION

7.1 Emotional Expression as a Coordination Mechanism

The design of Maru's emotional system acknowledges what CSCW researchers have long recognized: that effective collaboration requires not just information sharing but also the establishment of shared meanings and interpretive frameworks. However, unlike traditional CSCW insights that rely primarily on explicit verbal communication or structured information exchange, our work demonstrates how emotional cues can function as mediator that bridge different knowledge domains and facilitate coordination among diverse stakeholders.

Maru expresses emotions in a multimodal way, including visual, auditory, and tactile channels, distinguishing it from traditional social robots that focus on a single mode of interaction. We found that this multimodal emotional expression not only enhanced the naturalness of human-robot interaction but, more importantly, became an intermediary and catalyst for collaboration between elderly people and caregivers. Research indicates that elderly people "prefer the robot to take action when they need the caregiver's attention, allowing Maru to notify caregivers of their needs," and caregivers also confirm: "The system's color and the information Maru provides make it clearer for me to understand when and how to respond to elderly people." The design of Maru's emotional expression originates from an in-depth observation of emotional communication patterns in caregiving environments [31]. During the study, we found that successful caregiving interactions often rely on rich emotional expressions that not only convey emotions but also coordinate actions, build consensus, and promote understanding. Through ethnographic observation, we identified multiple functions of emotional expression in collaboration: conveying important information, signaling action requests, indicating states of understanding, and coordinating interaction rhythms [82]. These observations were transformed into design principles for Maru's emotional expression, emphasizing the importance of emotional expression as a core coordination mechanism.

This finding supports our theoretical claim: emotional expression is not an add-on feature of robots but a core resource for collaborative knowledge construction. Through emotional expression, Maru not only conveys information but also transforms the nature of caregiving practice, shifting it from one-way care to multi-party collaborative construction. This transformation aligns closely with Hickman's theory of pragmatic technology [38], which views technology as an intelligent method through which natural and human energies are guided and used to meet human needs, and directly addresses the issue raised in the introduction of how technology changes existing practices.

Particularly noteworthy is that Maru's emotional expression established an effective translation mechanism between heterogeneous knowledge systems. When caregivers found it difficult to understand the elderly person's needs, Maru's emotional responses (e.g., showing confusion or concern) often prompted caregivers to reassess the situation and adopt different communication strategies. This observation reveals how emotional expression participates in the reconstruction of knowledge boundaries, promoting understanding and collaboration among different participants. Furthermore, this emotional mediation is not a pre-set function but arises from the actual demands of caregiving practices, supporting the "reverse engineering" design approach—starting from users' actual work practices and working backwards to deduce technological needs.

7.2 The Complementary Role of Ethnographic Reflection and the WoZ Method

From a methodological perspective, this study combines ethnographic reflection and the WoZ iterative design method to construct a research framework that mutually promotes theoretical guidance and practical validation [45, 83]. This combination is not merely parallel but forms a complete cycle of understanding-action-assessment, allowing us to gain deep insights into the complexities of social robot design. This methodological combination directly responds to the introduction's "interventionist ethnography" research path, positioning the researcher as a dialogue maker to facilitate the translation of heterogeneous knowledge systems.

Ethnographic reflection, as a key research tool, reveals work practices and social interaction patterns often overlooked in traditional HRI research. In elderly care environments, this method is particularly valuable because these work practices and social interactions are often implicit and subtle, making them difficult to capture through standardized measurement methods. Through long-term participant observation and reflection, we not only identified clear technical needs but also revealed the values and social norms behind daily practices, which are crucial for designing truly useful social robot systems. Meanwhile, WoZ can be applied throughout the iterative design process, helping us avoid being trapped in specific designs or working with increasing assumptions about users' cognition. The WoZ method allows us to explore and evaluate designs before committing significant development time to create a full product.

The combination of these two methods forms a design-assessment-improvement feedback loop: ethnographic observation provides deep understanding of the context, the WoZ method supports rapid testing and validation of design solutions, and subsequent ethnographic observation assesses the effectiveness of the solutions and guides further improvements. This loop not only improves design quality but also promotes the organic integration of theoretical insights and practical applications, forming a "dual-loop learning" model that optimizes design solutions and enriches understanding of the practice field simultaneously through the process of dual translation. The combined application of these methods responds to the call by Hornbæk, Oulasvirta, and Šabanović [45, 83] to bring robot design into the "field." Field research not only verifies the practical applicability of laboratory findings but also reveals interaction patterns and needs that only emerge in complex social contexts. For example, we found that caregivers' ability to interpret robot emotional expressions was much more important than elderly people's direct recognition of these expressions.

7.3 CSCW Implications for Designing Heterogeneous Teams and Social Robots

The value of heterogeneous teams in social robot design lies in their ability to integrate knowledge from multiple domains. HRI researchers, robotics experts, elderly people, and caregivers each contribute unique knowledge and perspectives, and successful design requires effectively merging these diverse knowledge systems. However, this interdisciplinary collaboration faces deep challenges arising from differences in epistemological foundations, values, and methodologies. The previous work Pan [63], Sauppé and Mutlu [73] reveals the fundamental differences between mechatronics engineers and HRI researchers in their understanding of human-robot interaction—while the former tends to view users as functional components of the system, the latter emphasizes the social and contextual dimensions of interaction. This professional divergence is reflected in the design concepts for robot behavior. While robots in certain research settings should behave anthropomorphically, the actual application of robotic technology in home, medical, and care environments may be far from achieving this ideal [5, 25, 55]. The core issue of this cognitive divide is not about validating or confirming the ability to express emotions, but rather about the epistemological differences inherent in our cognitive frameworks.

To address these challenges, we developed a multi-layered collaboration mechanism, including the establishment of a shared vocabulary across disciplines, the definition of common design goals, and the creation of a collaborative platform that supports knowledge exchange. These mechanisms not only facilitated effective communication among team members but also helped to find a balance in the complex design space to meet the needs and expectations of diverse stakeholders. Our collaboration framework aligns closely with the boundary object theory proposed by Star and Griesemer [42, 82]—the technical prototype itself evolved into a "knowledge-transformation boundary object," through interaction with which different participants were able to reassess and adjust their professional practices and cognitive frameworks.

A systematic analysis of the entire collaboration process revealed the dual role of heterogeneous teams in social robot design: on one hand, the diversity of team members provides rich knowledge resources and innovation potential; on the other hand, the complex internal interactions within the team form a micro-social-technical system, mapping the complexity and dynamic nature of the broader design environment. By deeply understanding and effectively managing this duality, we can more fully leverage the innovative potential of heterogeneous teams while minimizing cognitive friction and communication barriers in the collaboration process [1, 2].

7.4 Privacy, Trust, and Diversity in Social Robot Design

Introducing social robots into elderly care environments is not only a technical challenge but also a social one involving privacy protection, trust building, and respect for diversity. These factors are not supplementary considerations in design but are core factors that directly impact the system's success [85]. This discussion directly responds to the second research question in the introduction: How can the needs of multiple stakeholders be integrated into the design process while addressing privacy issues and building trust?

Privacy protection is particularly important in social robot design because these systems often need to collect and process large amounts of sensitive personal data. Research findings highlight that elderly people have clear concerns about the information collected by robots: "They prefer that the robot take action when they need the caregiver's attention, such as having Maru enter a different mode to notify the caregiver of their needs." This indicates that system design must balance functional needs with privacy considerations. Our research shows that effective privacy protection depends not only on technical measures (e.g., data encryption or access control) but also on building privacy awareness throughout the design process [19, 53]. This includes considering the necessity and proportionality of data collection during the requirements analysis phase, prioritizing privacy-protecting features, and ensuring transparent communication and user control during implementation. We translated privacy requirements into specific technical specifications, such as the timing of data collection, storage duration, and access permissions. This translation process involves not only technical implementation but also value judgments and ethical considerations, reflecting the pragmatist emphasis on the integration of technology and values.

Building trust is a key prerequisite for the successful deployment of social robots. Some research findings point out that elderly people's trust in robots is based on actual need fulfillment: "In this study, we found that elderly people living in nursing homes were less concerned about the robot's emotional expressions (e.g., whether Maru can correctly respond to their emotions); they preferred the robot to take action when they need the caregiver's attention." In care environments, trust exists not only between the user and the robot but also involves a broader social network. Our research finds that effective trust-building needs to consider multiple levels: technical reliability and safety, interaction intuitiveness and controllability, social role positioning, and relationship coordination. This multi-layered trust framework enables us to comprehensively understand and manage trust issues rather than merely optimizing a single aspect. This aligns with the view presented by Lee et al. [51] in related research that trust is based on perceptions of a technology's ability, honesty, and kindness.

In elderly care environments, diversity and inclusive design are particularly important due to the significant differences in elderly people's cognitive abilities, physical conditions, cultural backgrounds, and technological experience. Some research [17] highlights this: "The design of social robots must be constructive, and we must think about whether we have considered new forms of reasoning for heterogeneous team actions based on this constructiveness. Then, to seek a satisfactory solution for robot design, we can draw knowledge from the users' experiences, which is one of the most important design standards." Traditional one-size-fits-all design cannot meet this diversity, so we adopted adaptive design strategies, including multimodal interaction, adjustable complexity interfaces, and culturally sensitive design elements. This inclusive design considers the different needs and capabilities of direct users (elderly people) and indirect users (caregivers and family members) to create systems that adapt to various usage environments. This approach aligns with the "feminist HCI" framework in related research, which emphasizes that the design process should include voices from different groups, especially those traditionally overlooked [89].

Although privacy, trust, and diversity are conceptually different, they are closely related in practice. Strong privacy protection can enhance user trust, and inclusive design, by respecting the needs and preferences of different users, can also foster trust. Our research shows that successful social robot design must incorporate these factors as an integral part of the design process, not as afterthoughts. This directly responds to the second research question posed in the introduction regarding integrating multiple stakeholders' needs while addressing privacy issues and building trust. We demonstrate how robots can serve as boundary objects, coordinating interactions between different care stakeholders while respecting their unique needs and concerns. By focusing on the collaborative aspects of robot integration, our research extends CSCW's ongoing examination of how new technologies transform work practices and social relationships. This aligns with CSCW shift toward designing for complex socio-technical ecologies rather than discrete technological interventions, recognizing that successful technology adoption depends on its ability to support and enhance existing collaborative practices while meeting new demands for coordination and mutual awareness.

7.5 Quality and Theoretical Contributions of This Study

The value of interaction research primarily depends on the type of knowledge it generates and the way it contributes. The academic quality evaluation framework for interaction research proposed by Höök and Löwgren [39] emphasizes the importance of knowledge contributions, particularly pointing out that intermediary knowledge should be controversial, defensible, and substantial. This study contributes intermediary knowledge with these characteristics by applying pragmatist philosophy to social robot design in elderly care scenarios. By incorporating CSCW into traditional HRI research, the study shifts away from merely assessing the accuracy of robot emotional expressions or direct measurement of user responses. This study reveals that traditional HRI methods, based on assumptions like "if they allow participants to explore three modes and their combinations, they are likely to find useful modes," fail when robots are deployed in real-world settings. As one robotics expert reflected: "This is the first time we can leverage the knowledge of participants (elderly people and caregivers)."

Our pragmatist inquiry framework, based on Dewey's theory of experience and Hickman's pragmatic technology practices, defines technology as an intelligent method through which natural and human energies are guided and used to meet human needs [37]. This perspective avoids the binary thinking common in HRI research, instead viewing robots as an element in a social-technical system, with its meaning continuously constructed through interactions with humans and the environment.

Reflections from robotics experts in our study validate the value of this framework: "Our previous view of robots may have been too narrow. We never thought that tablet systems or network systems could combine with Maru to enhance its functionality because we never saw them as part of the robot. Now we realize that a robot can be a complete system, consisting of Maru and any tools that make Maru useful." This shift in understanding corroborates the pragmatist design principle proposed in related research: design should start from actual needs, evaluation should be based on real-world usage contexts, and technology should focus on how it changes existing practices [60, 61].

8 CONCLUSION

This paper presents a longitudinal study of human–robot interaction (HRI) in elderly care work. Our focus is on designing useful robot-supported care through robots' emotional expressions. Unlike most HRI studies, which emphasize novel mechanisms and computational tools, our research incorporates complex social content. We explored the relationships between elderly people, roboticists, HRI researchers, and caregivers through reflexive elaboration on robot use and design, as well as the proposed methods. Additionally, we demonstrate how insights from computer-supported cooperative work (CSCW) can illuminate complex social contexts, from engineering discourse to elderly care. Although much remains to be learned in real-world settings and further HRI studies are necessary, we do not aim to replace controlled lab studies in the HRI community or develop a generalizable theory for specific contexts. As a heterogeneous team interested in CSCW research, we believe our study presents an alternative solution for supporting robot-mediated collaborative work in teams. Moreover, our methodology can meaningfully contribute to heterogeneous teams of professionals, empowering them to address oversimplified design studies in socio-technical contexts.

Just as emotional expressions and the development of robotic systems are improved through co-creativity, joint appropriation, and alignment and merging of interests, values, and routines, we provide an understanding that guides CSCW researchers to integrate pragmatic insights—knowing and doing, theory and practice—to facilitate cooperation, coordination, and social accessibility for all stakeholders. This includes not only technology users but also those involved in design processes. Therefore, the work of researchers, caregivers, elderly people, and roboticists engaged in real-world robot use represents a pragmatic approach to technology. If explicit challenges are addressed promptly, this focus can be enlightening and even groundbreaking.

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