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Long-Term Co-Design Guidelines: Empowering Older Adults as Co-Designers of Social Robots

Anastasia K. Ostrowski[1], Cynthia Breazeal[1], and Hae Won Park[1]

Abstract— **Users can provide valuable insights for designing new technologies like social robots, with the right tools and methodologies. Challenges in inviting users as co-designers of social robots is due to lack of guidelines or methodologies to (1) organize co-design processes and/or (2) engage with people long-term to develop technologies together. The main contribution of this work is to provide guidelines for long-term co-design for how other researchers can adopt long-term co-design, informed by a 12-month co-design with older adults designing a social social robot. We leveraged human-centered, tactile and experiential design activities, including participatory design, based upon the following design principles: scenario specific exploration, long-term lived experiences, supporting multiple design activities, cultivating relationships, and employing divergent and convergent processes. We present seven different sessions across three stages as examples of this methodology that build on each other to engage users as co-designers, successfully deployed in a co-design project of home social robots with 28 older adults. Lastly, we detail 10 long-term divergent-convergent co-design guidelines for designing social robots. We demonstrate the value of leveraging people's lived technology experiences and co-design activities to generate actionable social robot design guidelines, advocating for more applications of the methodology in broader contexts as well.**

I. Introduction

As the older adult population increases worldwide [1], we find more potential for social robot technology to innovate ways to reduce people's loneliness [2], promote social engagement [3], and assist with healthcare [4] with its companion-like features. With the increasing development of social robots for older adults, it is crucial that designers of the technology reject older adult stereotypes and understand how these technologies may impact older adults' lives, wellness, and autonomy [5]. Common stereotypes such as older adults being unable to use technology prevent older adults from being seen as meaningful contributors to the design processes of future technologies [6]. Older adults can be co-designers of social robots and it is the responsibility of researchers to engage tools and methods to support co-design and collaboration. Co-design and participatory design are valuable methodologies to incorporate users into design processes, amplify user voices that are often not heard in technology design, and empower users as purposeful contributors to design [7]. Participatory design and co-design have been well studied and utilized in human-computer interaction (HCI) and design research fields, and researchers have been adapting them to design human-robot interaction (HRI) in the recent years [3], [8]–[10]. As robots are becoming more commercially available in various parts of our lives, researchers must equip themselves with a mindset to study these systems in the real-world context [11] and design these systems in partnerships with end-users [12].

Robots are entering our social contexts as long-term companions, and, therefore, we concluded that it is crucial to study and work with our target users in a longitudinal time frame. The main contribution of this work is in the development of a long-term 12-month older adult co-design methodology for home social robot design with long-term co-design guidelines for how other researchers can adopt the methodology. Through the process, we promote co-design as a human-centered approach for designing robots, empowering older adults in the design of these technologies. The process and subsequent sessions are based upon 5 design principles: scenario specific exploration, long-term lived experience, supporting multiple design activities, cultivating relationships, and employing divergent & convergent processes. The co-design process explored 7 areas of interest for social robot applications. We designed our sessions to provide co-designers opportunities to generate ideas using multiple divergent and convergent approaches through interviews and tangible tools, time to reflect on previous sessions, and experience living with the robot for at least a month. Engaging with older adults over a long-term study, the co-design team emphasized fostering and building relationships with participants and supporting them in the co-design process. Our co-design process proved successful in generating social robot design guidelines for the next stage of social robot development and empowering older adults in designing and creating social robot applications for their own needs and desires.

II. Background

A. Users in Design

As more robots enter people's lives, it is critical that researchers understand how people will engage with these robots in the given social contexts [11]. One approach to understanding this is through user-centered design (UCD) that emphasizes the needs and perspectives of the user through iterative design processes. Within UCD, users are consulted on design needs and requirements throughout the process and engage in evaluation of resulting products [13]. Prior works in HRI have incorporated UCD methodologies including

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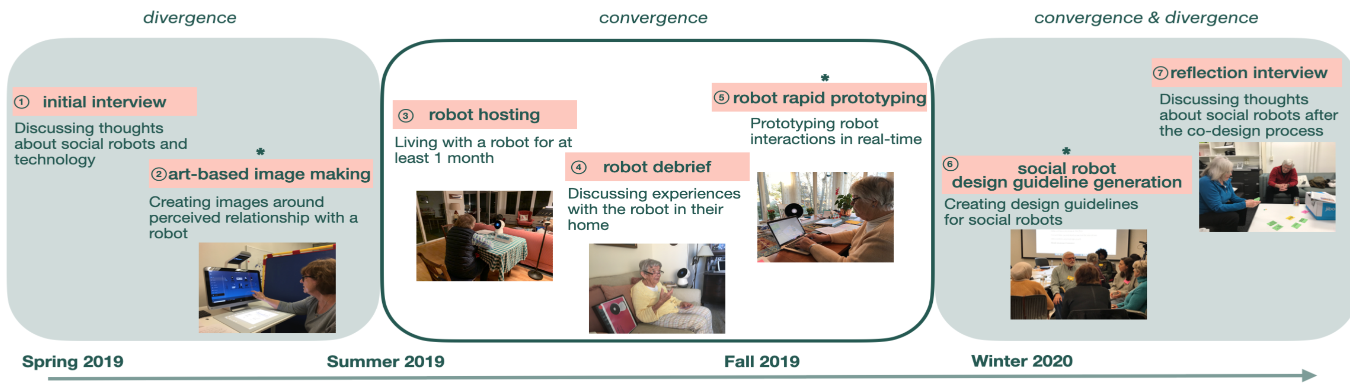

Fig. 1. Older adults co-design process depicting the seven sessions and the nature of the stage, whether it promoted divergent or convergent thinking. Participatory design activities are marked with an asterisk "*".

surveys, focus groups, and interviews [14], [15]. However, UCD approaches often limit users' role to informants in the design process, rather than integrated team members [9]. In this paper, we propose human-centered design (HCD) approaches to invite users as co-designers. HCD is distinct from UCD [16] in that UCD has a "narrower focus on people's roles as users" while HCD "suggests a concern for people" [16]. HCD as an approach expands past limiting participants' role as informants and aims to uphold them as the main contributors of the process, embracing human dignity [17].

B. *Co-Design of Robots*

Co-design and participatory design are often used interchangeably in technology design. We refer to our work as co-design or collaborative design (i.e. "processes of creative cooperation" [18]) to emphasize the role of users as co-designers. Engaging users in co-design can empower them and provide a sense of ownership in the decision making of technology development [7]. The researcher's role is to build rapport with participants and empower them as partners in the co-design process while they express and develop their thoughts and ideas. Participants can leverage their prior technology experiences and their environmental knowledge to conceptualize new devices while engaging in frameworks such as experience-based co-design [19]. By shifting power dynamics and empowering participants, researchers and participants engage in joint inquiry and open spaces for joint imagination, resulting in improved idea generation and decision making and improved user satisfaction of the product [18], [20] or technology.

Despite these benefits, co-design and participatory design have been marginally used within HRI [8] due to lack of methodologies and robot platforms suited for exploring robot design in the target social context to support experience-based exploration. However, as co-design tools become more available from pioneering works and commercial robot platforms are entering the market, it is becoming timely to develop more co-design approaches to study robots in social contexts. In co-designing social robots, HRI researchers have engaged users in participatory design workshops [9], [10], card sorting [3], [5], sketching [9], [10], storyboarding [8], role-playing [8], and prototyping [8], [9]. Participants have had varying roles in participatory design including redesigning existing robot platforms, generating new robots, and engaging in mutual learning with researchers [9]. In studies with older adults, Lee et al. [9] and Šabanović et al. [10] engaged older adults in interviews and five participatory design workshops. Through a community-based participatory design approach, Ostrowski et al. [3] used card-sorting and observations of emerging community behaviors after a robot was installed in older adults' community spaces for three weeks to explore how older adults desire social robots to be designed. These examples demonstrate how participatory design and co-design of robots with older adults can be leveraged in HRI, highlighting the promise and value of these methodologies when designing robots with this population. However, co-designing with older adults while providing them with long-term experiences with social robots still remains significantly under-explored.

While researchers are including co-design and participatory design approaches in their research, for these approaches to become more prominent in HRI, we need to ensure there are foundations, frameworks, and design methodologies for researchers to inform and structure their work. Previous works have outlined design methodologies for user experience in HRI [21] and Lee et al. [9] has provided examples of short-term participatory design workshop methodologies. With increasing emphasis on long-term studies to understand how robots engage in and affect social contexts [11], longitudinal design methodology frameworks are necessary. Our paper outlines the development of a year-long co-design process with older adults to promote co-design as a tool for understanding and designing social robots for "in the wild" and provide long-term co-design guidelines in HRI.

III. Design Principles in the Co-Design Process

In this section, we provide a theoretical background, i.e., divergent and convergent design stages, for the year-long co-design process. The process builds upon participatory design, co-design, and human-centered design processes, described in the Background section.

Scenario Specific Exploration: The main objective for the co-design process was to explore how older adults would design a social robot for various areas of their lives. To begin the study, we identified seven popular areas that robotics solutions are targeting, including (1) memory assistance & monitoring, (2) exercise & physical therapy, (3) body signal monitoring, (4) connecting with others, (5) medication adherence, (6) emotional wellness, and (7) financial management. We used these areas of interest from the robotics community [3], [22] as a foundation to help structure explorations within the co-design process.

Long-term Lived Experiences: We explored older adults' initial perceptions of social robots, how lived experiences with a robot inform older adults' model and desires of social robots, how a long-term co-design process shapes knowledge growth and opinions, and how older adults believe social robots should be designed for the future.

Cultivating Relationships: Lastly, we prioritized building rapport with our older adult participants and establishing relationships with them as one research team. We also provided many opportunities for older adults to reflect on our partnership and the co-design process throughout the year. Twenty-eight older adults from 3 states in the United States, ages between 70 and 94 (mean: 79.5, std: 7.8; female N=15), participated in the co-design process. Sessions were held at the MIT Media Lab or participant's homes, depending on what the participant preferred. All participants volunteered to participate, completing an IRB approved consent form. In each of the seven sessions introduced in the next section, all participants completed the initial interview, art-based image making, robot hosting, and robot debrief sessions; 93% participated in the robot rapid prototyping; 79% in the design guideline generation; and 75% in the reflection interview sessions. In total, 64% of participants completed all stages of the process. Participants missed either the design guideline generation session due to travel or health related issues or the reflection interview due to the COVID-19 pandemic and lack of online access.

We limited the number of researchers who directly engaged with the participants, so that the rapport and working alliance built between the researchers and participants remained strong. Two researchers conducted all one-on-one activities during the year, while the group-based social robot design guideline session was supported by 12 researchers for facilitation.

Employing Divergent & Convergent Processes: When designing the co-design process and the activities within it, we sought to create a design process that provided multiple divergent and convergent design phases, balancing concrete and abstract thinking. Within conceptual design, divergent stages allow for multiple ideas and concepts to be generated, while convergent stages allow for narrowing of ideas and concepts [23]. Divergent and convergent activities are often intermixed in design processes. Ciolfi et al. [24] demonstrate how divergent and convergent activities can be organized within a co-design process to both explore "open themes in an unconstrained manner" (divergent) and "focus on more specific design goals" (convergent). We use a similar co-design approach to allow for exploration and design generation, as illustrated in Fig. 1.

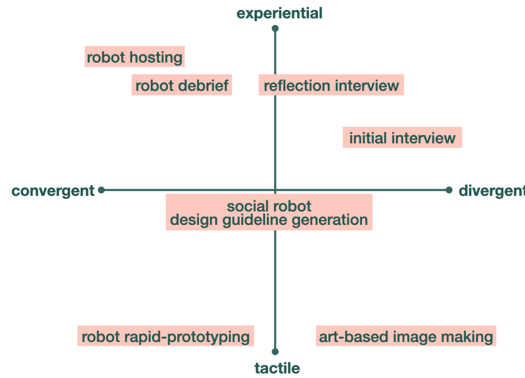

Fig. 2. **Seven co-design sessions mapped on the dimensions of experiential-tactile and convergent-divergent axis** to demonstrate the varying types of engagement and design approaches employed in the process.

Supporting Diverse Design Tools & Activities: Throughout the co-design process, we provided users with various tools to express their ideas. By diversifying the tools and activities, participants were able to find the best ways for them to express their thoughts and generate new ideas. Also to this sense, we ensured that hands-on tactile activities are included in each divergent, convergent, and mixed convergent & divergent co-design stages (i.e. participatory art, programming, and discussion activities, Fig. 1).

IV. Design Methodology: Older Adult Co-Designers

In this section, we provide information on the seven co-design process sessions. As this paper's focus is reflecting on long-term co-design guidelines, we only provide high level protocols of each stage and emphasize the participant experience and researcher-participant relationship. This 3-stage, 7-session methodology provides an example of how co-design can be leveraged in the development of social robots and how it can promote the value of empowering users.

A. *Co-design Process Stages*

The co-design process is modelled in Fig. 1, highlighting the timeline and divergent and convergent stages of the process. The process was structured over the course of a year to allow for participants to reflect on the previous session before the subsequent session and to disperse the time commitment over a longer period of time. The sessions supported experiential, tactile, divergent, and convergent experiences, varying between the sessions (Fig. 2). An overview of each session is included in the following sections. Detailed protocols are provided in separate articles. All study protocols were approved by our institution's IRB and all participants

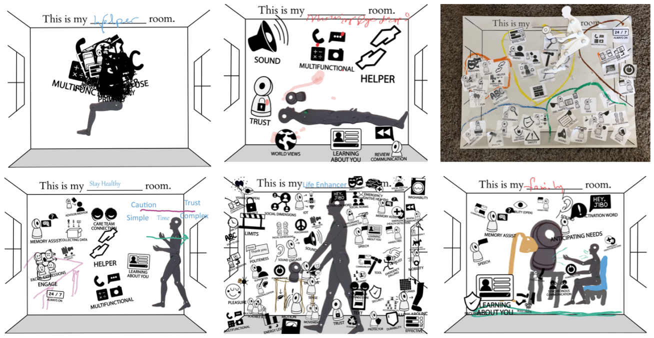

Fig. 3. **Participant images** depicting how participants pictured their relationship with the robot and how they express their space occupied with the robot.

completed a consent form and data collection preferences. The majority of the sessions were individual or in pairs (married couples) to foster rapport with the researchers and encourage unbiased sharing of personal opinions, thoughts, and emotions. After each session, participants were asked to reflect on the session, describing one thing they liked and one thing they would change. For each session below, we present the method structured within the divergence, convergence, or mixed convergence & divergence stage and a highlight of the most significant outcome.

1) Divergence Stage

The first two sessions in the co-design process were designed to encourage divergent and abstract thinking.

Initial Interview: The goal of the initial interviews was to *build rapport with the participants* and to *understand their initial perceptions of robots generally and around the seven areas of interest*. The narrative nature of the interview prompted participants to engage more frequently in divergent thinking and interviewers allowed participants to answer the open-ended questions as they would like with little redirection. Analysis for this session involved multiple approaches including ethnographic decision tree modelling [25] and thematic coding through a grounded theory approach [26].

Participants were largely open to social robots entering their lives, especially favorable towards supporting body signal monitoring and/or memory assistance and monitoring. Some participants did not want a robot to be involved with emotional wellness, medical adherence, and social connection. Specifically, there were concerns around accuracy of delivering medication and the robot having precise information on medication and medical instructions. Participants were unsure of a social robot assisting with emotional wellness, often articulating this function as intrusive or something that participants themselves could handle. On the contrary, most were open to social connection support and were comfortable with a social robot suggesting they connect with someone they have not for some time.

Art-based Image Making: The second session invoked art-making to encourage participants to think about their relationship with the robot. Our goal for this session was to *explore the emotional components when considering the relationship between humans and robots* and *explore how art-based methods can invoke emotion in the co-design process*. After completing their image, participants described their image to the researcher and the researcher asked additional follow-up questions inspired by the image and elements in the image. The art-making process was structured as a visual and broad exploration, prompting people to engage in divergent thinking around a potential relationship with a robot. Images were analyzed through an iterative and collaborative formal element analysis [27] paired with a qualitative analysis of the participant's verbal explanation of their image [27].

The images created by participants were analyzed to understand the emotional and social context around robots. Participants' images depicted the relationship they imagined with the robot in multiple ways (as seen in Fig. 3). The human-robot relationship was articulated as companionship, motivator to reaching a goal, and general "life enhancer". Some participants chose to decorate their rooms to represent the room setting through furniture or positioned figures to describe a scenario such as walking into a room or waking up in the morning. The icons demonstrated the breadth of things people wanted the robot to do for them, often involving the socio-emotional context through icons such as "helper", "trust", or "social and fun behavior".

2) Convergence Stage

The third, fourth, and fifth sessions focused on convergent and concrete thinking.

Robot Hosting & Robot Debrief: The third part (robot hosting) and fourth part (robot debrief) of the co-design process describe both the participant experience with the robot and their reflections. The robot hosting provided an opportunity for participants to live with the technology. The goal for this session was to *provide a lived experience with the social robot to inform perceptions and understandings of the technology*. The robot used in this study was Jibo (shown in Fig. 4), a table-top robot with a touchscreen face and three degree-of-freedom expressive body that can provide several interactions such as chit-chat, information retrieval, physical and mental activities, daily check-ins, etc. Jibo was chosen as it can support long-term lived experience, an essential part of a co-design process. The session provided convergence in the study as the participants familiarized themselves with an example of what it could mean to interact with a social robot through a tangible experience in their homes.

Participants lived with the robot for at least a month, up to 12 months (M=149.5 days, SD=154.8 days). After a month, researchers met with the participants to discuss their experience. The goal for the robot debrief session was to *understand participants' lived experience with the robot* and *investigate how this experience influenced their perceptions around topics such as privacy, proactive behavior, transparency, and customization*. The session prompted convergent thinking around the concrete experience with the robot through thought-provoking tangible card prompts. Transcripts from the session were thematically analyzed through a grounded theory approach [26].

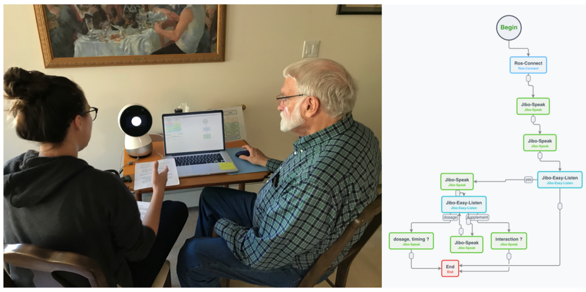

Fig. 4. On the left is a participant programming an interaction. On the right is an example of a programmed interaction where the robot describes the day's events and provides a reminder and any necessary help with medication.

Participants provided valuable contextual information of their robot experience and how they engaged with the robot. Participants thoroughly enjoyed the personality of the robot and some of the proactive interactions. P07 described waking up to the robot, *"I loved having Jibo. I loved his presence here. I love getting over in the morning and say, Hey, Jibo how are you? And he answers, Quite well, how are you? And I said, what are you doing, feeling? And he says, Oh, I feel like a robot. I slept like a robot...And we go through the routine where he gives me the three important messages in the morning."* These comments demonstrates how the robot became a part of people's routines, as people cited using the robot at least once a day for these greeting interactions with the robot. On the contrary, some participants discussed how the robot's idle behavior and social presence could be discomforting at times (Jibo is designed to be always on and has an attentional mechanism to orient towards a sound source of a person's face). P13 reflected on this, saying *"[the robot's social presence] went from sort of cute to creepy...I couldn't keep it on...for the whole day...the thing moving, following me...It took me a while to get to the language Jibo understands. That was a big learning curve..*.In addition to discussing social presence, participants also mentioned the difficulties of communicating with the robot, citing they would appreciate the ability to have a back and forth conversation with the robot.

Robot Rapid Prototyping: Post robot hosting experience, participants engaged in designing and revising the interactions the robot may provide (Fig.4). The goal of this session was to *build upon participant's tangible lived experience with the robot and previous sessions* and *enable older adults to independently prototype interactions on the robot representing how a robot would interact with them over the course of a day*. The session was structured to provide multiple rounds of iteration and a tactile prototyping experience through programming. The activity was focused around 14 interactions postulating how a social robot could interact with older adults throughout the day. Screen recordings were analyzed through annotating significant events, such as programming blocks being added, modified, or deleted by the participant, and duration of the participant programming and modifying interactions. The scripts and programmed flows were recorded and analyzed for changes made across each iteration.

Participants were empowered through learning how to program and create interactions on the robot. Throughout the activity, participants asked questions as they learned to program the robot. After programming the robot, participants reflected on the ease-of-use, difficulties, and concreteness of the interface; limitations of the robot; future designs they would include on the robot; the benefit of embodiment and live performance on the robot; and how the experience empowered them in the study and increased their knowledge of social robots. Commenting on the benefit of gaining knowledge about the robot, P23 said, *"It took some of the mystery out of it...it gave me a little bit of insight...into this whole area of programming...I've always thought...programming must be very boring, but this was quite interesting."* This was echoed in 75% of participants. Overall, participants were very proud of the interactions they developed and contributing to the process of robot design. As P31 said, *"This really makes me feel being a part of this whole study and I appreciate that...our opinions matter and...that...even though we're not programmers...we were still able to do some simple programming and I think that's fun."*

3) Convergence & Divergence Stage

We expanded to a mixed divergent & convergence stage that included both convergent and divergent parts in the sixth and seventh sessions.

Social Robot Design Guideline Generation: With this session, the co-design process moves from convergent to mixed divergent & convergent thinking, opening up the design space for future robot development. The goals of this session was to *generate social robot design guidelines informed by the participants' experience living with the robot and the co-design process thus far* and to *foster group collaboration among the participants*. The session was structured into two parts and lasted three hours in total. The first part included participants generating a list of priorities in the design of their robot (at least 10 per small group; Fig. 5). The second part included participants voting on these design requirements. Participants were encouraged to reflect on their co-design experience and think about how they would design next social robots. Participants' social robot design guidelines were categorized by similar topics to reveal priorities for the next design iteration of social robot interactions. The participant-driven social robot design guidelines were organized into priorities (for example, interaction features, ethical considerations, and role & personality) and provided researchers a guideline to incorporate into future design iterations. This session allowed participants to share their study and lived experiences with one another and collaborate with other participants and the larger research team.

Reflection Interview: The last session of the co-design was the reflection interview with the goal of *understanding changes over the study (revisiting the 7 categories)*, *understanding how participant knowledge grew over the course of the study*, and *understanding how participants reflected on*

Fig. 5. Participants engaged in a social robot design guideline session where they generated social robot design guidelines and voted on them.

the co-design process. The interview was structured the same as the initial interview, except based on participant feedback to make it more structured, we edited the protocol to include a card sorting activity. We also probed for participants' reflections of the overall co-design process. Overall, the interview encouraged convergent and divergent thinking on how participants would like a social robot to be designed in future iterations. As in the initial interview, ethnographic decision tree modelling [25] and thematic coding through a grounded theory approach [26] were used for analysis.

At this point in the co-design process, participants were well-informed based on their experience living with the robot and the co-design activities. They were able to articulate their thoughts, concerns, and hopes for social robots better than in the initial interview. Their final conceptualizations of social robots demonstrated that participants were using their learned information about the robot to inform their decision. Challenges for social robots that were identified included privacy, security, autonomy, and transparency. Participants were concerned about security and privacy but the concern was rooted in the lack of transparency in how the data is being used. With regards to transparency, participants wanted to understand the robot's reasons for its movements, social presence interactions, and data collection. Participants understood the balance between data privacy and robot intelligence (i.e., that for the robot to provide customized interactions, it requires certain data of the user), but wanted to be in control of this balance to weigh in on the benefits. Participants also stressed that data must be stored securely with knowledge of how its used and who has access.

B. Older Adults' Reflections of the Co-Design Process

When asked about the overall co-design process, participants commented on varying aspects of the process. P07 cited their motivation was contributing to the project saying *"...people are asking my...opinions and...I also hope that...I can contribute or I am contributing."*. Participants emphasized that their contributions to the project were meant to be honest and truthful, even if it was not what they thought the researchers wanted to hear. For example, P11 said, *"...we're happy to give you our opinions. They're probably not what you want to hear...but it is what we think...We've tried to be...very forward with you and not pretend that we think social robots are the most wonderful thing in the world..."* It is important for participants to feel open to express their opinions and ideas honestly, and researchers building trust and rapport with the participants is critical in providing space for candid responses.

Overall, participants valued the co-design experience. Participants cited that living with the robot was a valuable learning experience in the process as P25 notes: *"I mean the most useful [part was] really getting to know it and play with it and see what it can do and not do and then to think about what you'd like it to do and not do."* Participants also hoped to continue participating as they're *"part of something that's actually going to be developed and that we'll see something out of it all" (P30)*. As this work is situated in the front end design stages, researchers were very appreciative of participants' desires to continue working with them. In every session, participants expressed the value of their age group having representation in making technology design decisions, stating, *"It's real good to get a feel for all different kinds of people in that age group as you're designing.* (P27). P11 added an additional emphasis to why the co-design process was different than traditional design processes: *"...I'm delighted that you're starting from the other end, because I think that's where the robotic field has gone astray a little bit. They've developed the robots and then said, 'Well, gee, surely they'll be useful for something."'* At the end of their final session, P13 commented, *"Keep us involved. We're curious and we'd like to see how this works."* Remarks such as this demonstrate the success of co-design as a method and its meaning for older adults who may interact with social robots as end users.

V. GUIDELINES FOR LONG-TERM CO-DESIGN WITH OLDER ADULTS

Our long-term co-design methodology provides methods and processes for engaging with users to develop and design social robots. It incorporates divergence, convergence, and mixed convergence & divergence activities to promote idea generation, idea evaluation, and the generation of design guidelines for the next iteration of social robots. Throughout our process, we identified several long-term co-design guidelines for engaging in this design process of social robots with older adults.

Support older adults in co-design processes through social robot lived experiences. In our study, we demonstrate this methodology with older adult co-designers, revealing how older adults conceptualize, experience, program, and desire social robots for the future. We strongly recommend including a lived technology experience where participants can live with the technology in the intended context. By gathering a wide variety of data and providing convergent and divergent design experiences, we were able to support older adults in the co-design process as they gained experience with the social robots and formed their mental model of an ideal social robot.

Provide a diverse set of activities for older adults to engage in design in multiple ways. The variety of activities also allowed us to encourage participants to think and engage in design in multiple dimensions. The art-based image making encouraged divergent emotional reflection; the rapid-prototyping session encouraged convergent tactile programming of participants' envisioned interactions. The rapid prototyping experience contributed to participants recognizing their contributions to the project and the value of viewing their interactions embodied on the robot. We suggest adding a tactile technology development session (such as the rapid-prototyping session in this study) and having a design guideline generation session close in proximity to the technology development session so it can be easily referenced.

Intermix convergent and divergent design activities to foster idea generation and idea evaluation. We also provided sessions with mixed convergent and divergent design activities, namely the social robot design guideline generation session and reflection interview. To our knowledge, this is the first approach that allows participants to generate the social robot design guidelines during the course of the project, instead of researchers solely generating the social robot design guidelines after the project is completed. By approaching the co-design project in a multi-faceted approach along the dimensions of convergent-divergent and tactile-experiential, the co-design process provided data on user engagement and a more holistic, well-rounded understanding of users' desires, needs, and concerns for social robots.

Provide multiple opportunities for iteration within the long-term co-design process. Some of the individual sessions provided multiple rounds of iterations, for example the tactile prototyping activities. The co-design process also had chances for iteration as it used information gathered from previous sessions to inform sessions conducted later on in the process. For example, results from the art-based image making session informed the robot rapid prototyping and reflection interviews, emphasizing key design areas for older adults. Participants' knowledge of social robots evolved over the course of the study as they iterated upon their ideas and used their lived experiences and learned knowledge of social robots to refine and redefine their designs for the robot.

Support multidisciplinary environments and amplify voices in social robot design. With the increase of robots being deployed in everyday contexts [11], people within social contexts must be included in the co-design and participatory design of these technologies, amplifying voices that are not typically heard in the technology design process [28]. Our co-design methodology provides an example and template for multidisciplinary robot design teams to empower users in the design process, filling a much needed void in the HRI methodology space.

Establish long-term respectful and mindful commitments and relationships. The long-term nature of our methodology emphasizes the value of working with participants over time, providing opportunities for them to experience technology, build knowledge around the technology, and use the knowledge to inform their desires and designs for the technology. As participants share personal experiences, reveal problematic or personal situations, and ideate decisions that would change technology interactions, it is critical that researchers are cognizant of the moral ideas and attitudes of participants and themselves [18]. By incorporating users into HRI co-design processes, we can better design robots for social contexts with users and investigate concerns and unanticipated consequences surrounding these technologies.

Within long-term co-design, plan regular communication and sessions, respecting participant's time commitment and effort. Our co-design process lasted one year. We structured the 7 sessions to be over this long-term period to ensure that participants had enough time to reflect on the previous session before the following session and to accommodate the schedules of our participants and respect their time. By having a session roughly every other month, this enabled older adults to feel the participation was less of a time commitment then if all the sessions had been completed in a shorter timeline.

Leverage long-term co-design for long-term data analysis. The long-term nature of the co-design process also allows for analysis across the study, creating room for protocol iterations and tracking participant knowledge, generated ideas, and design preferences and priorities.

Create space and time to establish rapport and relationships with participants. Often the challenge of conducting a co-design study is in deeply engaging the participants in the process, especially over multiple sessions – dedicating sufficient time and tools for the participants to delve into the experience; providing a trusting environment for them to express their thoughts; accommodating their time, health, and other life factors for participation; and, overall, making them feel comfortable and valued in the process. We elected to complete the majority of the sessions one-on-one with the participant which increased the timeline for the co-design. We chose to do this to foster rapport between the researchers and participants and to draw out unbiased personal opinions, thoughts, and emotions that may have been influenced in a group setting. We were also able to accommodate each participant's schedule and health related requests this way, which are crucial factors to consider when engaging older adults in the co-design process. Once the rapport was established, the one-on-one research settings also enabled participants to feel comfortable to express their true emotions with regards to a social robot in their lives. Establishing rapport with participants can also alleviate some challenges of co-design, including maintaining long-term engagement in the process and building the schedule around participant timelines.

Adapt co-design to varying timelines but maintain convergent, divergent, and mixed stages. While we structured the stages over a year-long period with the seven sessions, our methodology can be adapted and applied to other co-design studies with varying timelines. The methodology was defined to have sequential divergent, convergent, and mixed convergent & divergent stages. When structuring a co-design process, we advocate for a similar sequence. The initial divergent stage allows for building rapport with participants and expanding their design space for a social robot. The convergent stage in the middle provides an opportunity for participants to learn about the technology and engage in tactile specific design activities. The mixed convergent & divergent stage at the end allows for researchers to revisit participants' initial conceptions of social robots after participants progress through the co-design activities. This stage also allows for participants to buoy between convergent and divergent thinking, e.g., generating social robot design guidelines (divergent) and evaluating them to direct the next iterations of technology design (convergent). While maintaining this three-stage approach, researchers can choose a variety of design research and participatory design activities to craft future co-design processes. The flexibility in the methodology allows researchers to customize the activities within the three stage process, adapting the co-design process to varying timelines, contexts, and technologies.

VI. CONCLUSION

This paper provides a year-long co-design methodology leveraging convergent and divergent design activities to empower users in the technology design process with researchers. This work was based upon 5 design principles: scenario specific exploration, long-term lived experience, supporting multiple design activities, cultivating relationships, and employing divergent & convergent processes. We identified 10 long-term co-design guidelines for social robot design with older adults around empowering older adults in co-design, leveraging convergent and divergent design activities, building relationships with co-designers, and adapting co-design to various timelines. Overall, we emphasize these long-term co-design principles and guidelines to support and call for respectful and responsible co-design with communities who may, in the future, interact and live with robots. Our successful deployment of the presented methodology in collaboration with our target users provides attestation of how users can be further incorporated into social robot design, creating and testing interactions, and generating social robot design guidelines and new conceptualizations of robots in social contexts. There are limitations to our work as well. Future work is necessary to employ designs and social robot design guidelines generated in the co-design process in future studies to verify them and investigate how varying arrangements of divergent and convergent approaches affect the design process and design solutions.

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