Children using Tabletop Telepresence Robots for Collaboration: A Longitudinal Case Study of Hybrid and Online Intergenerational Participatory Design

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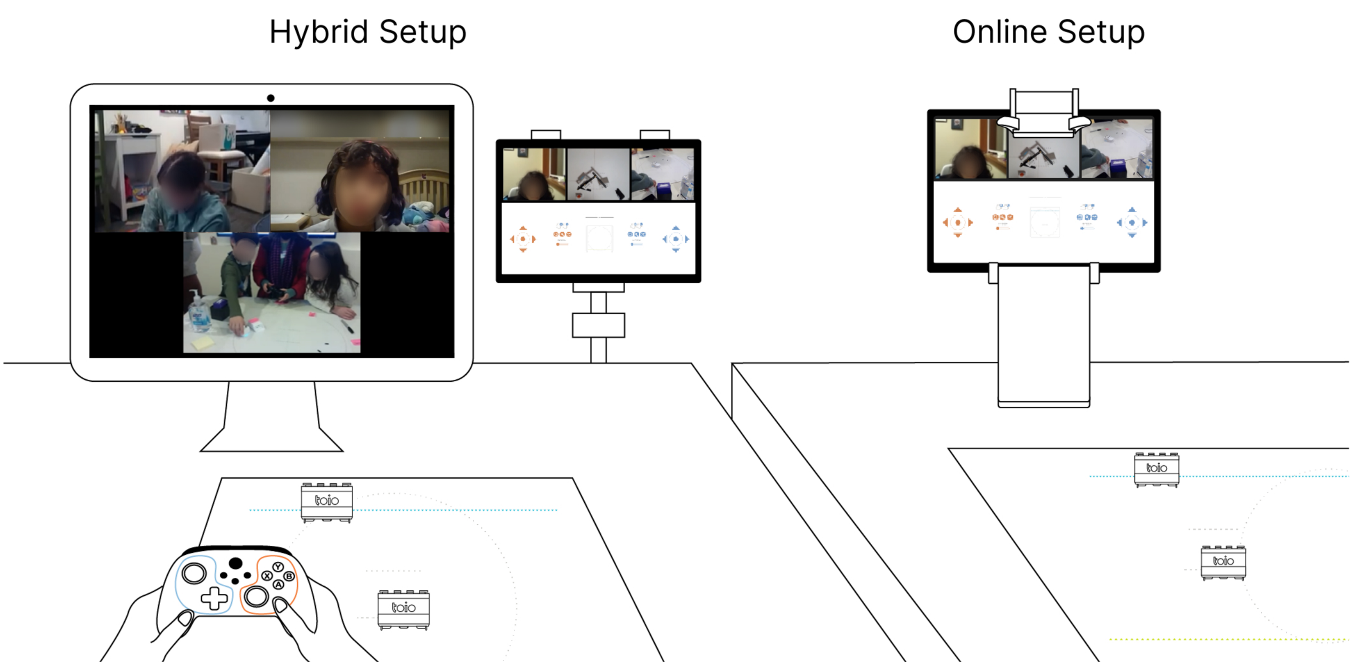

Figure 1: Platform setup during hybrid (left) and online (right) participatory design with children.

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Abstract

Improving telepresence for children expands educational opportunities and connects faraway family. Yet, research about child-centered physical telepresence systems (tangible interfaces for telepresence) remains sparse, despite established benefits of tangible interaction for children. To address this gap, we collaborated with child designers (ages 8-12) over 2-years of online/1-year of hybrid participatory design. Together, we adapted one approach to physical telepresence (tabletop robots) for child users. Using a case study methodology, we explore how our tabletop telepresence robot platform influenced children's connections with one another over the 3-year study. In our analysis, we compare four vignettes representing cooperation/conflict between children while using the platform; centering theories of ownership, collaboration, and co-design roles. Through this exploration of children's interpersonal dynamics while using the platform, we uncover four key features of tabletop telepresence robots for children: (1) Anonymous Robot Control (2) Robot/Material Distribution, (3) Robot Form/Size, and (4) Robot Stewardship.

CCS Concepts

• **Human-centered computing → Systems and tools for interaction design**; **Empirical studies in HCI**; **Haptic devices**.

Keywords

Physical telepresence; Actuated tangible user interfaces; Hybrid collaboration; Online Collaboration; Participatory design; Children

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1 Introduction

For children, telepresence enables more flexible and wide-reaching educational opportunities [13, 76, 77], and closer relationships with faraway family [21, 81]. Despite these potential benefits, many remote collaboration technologies remain under-explored for child users [17]. Notably, although embodiment and tangibility play a significant role in children's development and cognition [45, 56], offering a promising avenue for child-computer interaction [3, 4, 18]; physical telepresence systems (tangible interfaces for remote collaboration) are predominantly explored within offices, universities, and laboratories [11, 41, 42, 55, 73]. In this study, we set out to research the less-familiar *child-centered physical telepresence*, focusing on a promising and emerging approach–tabletop telepresence robots.

Tabletop interactions are fundamental to collaboration in co-located teams [33, 64, 72]; and tabletop telepresence robots facilitate remote participation at this pivotal site of creative partnership [37, 42]. Limited past research has explored how children understand tabletop telepresence robots through metaphor [31], how these robots facilitate play across distances [74], and how their use influences online co-design methods over time [30]. As remote and hybrid collaborations have persisted since the COVID-19 pandemic, unknowns remain about *which features of tabletop telepresence robots play an outsized role in children's peer to peer dynamics.* The hybrid setting in particular, blends both in-person and remote participants, introducing unique questions on social presence, co-regulating group activities, and equitable member participation [22, 29]. Our study presents the first exploration of children's interactions with tabletop telepresence robots *across remote and hybrid contexts.* We examine key features of our system that shaped children's collaborations during various levels of co-location and mediated presence, exploring how to design tabletop telepresence robots for children in remote and hybrid environments—which have become more prevalent in social and educational contexts post-pandemic [8, 15].

In this work, we analyze a 3-year intergenerational participatory design (PD) [16] project with KidsDesign–a group of children (ages 8 - 12) experienced with design [84]–to produce a child-centered tabletop telepresence robot platform. To distill this undertaking into meaningful takeaways for designers of tabletop telepresence robots for children, we analyze 4 vignettes using a 2x2 comparative case study methodology [82]. Our analysis is structured around three theoretical lenses relevant to children's experiences with shared technology (platform/artifact ownership [5, 12]), telepresent collaboration (collaborator coupling [9, 25]), and intergenerational participatory design (intergenerational co-design roles [83]). By comparing children's cooperation and conflict while using the platform across online and hybrid design sessions, we identify four key features of child-centered tabletop telepresence robots: (1) Anonymous Robot Control (2) Robot/Material Distribution, (3) Robot Form/Size, and (4) Robot Stewardship. Finally, we consider the implications of these key features in the context of past research in robotics, physical telepresence, and telepresence for children.

2 Related Work

2.1 Physical Telepresence

Physical telepresence refers to tangible interfaces for remote collaboration and communication [11, 41]. Physical telepresence strengthens social presence and shared context [58, 62]–facilitating relational cues and trust building [40] and enhancing virtual co-working experiences [59, 67, 73]. There is a long history of tabletop collaboration platforms within physical telepresence research [11, 59]. For instance, Leithinger et. al. researched shape displays for remote video instruction and creative collaboration [41]; and Gomez et. al. explored how expressive tabletop robots might enhance text messaging [24]. In the past, tabletop physical telepresence systems were often unwieldy and expensive [39, 59], or task specific [20, 24, 49, 65]. Recently, tabletop robots–such as Sphero [78], and toio [79]–have become inexpensive and commercially available. As a result of this increased availability, tabletop robots (which are portable, low cost, and adaptable) have emerged as powerful tools for tangible interaction [27, 51, 71]. Subsequently, tabletop robots have sprung up as a promising and robust pathway for physical telepresence: supporting spatial [42], interpersonal [37], and task-based [37, 42, 70] interactions during remote collaboration.

Although commercial tabletop robots adopted for physical telepresence are often originally designed for children, *research exploring tabletop telepresence robots for children is limited*. Previously, Tsoi et. al. publicly listed an app to facilitate play through remote control and point-of-view (POV) video streaming using Vector robots to help children connect with remote family [74]. However, despite a large number of downloads, only a small portion of users made use of telepresence features. As a result of this limited adoption, the researchers were unable to provide significant insights on how physical telepresence features of their platform impacted children's relationships with faraway family [74]. Meanwhile, Hunt et al. explored how tabletop telepresence robots co-evolved alongside longitudinal online participatory design practices with children as facilitators and children became more familiar with the platform over time [30], as well as how children made sense of tabletop telepresence robots using metaphors [31].

However, little is known about *how the features of tabletop telepresence robot systems affect children's hybrid and online collaboration with their peers*. Before these systems are adopted for education and play, it is important to understand which features of these systems impact peer to peer relationships. To address this, we analyze how tabletop telepresence robots shape children's online and hybrid collaborations during 3-years of Cooperative Inquiry [16]. This work is unique because it explores key features of tabletop telepresence robot platforms in the context of children's collaborations, and also because it is the first exploration of tabletop telepresence robots with child-users across remote and hybrid contexts.

2.2 Cooperative Inquiry: Children as Equal Design Partners in Online/Hybrid Settings

Cooperative Inquiry is a sub-discipline of participatory design (PD) focused on empowering child design partners to share ideas during the creative process [16, 86]. The Cooperative Inquiry method of intergenerational co-design facilitates balanced and reciprocal creative collaborations between adult and child co-designers [16, 86], which precipitates a deeper understanding of child-computer interaction [26]. While Cooperative Inquiry is traditionally a co-located process, this practice has been adapted to online contexts, particularly during COVID-19 shutdowns [19, 30, 38]. While prior work has explored theories and techniques for remote Cooperative Inquiry [30, 38, 54]; our work centers a *technical intervention* for remote collaboration with children, designed using the adapted online and hybrid Cooperative Inquiry method [19, 38]. To understand the reciprocal relationship [30] between features of the tabletop robot platform and children's online and hybrid creative process [30], in this paper we analyze the both design journey of the system and the video data from intergenerational co-designers' system use.

2.3 Theoretical Framing

We frame our analysis around three theoretical lenses that, combined, address dynamics of technology sharing, technology mediated collaboration, and participatory design roles. In applying this blend of theories, we aim to produce a cohesive picture of children's interactions with one another during online/hybrid participatory design supported by tabletop telepresence robots. In this section, we provide description and justification for each theoretical lens. Theoretical lenses were selected based on their alignment with codes produced during open-axial coding. For more details about lens selection, see section 4.2.3.

2.3.1 Ownership. To understand how children engaged in shared use of the tabletop telepresence robots, we analyze how they navigated ownership of the system and activities during online and hybrid participatory design. Ownership is a psychological principle governing people's perceptions of which items, ideas, spaces, or roles are "theirs" [57]. It is also a central tension of cooperative work and technology supported collaboration [5, 36, 64]. In this paper, we focus on two theories of ownership: (1) ownership marking [12] and (2) ownership sharing [5].

Brown et al. highlights *ownership marking* (any actions that "construct and communicate territories") as a behavior used by colleagues to navigate ownership of shared technology systems [12]. The authors note that ownership marking may become *defensive* or even *retaliatory* in response to perceived ownership infringements, to "maintain and restore territory." Meanwhile, Arnott et. al. defined three types of *ownership sharing* between child technology users: *mutual ownership*–"using a single resource simultaneously and collaboratively", *parallel ownership*–"controlling [independent parts] of [technology] as part of a cluster", or *spectatorship*–supportive engagement with no technology use [5]. By focusing on children's ownership marking, we observe how they perceived and marked the robot system and associated activities as *theirs*.

By exploring children's ownership sharing, we highlight dynamics in children's collaborative engagement with the shared system and activities. Together, these theories of ownership provide a picture of how the tabletop telepresence robots enabled or hindered children to establish shared territory (activities, robots) despite the physical distance between them during online/hybrid participatory design.

2.3.2 Collaborator Coupling. Remote work relies on technology to mediate collaborations [80]. It follows that, the way children form collaborative partnerships with one another during online/hybrid participatory design is shaped by the technology infrastructure supporting these engagements [30]. To explore how children formed and maintained collaborative partnerships with one another while using tabletop telepresence robots, we apply two theories of technology mediated collaboration: (1) collaborator coupling and (2) collocation blindness.

Gong et. al. distinguished three *collaborator coupling* styles in technology mediated collaborations–*divided, loose, and close collaboration* [25]. During *divided collaboration*, users complete tasks in parallel, working independently and without discussion. With *loose collaboration*, teammates communicate and help each other while completing parallel tasks. In *close collaboration*, task completion is tightly and sequentially coupled, with one team-member building/relying on the work of another [25]. Further, *collocation blindness* describes a pattern in hybrid collaboration where in-person team members overlook their online colleagues in favor of co-located associates [9]. As a result, participating and feeling heard in hybrid meetings is sometimes challenging for those who join online [9].

Through the lenses of collaborator coupling and collocation blindness, we consider the influence of our tabletop telepresence robot platform on children's relationships during online and hybrid participatory design. Ultimately, this analysis reveals which platform features strengthened children's connections with remote collaborators, and which presented challenges to these connections.

2.3.3 Intergenerational Co-Design Roles. This project exists within the context of intergenerational co-design. Markedly, creative collaboration with children requires careful consideration to role division and power dynamics [16]. To capture the impact of our platform on online/hybrid co-design with children, we look to theoretical work which describes the dynamics of successful intergenerational co-design.

Specifically, Yip et al. outlined four overlapping but distinct roles that adults and children share during intergenerational co-design–*facilitation*: co-organizing design activities, *relationship building*: cooperative social participation, *design-by-doing*: contributing equally to design products, and *elaboration*: co-producing and mixing ideas [86]. During equitable intergenerational design engagements, adults and children share balanced participation with these roles.

By considering the co-design roles taken up by adults and children during online and hybrid participatory design with the tabletop telepresence robots, we reveal how our platform facilitated and/or disrupted children's relationships with their adult collaborators (intergenerational collaboration) and their process (co-design). Through this analysis, we specifically consider the impact of our platform on children's operational context (online/hybrid co-design), as well as how tabletop telepresence robots shaped children's relationships with adult facilitators/collaborators.

3 Tabletop Telepresence Robot Platform Evolution

In this section, we identify the three phases (Fig. 2) of improvements to our platform, guided by feedback and ideas gathered during 28 participatory design sessions (For details about design sessions including procedures and activities, see Section 4.1.2). At the beginning of the project, each child or sibling pair was provided with a Microsoft Surface tablet, 3D printed tablet stand and flip mirror, two Sony toio robots, and various craft materials/robot accessories (Fig. 3). Adult researchers were provided with the same setup.

Robots were controlled using a single page website, structured around a WebSocket to send control messages to remote robots in near-real time. Robots were connected to the website via Web Bluetooth. No limits or restrictions were placed on which users could connect to a single robot for remote control. Therefore, multiple remote users might control a single robot simultaneously. Children used the tablets to log into the Zoom meeting where design sessions were conducted, as well as the website for robot control. Children paired their robots to the website on the tablet at the start of each design activity. Robots were used on the table or floor in front of the tablet, and children used the flip mirror to toggle between sharing their robots or their faces over video call (Fig. 3).

In phase one (sessions 1-7), we introduced children to a basic prototype and encouraged them to pair robots with the website via Bluetooth. Once paired, users could control their robots locally or select remote robots from a drop down menu. Using the site, users could drive selected robots forward, down, left, or right (Fig

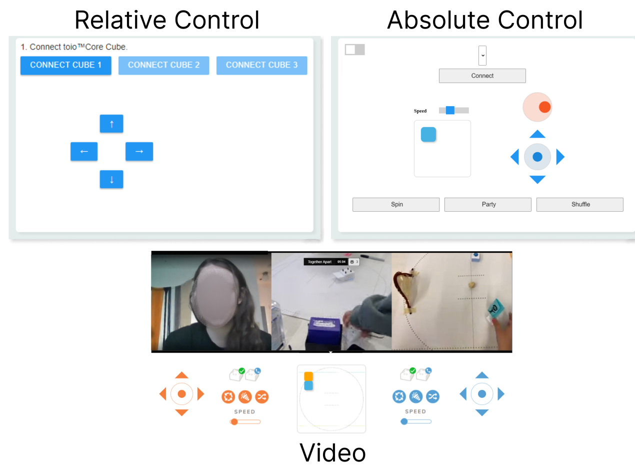


Figure 2: Three key phases of our tabletop telepresence robot platform design. (top left) *Phase 1*: selected robots (local or remote) moved with relative control (forward, back, left, right); (top right) *Phase 2*: addition of absolute position control (robot map) and expressive buttons (e.g., dance and shuffle); (bottom) *Phase 3*: addition of easy toggling between local and remote robots added to robot map, as well as integrated video calling within the application

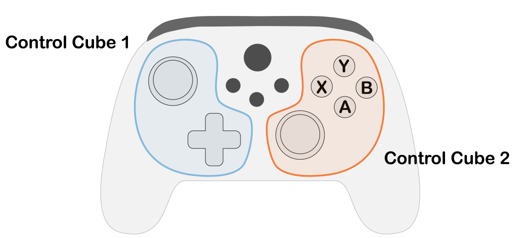
2 left). Based on feedback from the children during this phase, we introduced a "charge forward" button, variable speed, and an on-screen joystick. Initially, all remote actions were anonymous, with no features indicating which users were controlling the robots remotely.

During the second phase (sessions 8-15), we introduced absolute position control, adding a square map to the site which reflected the location of selected robots on a provided play-mat (Fig 2 middle). This feature leveraged the toio robots' ability to track their exact position (within mm accuracy) on a compatible play-mat. With the absolute position feature, children could see the position of selected remote robots in near-real time. For instance, if a child moved their robot by hand across the mat, this movement would be reflected in the web client for all users connected to their robot. The absolute position feature also allowed users to move selected robots to a position on the play-mat by clicking a corresponding location on the website. Additionally, with absolute control, we introduced a "mirror" feature, enabling one robot to follow a selected robot's position on the play-mat. We also added three pre-programmed expressive movement buttons—dance, shuffle, and party—based on children's suggestions.

The third phase (sessions 15-28) marked our transition from online to hybrid collaboration (session 17). During hybrid, children could choose to attend remotely or in person. At this time, robots were collected from children and stored at the university facility. Because children's remote attendance was sporadic (any child might be remote at anytime), remote children did not have access to robots at home. However, adult researchers still had two robots at home during hybrid sessions. Responding to feedback from children about the challenge of using Zoom alongside the website, we integrated real-time video calling to the robot control website (Fig 2 right). During hybrid sessions, facilitators adapted this integrated video feature to provide online participants with two video streams: a face view (Zoom) and a tabletop view (our platform) (Fig. 1). Additionally, we introduced USB game controller compatibility, allowing users to drive selected robots using the joystick, and mapping controller buttons to dance, party, and shuffle (Fig 3).

During this phase, remote movement was de-anonymized based on children's requests. Specifically, notifications describing remote user's control actions were added for robot hosts (e.g. "Sarah moved robot 2 forward," "Stephen pressed party (robot 1)"). The absolute position map was also modified to simultaneously display local and connected remote robots. With all four robots displayed, users could click on the square corresponding to the robot they wanted to drive. This way, toggling between remote/local robots did not require users to close their connection to remote robots (reducing the number of clicks required to toggle control between remote and local robots).

(a)



(b)

Figure 3: (a) Each child/sibling pair was provided 2 robots, a tablet, 3-D printed stand with flip mirror, and various craft materials, (b) In phase 3, we added USB game controller compatibility to the platform. Each controller was controlled the robots selected on the website.

4 Case Study Design

In this paper, we use a case study methodology to explore the impact of our platform on children's relationships with one another during our ~3 year project [82]. We analyze four representative vignettes, using our three theoretical lenses (ownership, collaborator coupling, and co-design roles); structuring our analysis in a 2x2 comparative case study [82]. Using the 2x2 format, we compare children's social interactions while using the robots across two dimensions: cooperation vs conflict, and online vs hybrid (Sections 5.1 and 5.2). Finally, we summarize the findings from all four vignettes and examine broader patterns in our data (Section 5.3). Looking at these patterns in children's interpersonal connections while using the robots, we identify four key features of our platform: anonymous control, robot/material distribution, robot form/size, and robot stewardship.

4.1 Context

4.1.1 Participants. Over the course of this project, we worked with a total of 17 children aged 8 to 12 at KidsDesign intergenerational participatory design team (Table 1). These children are recruited from the community surrounding the University of Washington through word-of-mouth, mailing list, and posters. Children who join KidsDesign are selected to represent diversity across gender, socioeconomic status, and ethnic background.

When children join KidsDesign, parents sign an IRB-approved consent form, and children sign an assent form. During the consent process, families are informed that children may withdraw at any time. Each child participant is compensated with a one-time $150 gift card when joining the design group. Annually, participating children and families are asked whether they would like to continue or leave the program. All adult facilitators complete ethics and safety training for research with children. All child data is anonymized and securely stored on a university server.

4.1.2 Design Process. KidsDesign uses a Cooperative Inquiry approach [16]. Cooperative Inquiry prioritizes equal design partnerships between adults and children to produce technologies that are in alignment with children's unique culture, capabilities, and preferences [16]. Our project was motivated by KidsDesign's choice to shift to online meetings in response to COVID-19 lockdown. This setting provided a unique opportunity to explore physical telepresence with children, as KidsDesign was one of few intergenerational design groups conducting regular sessions via video conference during lockdown [19, 38]. As social distancing measures eased, KidsDesign transitioned to hybrid meetings. During hybrid sessions, children could either attend PD sessions in-person at a local university, or remotely via Zoom. As a result of our long term partnership with KidsDesign, this project followed the same format, starting online (March 2020 to February 2022), then transitioning to a hybrid configuration (February 2022 to May 2023).

From March 2020 to May 2023 (38 months), we conducted 28 (16 remote/12 hybrid) participatory design sessions. During these sessions, participants collaborated in small groups of 2-3 children and 2-3 researchers (graduate/undergraduate students and faculty) from computer science, industrial design, and child-computer interaction. In each session, we either prompted children to contribute to the telepresence platform directly–e.g. "design a new button for the robots"; or to design *using* the platform–e.g. "design and play a sport with the robots". During sessions, adults played a supporting role in design, prioritizing helping children feel safe to share and expand on their own design ideas. Adults also contributed to children's designs building on their ideas and proposing new directions.

Each session followed a structured format, broken into *Welcome Time* (15 minutes): participants socialized, discussed a warm-up question related to the session goals, and facilitators introduced the design prompt and activity; *Design Time* (45 minutes): small groups used Cooperative Inquiry techniques to address the design prompt; and *Discussion Time* (15 minutes): groups reconvened, summarized and reflected on Design Time, and proposed topics for future sessions.

4.2 Data Collection and Analysis

4.2.1 Data Collection. In all sessions (hybrid and remote) we used Zoom to record video and audio data. During hybrid sessions, we also used screen recordings to capture video data from our platform's integrated video feature (Section 3. In each design session, child and adult collaborators shared editing privileges in a Google Slides file. We used this file to share the warm-up question and design prompt, as well as to collect notes and screenshots of artifacts produced during Design Time. In total, we collected ~150 hours of video data during the 28 (16 online/12 hybrid), 90-minute design sessions. Video transcripts were initially auto-generated using Zoom, then reviewed for accuracy by graduate students. To avoid audio interference during Design Time in hybrid sessions, each small group of in-person participants (Section 4.1.2) worked in separate rooms.

4.2.2 Codebook. To process and structure our large corpus of video data, we employed an open inductive analytical approach using grounded methods [14]. During this process, seven coders (graduate students and faculty) created analytic memos from 10-minute segments of design session recordings [60]. These memos summarized the actions and conversations of participants. Afterward, memos were reviewed by a second member of the coding team for accuracy and completeness.

During memo writing, we asked primary and secondary reviewers to flag noteworthy moments and apply open codes to them. We used these initial open codes to develop a first draft of our codebook. Using this initial codebook, the same seven coders reviewed all analytic memos, applied axial codes from our codebook where applicable, and highlighted edge cases which fell outside existing code categories. To ensure validity, we followed a primary/secondary review process. With the primary coder reviewing each memo and applying relevant categories/subcategories, and the secondary coder reviewing codes for accuracy and completeness.

When data did not align with existing codes, or primary and secondary coders disagreed about which codes to apply, we engaged in a dialogic consensus process during 10 weekly code review meetings attended by all coders and advising faculty [47]. In these meetings, we worked toward unanimous agreement about how make changes to the codebook or categorize contested data.

4.2.3 Vignette Selection. Given the large corpus of data, we selected a subset analytic memos to focus on the interpersonal dynamics between children while using the platform (child to child, via robot). In this process, four graduate students from the coding team collaborated to review all memos, each highlighting 5-8 segments, 10-20 minutes long, depicting interesting interactions between children while they used robots to design together. In total, 30 relevant segments were identified.

Addressing only this subset, the four graduate students again engaged in an open-axial coding process [60], refining the broader codebook for this focused view of the data. Five descriptive categories emerged: "control scheme affordances/challenges," "boundaries/interpersonal frustrations," "children collaborate vs work independently," "robot distribution," and "roles and responsibilities." Based on these categories, graduate students and advising faculty on our research team proposed several theories from existing literature which could further contextualize and guide our analysis of this subset of data. We selected our final theoretical framing based on: (1) alignment with axial codes/categories, (2) suitability for our population (prioritizing child-specific theories where possible), and (3) applicability to our intergenerational participatory design context. Guided by these theories, each of the four graduate student was asked to select four vignettes from the 30 segment sample, based on which combination best captured the patterns we observed in the data. These selections were reviewed and discussed at weekly research meetings, until we reached a unanimous agreement about which vignettes best represented the data [47].

Although the four selected vignettes were not initially categorized as contrasting cases, once we selected them, it became clear that they covered two sets of contrasting contexts–cooperation vs conflict, and online vs hybrid. Therefore, we opted to apply a 2x2 comparative case analysis [82] to analyze them. In our analysis, vignettes are analyzed in two pairs (online vs hybrid cooperation and online vs hybrid conflict) using our three theoretical lenses (Section 2.3). After analyzing both pairs of cases, we consider all four vignettes together–paying special attention to the features of our platform that repeatedly appeared during pivotal moments in children's interpersonal relationships.

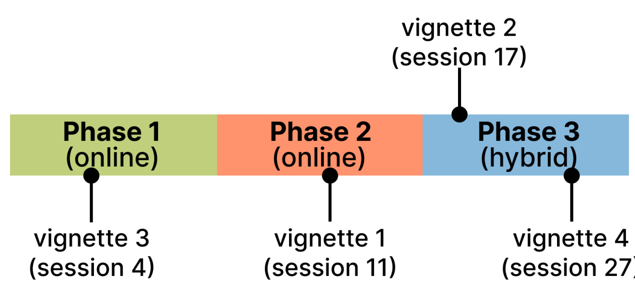


Figure 4: Timeline of phases of the system design (Sec 3) including selected vignettes.

4.2.4 Triangulation with Children. To ensure construct validity and triangulate our interpretations [23, 69], we asked KidsDesign to analyze the four vignettes we selected as well [85]. To facilitate children's understanding of the vignettes, we condensed them

Participant #	Age	Gender	Ethnicity	Year in KidsDesign	Project Active Year
C1	10	male	White	4	2020 - 2022
C2	9	female	Black Asian	3	2020 - 2023
C3	11	male	Asian	4	2020 - 2021
C4	10	male	Latin American	4	2020 - 2023
C5#	12	female	Asian White	3	2020 - 2023
C6#	8	female	Asian White	3	2020 - 2023
C7&	8	male	Asian White	2	2020 - 2022
C8&	10	male	Asian White	3	2020 - 2022
C9	9	male	Asian White	2	2020 - 2021
C10	10	female	White	1	2020 - 2021
C11**	9	female	White	1	2021 - 2022
C12**	11	female	White	1	2021 - 2022
C13	10	male	Black	2	2021 - 2023
C14	8	female	White	1	2022 - 2023
C15	8	male	Asian White	1	2022 - 2023
C16*	8	male	White	1	2022 - 2023
C17*	10	male	White	1	2022 - 2023

Table 1: Demographics of child participants. Siblings are denoted by *, **, &, and #

into storyboards using screenshots, quotes, and descriptions [48]. During one 90-minute PD session, we asked KidsDesign to act out these storyboards. Then, to and discuss them guided by provided questions addressing four topics: distribution/role of robots, boundaries/interpersonal considerations, the role of adults, and likes/dislikes of online versus hybrid. Afterwards, three graduate students reviewed video data, slides, and transcripts from this session to produce a written summary. We used this summary to inform and refine our analysis of the vignettes (Section 5).

5 Findings

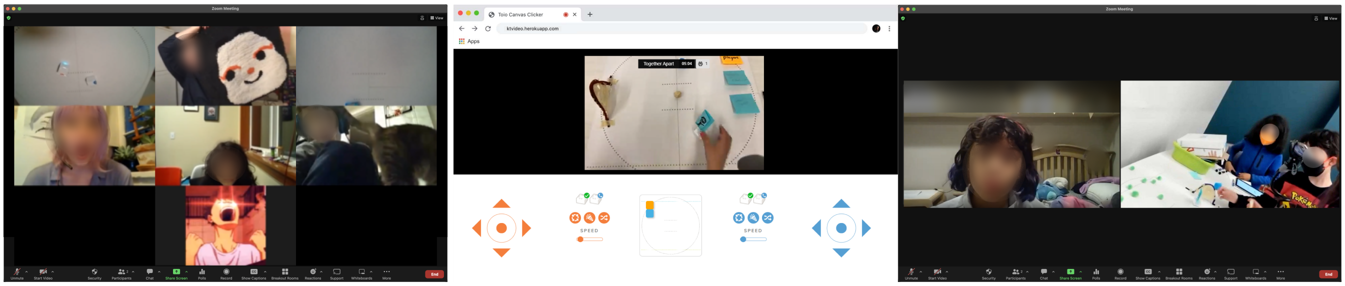
This section contains analysis of: cooperative vignettes (online vs hybrid) in section 5.1, conflict vignettes (online vs hybrid) in section 5.2, and key features for child-centered tabletop telepresence robots in section 5.3. For section 5.1 and 5.2, we present the paired vignettes (short summary of a 10 to 20 minute segment of video), then analyze them through our three theoretical lenses (ownership, collaboration, and co-design roles). Finally, we compare all vignettes using the same theoretical lenses, paying special attention to features that impact children's interpersonal interactions. For readability, we refer to children by their participant number (Table 1), plus a suffix indicating whether they were online during the vignette (O), or in-person (IP). Adult facilitators are also assigned a participant number and suffix. For details about how these vignettes were selected, see Section 4.2.3.

5.1 Vignette Pair 1: Online/Hybrid Cooperation

Vignette 1: Online Cooperation. During session 11, four children (C4-O, C7-O, C11-O, and C8-O) and two adults (A1-O and A2-O) were introduced to a new feature that enabled robots to mirror each others' movements. Before A1-O started introducing the feature, her robot began to move. She joked that, based on the robot's *"personality"*, she thought C8-O was driving it. C8-O began giggling, admitting that A1-O guessed correctly. Suddenly, C11-O's robot raced toward the edge of her table. She laughed, trying to catch it as it darted away, and sternly said *"whoever is controlling it needs to stop."* C4-O admitted that he was driving, and the robot stopped moving. A1-O smiled, saying she could tell he was driving. Later, A1-O introduced the new feature, and asked what it could be useful for. However, C11-O confessed that she was too overwhelmed with her own robot–which had resumed darting around–to learn.

A1-O pivoted, sharing a slide that read "what's next for Toio?" and asking how they would like to use the robots next. C7-O suggested a *"chicken army,"* while drawing a chicken on the slide. A2-O observed that C8-O had been nudging C11-O's arm with the robot, and suggested that the robots could "nudge" friends to log into *Animal Crossing*. Meanwhile, C7-O became annoyed with his cat, inspiring A2-O to ask how the robots could be annoying. C11-O said *"a robot that drives off the table is annoying."* A1-O agreed, adding that a beeping robot would also be annoying. C7-O began beeping, like an annoying robot. Then, A1-O asked how the robots could help children feel closer to each other. A2-O suggested adding personalized accessories to the robots, like a Goldfish for C7-O because he likes Goldfish crackers, C8-O agreed.

Vignette 2: Hybrid Cooperation. In session 17, children collaborated to build a robot soccer field. Two robots and assorted craft materials were provided to in-person participants C4-IP, C6-IP, A3-IP, and A4-IP at the university facility–while C2-O joined online. At the start of the session, C4-IP and C6-IP discussed how to make soccer players. First, C4-IP drew them onto sticky notes, but they tipped over–so C6-IP reinforced them with pipe cleaners. C2-O observed that they needed a goalie, and A3-IP asked her what she would use to make it, listing available materials. C2-O suggested a pompom, and A3-IP placed one into the goal. Meanwhile, C4-IP adjusted the weight distribution of a pipe cleaner goalpost, while C6-IP made more players.



(a) (b)

Figure 5: Images from (a) Online and (b) Hybrid Cooperation Vignettes

Then, A3-IP suggested that C2-O could play soccer with one of the robots, and C2-O agreed. Next, A3-IP helped her connect, and C2-O began pushing one of the pompoms on the table into the goal with the robot. As the robot drove close to a sticky note player, A3-IP joked that C2-O should be careful to avoid a penalty. While C2-O pushed the pompom, C4-IP noticed it did not roll well. To improve it, he started wrapping it in tape, while periodically asking C2-O to test the new ball. Afterward, A3-IP connected a second robot, suggesting that the children could team up and play soccer together. As C4-IP began driving, C6-IP corrected A3-IP, declaring that the robots should compete! In turn, C4-IP and C2-O's robots tussled, fighting to get the ball in the goal, while A3-IP and C6-IP cheered them on. While playing, C4-IP remarked that "someone random" was controlling the robot, but A3-IP reiterated that C2-O was driving.

5.1.1 Analysis of Vignette Pair 1.

Ownership. In the online vignette, C11-O appeared overwhelmed while wrangling her robots, as C7-O playfully used remote control to avoid capture. In this instance, *mutual ownership* resulted in conflicting concerns, with C11-O focused on robot safety while C7-O prioritized mischief. Notably, C11-O emphasized uncertainty about the identity of the robot driver, and *marked ownership* by directing them to stop moving the robot. In response, C7-O revealed himself as the *mutual owner*, and deferred control to C11-O. Later, when A1-O asked how the robots could be improved to support social presence, co-designers suggested *ownership marking* with accessories (like a Goldfish hat) to make faraway friends feel closer. Meanwhile, at the start of the vignette, A1-O playfully guessed robot drivers based on their *"personality"*, illustrating that children recognized and employed direct (words, accessories) and indirect (robot movement characteristics) *robot ownership marking*. In particular, we observe that co-designers ideas and discussions about *robot ownership* primarily concerned *remote ownership marking*.

In the hybrid vignette, C4-IP and C6-IP designed a soccer field for the robots, while C2-O controlled a robot at the university facility. Through her *sole ownership* of the robot on C4-IP and C6-IP's soccer field, C2-O acted as *parallel owner* of the activity, by providing feedback to improve the game. Later, A3-IP assigned C4-IP ownership of the second robot; and C6-IP, *spectating*, suggested that C4-IP and C2-O use the robots to compete. In response, both robots raced to score a goal. Soon after, C4-IP mentioned confusion over who was driving the robot, and A3-IP used *verbal marking* to remind him that C2-O was the robot owner. We note that use of the robots in this vignette resulted in *mutual ownership* of the activity–with A3-IP assigning/stewarding robot ownership, C6-IP suggesting rules to the game, and C4-IP and C2-O playing soccer together.

Across online and hybrid, robots *enabled mutual ownership* between remote children. In vignette 1, C4-O and C11-O *mutually owned* her robot. In vignette 2, C2-O and C4-IP *mutually owned* the soccer game. In addition, *spectatorship* played a significant role in *mutual ownership* during hybrid, like C6-IP's idea that C2-O and C4-IP should compete to score a goal. In both vignettes, *stewardship and control* emerged as important aspects of robot ownership, with C11-O acting as a steward online, while A3-IP played this role during hybrid. In both cases, we observe an ownership hierarchy–with those in *control* of robots deferring to *stewards'* suggestions.

Collaborator Coupling. During the online vignette, C11-O and A1-O discussed how the robot driving off of the table was annoying, while C7-O and A1-O considered how annoying a beeping robot would be. Though these child co-designers took inspiration from each other, they primarily focused on their own line of thought (*loose collaboration*), relying on *close collaboration* with their adult collaborator (A1-O) to refine their ideas. In contrast to this observed dependence on adults for discussion, we observe that the robots acted as a bridge between children, supporting their *close collaboration.* For instance, when C8-O nudged C11-O's arm, inspiring A2-O's suggestion to use robots to "nudge" friends to play *Animal Crossing*.

In the hybrid vignette, when C4-IP and C6-IP (in-person children) *closely collaborated* to design the soccer players, they focused on ideating with each other. However, at the beginning of the collaboration, C4-IP and C6-IP did not interact with C2-O. This *collocation blindness* resulted in *divided collaboration* between the online and in-person children, with C4-IP and C6-IP focused on their players while C2-O *closely collaborated* with A3-IP to create the pompom goalie. Later, C4-IP and C2-O played together with the robots, while A3-IP and C6-IP provided commentary. In this instance, the robots reduced *collocation blindness* for in-person children, and resulted in *close collaboration* between C4-IP, C6-IP, C2-O, and A3-IP as they iterated on the ball design, and then played/watched robot soccer together.

Across both vignettes, online children *collaborated closely* with adults. In the online vignette, children relied on discussion with A1-O to build ideas about how to design annoying robots, and were less likely to discuss their suggestions with one another. During hybrid, in-person children gravitated toward using craft materials at the university facility to create a soccer field design together. So, C2-O needed help from A3-IP to make changes to the design. In addition, in-person children exhibited *collocation blindness* toward C2-O, gravitating toward *close collaboration* with one another. However, across online and hybrid, the robots helped overcome these barriers to *close collaboration* between children. In both vignettes, as children used our platform, they shifted toward designing together—despite the physical (and subsequent interpersonal) distance between them.

Co-design Roles. During the online vignette, A1-O adapted the design activity to accommodate C11-O, who was overwhelmed with her robot. This act of *co-facilitation* resulted in a departure from the planned activity, with co-designers instead *elaborating together* to brainstorm ideas (e.g. how to make the robots annoying). In addition to discussion, co-designers played together with robots and co-edited slides to *design-by-doing*. Additionally, the robots played a role in co-designer's *relationship building*, such as A1-O guessing the robot driver, and C4-O playfully avoiding capture by C11-O.

During hybrid, co-designers used craft materials to *design-by-doing*, creating a robot soccer field at the university facility. While in-person children had direct access to the field, which resulted in more frequent *elaboration* between them, A3-IP *facilitated* collaboration between C2-O and the in-person children by listing available craft materials, and connecting her to a robot. Notably, this decision resulted in C4-IP and C2-O *elaborating* together to design a soccer ball–with C4-IP reinterpreting the C2-O's pompom goalie as a ball, then making incremental changes for the ball to roll better, relying on C2-O to test his ball designs and provide feedback. Finally, when A3-IP *facilitated* the connection of a second robot, she enabled *relationship building* between online and in-person children, with C4-IP and C2-O playing robot soccer together while C6-IP and A3-IP cheered.

In both vignettes, the robots aided in *relationship building* between children. Online, children used the robots to playfully nudge and prank each other. During hybrid, online and in-person children played soccer together, supported by the robots. Meanwhile, we observe that adult *facilitation* regarding how/when to use the robots played a crucial role in both vignettes. For instance, A3-IP connecting the second robot caused C4-IP and C2-O to play soccer together. Similarly, A1-O adapting the design activity and de-emphasizing the new features resulted in co-designers *elaborating together* to brainstorm ideas. Finally, despite *design-by-doing* taking different a format during online (discussion and slides) and hybrid (craft materials)–in both vignettes the robots played an important role in *elaboration* between remote children as they engaged in *design-by-doing* together.

5.2 Vignette Pair 2: Online/Hybrid Conflict

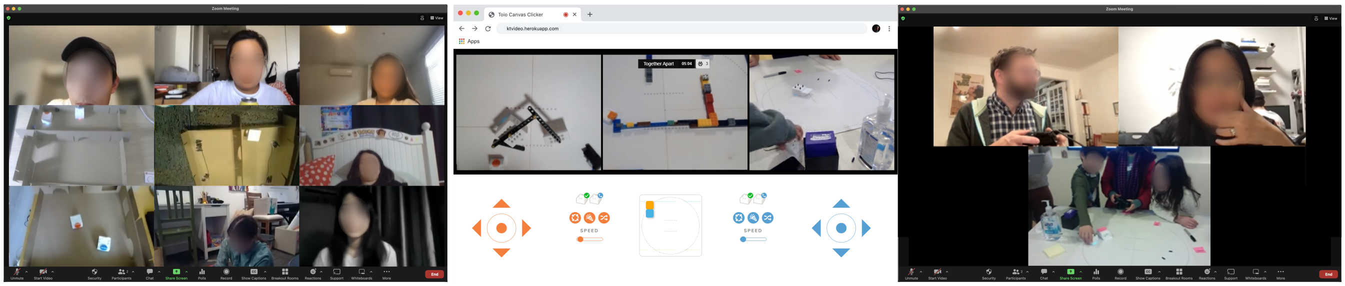
Vignette 3: Online Conflict. In session 4, two children (C5-O and C10-O) and two adults (A1-O and A5-O) designed a marble mazes for their robots using provided laser cut pieces. Initially, the group discussed A5-O's marble maze, deciding together on a design with three equal sections. Then, A5-O placed a few marbles and both of his robots inside. Soon, C5-O connected to one of A5-O's robots and began carefully moving marbles through the first partition. When a few marbles got stuck in a corner, A5-O and A1-O suggested spinning the robot. C5-O took their advice, and marbles flew throughout the maze. As the second robot remained still, A1-O asked C10-O if she needed help connecting to it. However, C10-O preferred to use her own robots, and A1-O helped her set them up.

While C10-O designed her own maze, C5-O continued solving A5-O's maze alone, periodically asking for help. The adults cheered her on and suggested new strategies. As C5-O neared end of A5-O's maze, she shared disappointment with adults, calling them *"bystanders, just watching [her] struggle."* Suddenly, A5-O's second robot started moving, darting in front of C5-O's robot and toward the the marbles she had carefully aligned near the maze goal. C5-O quickly drove her robot to block it from moving the marbles into the goal, yelling: *"hey yo, move move, I am putting those in, no!"*. The anonymous robot pushed past, nudging the marbles into the goal. C5-O burst out *"This isn't fair, I did all the work...I am gonna attack them"*, while dashing her robot into theirs. A1-O asked who was controlling the robot, and C10-O asserted it was not her. Addressing C5-O's disappointment, A1-O suggested that the second robot had *"assisted [the goal],"* but C5-O disagreed. A5-O reset the marbles and separated the robots, while A1-O encouraged C5-O and C10-O to try solving the maze a second time together. However, C5-O remained frustrated, calling the anonymous driver *"a ball hog, a glory hog"* and dashing into it again.

Vignette 4: Hybrid Conflict. During session 26, we provided a kit of Lego-like parts for children to design robot attachments. In-person co-designers–C6-IP, C15-IP, C14-IP, A6-IP, A7-IP, and A5-IP–had two robots, a tablet, a USB game controller, and an attachment kit. Meanwhile, A1-O and A8-O, each had two robots and an attachment kit available for remote play. At first, C14-IP used the tablet and C15-IP used the game controller to drive the in-person robots together, while C6-IP and A6-IP added sticky notes to each robot, labeling one "C14-IP" and the other "C15-IP."

When C14-IP shared confusion about which robot she was controlling, A6-IP asked A1-O and A8-O "do we know who is controlling which robot?" A1-O responded "can you tell us what's going on?" Before A6-IP could answer, C6-IP lifted both robots off of the table. Next, she set one robot down, instructed C14-IP to move it, and labeled it "C14-IP." However, C15-IP moved the robot instead, surprising himself. C6-IP, irritated, responded that he had "moved the wrong one." C6-IP held down the robot that C15-IP was driving, preventing it from moving, and modified the attachment design.

Suddenly, C14-IP asked to use the game controller, and C6-IP asked for a turn too–A1-O agreed that the children should share. Noticing that C15-IP ignored C14-IP, C6-IP, and A1-O's requests for him to share the controller, A6-IP asked him to pass it to her. Once C15-IP acquiesced, A6-IP passed the controller to C6-IP–who began driving both robots. While C6-IP was driving, C15-IP quickly tweaked one attachment, but C6-IP undid his change. He reached for the robot again, but C6-IP blocked his arm. Then, C6-IP started combining attachments to stack one robot on top of the other. A1-O said: *"I see there's a robot stack going on, what is happening?"* C15-IP,



(a) (b)

Figure 6: Images from (a) Online and (b) Hybrid Conflict Vignettes

leaning over the table, asked C6-IP: *"What are you doing?"* But C6-IP did not respond to either of them. Finally, C15-IP placed a sticky note on top of C6-IP's robot stack, saying *"I call it mount C15!"*, but C6-IP quickly removed it.

5.2.1 Analysis of Vignette Pair 2.

Ownership. Online, A1-O encouraged C5-O and C10-O to control each of A5-O's robots and *mutually own* the marble maze. However, C10-O preferred to *spectate*. Similarly, the adults watched C5-O drive A5-O's robot, suggesting strategies to solve the maze but opting not to move robots themselves. When A5-O's second robot suddenly darted toward the marbles, C5-O *defensively marked ownership of A5-O's marble maze*, using her robot to push the unknown driver away before finally angrily dashing into the *"glory hog"*. Notably, the second robot driver opted out of *ownership marking*, remaining anonymous even after A1-O asked their identity. We observe that, in contrast to C5-O's frustration with the second robot, she was understanding when A5-O reset the marbles–accepting his *mutual ownership* as maze/robot steward.

In the hybrid vignette, C15-IP drove the in-person robots, while C6-IP held them down to add attachments. From these early moments, we witness an *ownership conflict* between C15-IP and C6-IP over the robots. Although several co-designers attempted to negotiate ownership between them by suggesting *parallel ownership* between C15-IP and the other children, C15-IP was reluctant to share. However, when A6-IP suggested C15-IP share the controller, he listened, suggesting that he may have considered A6-IP *mutual owner* and steward of the activity/robots. Finally, we note that C6-IP and C15-IP's *ownership conflict* centered three components: the game controller, the in-person robots, and the in-person accessories. Interestingly, while C6-IP and C15-IP used *defensive marking* to maintain *sole ownership* of these contested items, remote robots and the tablet controller sat unused.

In both vignettes, conflicting expectations about robot ownership were communicated through *defensive ownership marking*. In vignette 3, when an anonymous robot driver attempted to *mutually own* the maze activity with C5-O, she dashed her robot into theirs. In vignette 4, when C15-IP drove the in-person robots, C6-IP held them down to change the attachments. Additionally, in both vignettes, ownership conflicts extended beyond the robots/controllers, to include the activity (e.g. solving A5-O's maze or designing robot attachments). Strikingly, despite access to many robots, controllers, and accessories during both vignettes, children exhibited ownership conflict over specific items–demonstrating preferred ownership of certain components. Finally, even while frustrated, children in both vignettes seemingly recognized one specific adult (A5-O and A6-IP) as *mutual owners* of the activity–deferring to their instructions and suggestions. In each case, we observe an emerging relationship/role division between robot stewards and robot controllers.

Collaborator Coupling. Online, despite A1-O encouraging C5-O and C10-O to *collaborate closely* to solve A5-O's marble maze, C10-O chose to control her local robots instead. As a result, C5-O and C10-O took a *divided* approach to the activity. Meanwhile, adults *collaborated closely* with children through discussion: contributing to C5-O's maze strategy, and helping C10-O set up her robots. Though the actions of the anonymous robot and C5-O were *closely coupled*, C5-O expressed that she did not see the robot as a collaborator, but rather a foe. Notably, when A1-O challenged C5-O to see the robot as her collaborator, C5-O became more frustrated and resumed ramming into the second robot.

During the hybrid vignette, C15-IP and C6-IP engaged in *closely coupled* actions, as they deconstructed each other's contributions. However, they never collaborated with one another, preferring a *divided* approach. Also, co-designers in this vignette encountered misunderstandings about collaboration styles. First, A6-IP and C6-IP encouraged *divided collaboration* by labeling the robots "C14-IP" and "C15-IP", but C15-IP confused the controls and drove "the wrong one". Later, C15-IP and A1-O tried asking C6-IP questions to engage in *loose collaboration*, but she ignored them. These points of confusion appeared to intensify conflict, (e.g. C6-IP lifting the robots off the table, and C15-IP/C6-IP's scuffle about the name of the design). Finally, in this vignette, children never responded to online adult A1-O's questions–demonstrating *severe collocation blindness*. A6-IP attempted to overcome this challenge by acting as a communication link, *closely collaborating* with both in-person children and online adults to relay messages between them (e.g. repeating C14-IP's question about the robots to the online adults).

In both cases, we observe *non-collaborative close coupling* in children's actions. For instance, in the hybrid vignette, C15-IP and C6-IP worked at cross-purposes, undoing each other's designs. And online, the anonymous robot solved the maze by rushing in front of C5-O's robot. Additionally, confused expectations about collaboration coupling between co-designers appeared to intensify conflicts in both vignettes, such as C15-IP accidentally moving "C14-IP's robot", and A1-O challenging C5-O's assertion that the anonymous robot driver was a foe. Finally, we found that *collocation blindness* was a significant barrier during the hybrid vignette, with in-person children demonstrating near-obliviousness to online adults. As a result, online adults and in-person children relied on *close collaboration* with A6-IP, to relay information between them.

Co-design Roles. *Online,* C5-O's sole effort to solve A5-O's maze demonstrated unbalanced *design-by-doing*, which she attempted to resolve through *facilitation* when she accused adults of "watching her struggle." However, the adults were focused on *elaborating*–discussing solutions with C5-O and helping C10-O connect to A5-O's robots–appearing reluctant to *design-by-doing* with robots. Also, we observe that co-designers repeatedly tried *facilitating* to diffuse conflict. For instance, C5-O instructed the robot driver to stop moving the marbles, and A1-O and A5-O tried distracting C5-O. However, despite this *balanced facilitation* between adults and children, C5-O demonstrated *disrupted relationship building* with adults, ignoring their attempts to diffuse her frustration and move past the conflict.

In the hybrid vignette, C15-IP and C6-IP focused on separate aspects of the activity: first, C15-IP drove the robots and C6-IP decorated them, then C15-IP tried to decorate while C6-IP drove. While they were each *designing-by-doing*, they did not *elaborate*. Then, when conflict arose from C15-IP and C6-IP's clashing goals, both children and adults attempted to mediate. For instance, A6-IP and A1-O responded to C6-IP and C14-IP's suggestion to share the controller–demonstrating *balanced facilitation*. However, when C15-IP passed the controller to A6-IP, she opted to hand it to C6-IP, bypassing a discussion with children about who should have a turn next (*imbalanced facilitation*). Throughout the vignette, we observe *disrupted relationship building* as a result of conflict over the platform/activity. For instance, when C6-IP ignored C15-IP's attempt to *elaborate together* by asking about her design.

In both cases, children attempted *facilitation* when their expectations were not met, such as when C5-O asked adults to help solve the maze or when C6-IP and C14-IP requested turns with the game controller. At the same time, during these moments of conflict adults sometimes misread invitations from children to engage in *balanced facilitation*. In both cases, when adults prioritized session flow, bypassing conversations with children about how to manage tension about robots and activities–conflict escalated. For instance, when A1-O and A5-O encouraged C5-O to try solving the maze again, and A6-IP passed the controller to A1-O (*imbalanced facilitation*). Finally, we note that, even amidst conflict and misunderstanding, the robots provided opportunities for children to *design-by-doing* and *elaborate* together, like C15-IP and A1-O asking C6-IP about her attachments, and C5-O suggesting adults help her solve the maze. However, these *balanced facilitation* attempts were ultimately unacknowledged, *disrupting relationship building*.

5.3 Summary of Findings: Identifying Key Features

In sections 5.1 and 5.2, we compared children's cooperation vs conflict across online vs hybrid PD sessions. Next, we analyze all four vignettes together, focusing on key features of our tabletop telepresence robot platform that affected children's interpersonal interactions in conflict *and* collaboration during online *and* hybrid design.

Ownership. In the collaboration vignettes, the robots supported *mutual ownership* of activities between remote children. However, in the conflict vignettes, despite attempts to engage in *mutual ownership*, children instead *defensively marked sole ownership* of robots, controllers, and activities. Notably, in all vignettes, use of the robots led to either *mutual ownership* of or *ownership conflict* about design activities. Because these dynamics extended beyond the platform and into design activities, we infer that the robots enabled children to invest in and contribute to each others designs, despite the physical distance between them.

Two platform features repeatedly shaped how children shared ownership of activities: anonymous robot control and robot/material distribution. For anonymous robot control, frustration/confusion over the remote robot driver's identity appeared in all four cases. Even during hybrid vignettes, when remote control notifications were available in the website, children still expressed confusion about who was driving the robots. To overcome this difficulty, children tended to use ownership marking strategies (e.g. accessories, personalities) and often relied on adults to clarify robot ownership and resolve ownership conflicts. Regarding robot/material distribution, our platform was designed to allow each participant to pair and control two robots, enabling *parallel and mutual ownership of robots*. However, robot distribution produced conflict in vignette 4, where the preferred ownership of the two in-person robots caused a resource shortage. Similarly in vignette 3, because only A5-O's maze was available at first, C6-O and the anonymous robot driver found themselves clashing for ownership of the marbles. In contrast, during vignette 2, two robots were co-located with in-person children allowed one online child and one in-person child to *mutually own* the soccer activity. Encouraging other in-person participants to *spectate*.

Collaborator Coupling. In all vignettes, the robots facilitated *close coupling* between children. However, in the conflict scenarios, this often manifested as children reversing each other's contributions. In both hybrid vignettes, *collocation blindness* distanced online participants from in-person children, with in-person adults stepping in to mitigate this effect. That said, the robots provided a way for remote children to collaborate with in-person children. For instance, in vignette 2, the platform enabled C2-O to contribute to the in-person activity by testing out C4-IP's soccer ball designs using the robot.

Across all cases, we find that the robots supported fluidity in collaborator couplings. For instance in vignette 2, in-person children decorated the robots and created the soccer field, while C2-O practiced her robot dribbling skills with C4-IP's ball (*divided*); then C2-O and C4-IP competed with the robots to score a goal (*close coupling*). **We attribute children's tendency to use robots in flexible ways to their unique form and size: small, block shape, and blank-slate appearance.** These characteristics encouraged children to customize the robots to suit each scene, as well as to decorate the environment around them.

Co-design Roles. In the collaborative vignettes, robots fostered *relationship building*–like children in vignette 1 nudging and pranking one another from afar. However, when conflict emerged in the latter pair–such as when C15-IP and C5-IP clashed over who would drive/decorate the robots (vignette 4)–we noticed *imbalanced facilitation* between adults and children (e.g., A6-IP passing the controller to A1-O without asking who should play next). When adults prioritized session flow over *co-facilitation*, *relationship building*–and subsequently *design-by-doing* and *elaboration*–were disrupted.

Interestingly in all vignettes, participants tacitly (without explicit discussion) assigned one person the role of robot steward. In our data, robot stewards helped remote children connect to robots (vignette 2), relayed information that was out of view or difficult to hear for remote participants (vignettes 2 and 4), and managed/tracked who controlled each robot (vignettes 1, 2, and 4). For example, in vignette 4, C15-IP ignored requests from in-person children and A1-O to share the controller, but calmly handed the it to A6-IP, the in-person adult. We infer that C15-IP acquiesced because he likely perceived A6-IP as the robot steward. In vignette 1, C11-O also acted as a robot steward as she instructed the anonymous driver to stop controlling her robot. Although the selected vignettes most often show adults as robot stewards and children as robot drivers, we note that these roles were not strictly adult/child specific during the study.

Stewardship roles are not a feature of our technology, but the emergence of a robot driver/stewardship dynamic in all vignettes appears intertwined with children's use of the tabletop telepresence robots. Notably, our platform enhanced children's remote participation in *design-by-doing* and *elaboration*. However, these benefits depended on how robot stewards approached their role, *and* whether adults prioritized *co-facilitation* over session flow. Therefore, our findings suggest that robot stewardship is a role distinct from *co-facilitation*. Additionally, stewardship played an important role during all phases of the design–suggesting it is not merely a strategy to compensate for missing features in the technology system. We conclude that **robot stewardship is an important social feature of effective child-centered tabletop telepresence robot systems.**

6 Discussion

6.1 How Did Tabletop Telepresence Robots Impact Children's Online/Hybrid Relationships?

In this paper, we considered the impact of our platform on children's relationships with one another during online/hybrid participatory design, analyzing children's ownership [5, 12], collaborator coupling [9, 25], and intergenerational co-design roles [83] during collaboration and conflict while using tabletop telepresence robots (Section 5). We found that our platform created a bridge between physically distant children, facilitating shared ownership, close collaboration, and design-by-doing/elaboration. This finding is consistent with past work exploring physical telepresence [11, 41] and tabletop telepresence robots [42] for adults, which has found that these systems increase social presence and strengthen shared context [37, 41, 59] between remote collaborators.

Reminiscent of Yarosh et al.'s finding that ShareTable (telepresence platform for children and caregivers) was sometimes a point of conflict for participating families [81]; our platform also produced conflict for children. Conflict is an important aspect of creative collaboration [6], as well as children's socio-cognitive development [46, 66]. While it may be tempting to conclude that conflict surrounding a physical telepresence platform for children is a negative outcome; we infer instead that the conflict observed is actually a sign that *our platform deepened children's connections and helped physically distant peers develop shared investment in designs*.

A key concern during the COVID-19 pandemic was the negative impact of remote school on children's social skills [2, 28]. Additionally, overcoming social barriers is a common challenge for disabled students who attend school remotely [53]. Therefore, finding that our tabletop telepresence robots allowed remote children to design together, and provided an opportunity for physically distant children to negotiate conflict and collaboration, suggests that this technology is a promising avenue to mitigate shortcomings of remote educational experiences for children.

6.2 Implications of Key Features

In Section 5.3, we considered the interplay between children's relationships while using the robots and the features that play an outsized role in these important moments. In particular, we identified four key features of our system: anonymous robot control, robot/material distribution, robot form/size, and robot stewardship. In this section, we consider these four features in the context of existing literature about robots, telepresence, and child users of these systems.

6.2.1 Anonymous Robot Control.

Although realistic avatars have been linked to increased social presence during screen-based interaction [34, 35], and research has explored how appearance customization can increase social presence in telepresence robot systems [43], these designs rely on 1:1 mappings of users to robots/avatars. However, in tabletop telepresence robot systems, one robot rarely equates to one remote user. Similarly, our platform enabled children to toggle freely between all available robots, and to share control of a single robot with other operators. Consequently, confusion about robot ownership was common during our study.

Notably, adding notifications for remote control events did not resolve ownership confusion. In fact, children appeared unaware of these notifications, as they were focused on the robots/activities (not on the tablet). Instead, children tended to use robot-centered strategies to mark ownership–such as creating robot accessories/labels, and developing unique robot "personalities." Our child design partners' approach aligns with design strategies for active tangible systems–which encourage *prioritizing input and output within tangible components*, and de-emphasizing screens [32, 59]. In accordance with this finding, we underscore the need to *mark robot ownership on robots* in tabletop telepresence robot systems for children.

Children in our study effectively made use of craft materials (such as sticky notes) to mark robot ownership on robots. Therefore, future designs of tabletop telepresence robots for children may consider developing modular, passive accessories for robots to manually mark ownership. Additionally, we see an opportunity for a technical solution to communicate dynamic robot ownership *on robots*. In particular, Nakagaki et al. considered how toio robots might change shape in response to events in a tabletop game [52], or important moments in a story [51]. These shape-changing attachments are a great example of how tabletop robots can change their characteristics to indicate changes in context/environment. Such technical interventions, would strengthen ownership marking in tabletop telepresence robot systems for children by enabling *dynamic* robot ownership marking *on robots*.

6.2.2 Robot/Material Distribution. Physical telepresence systems are unified by their tangibility, but the location and number of their tangible components vary greatly. For instance, each user might possess equivalent tangible artifacts [50, 65, 68, 81]; or several distributed users might control a single output [11, 24, 41, 61]. Within tabletop telepresence robot research, robot distribution is similarly diverse. For instance, Asteroids enabled many remote students to share control of many tabletop robots at one location [42]. Whereas Zooids functioned as a smart tabletop, with equivalent and bidirectional interaction between many robots at two locations [37]. In our study, robot and material distribution (which changed as a result of the shift from online to hybrid sessions) significantly impacted children's collaborations.

For instance during hybrid vignette 2, online and in-person children shared the in-person robots and used craft materials to design, producing close collaboration and mutual activity ownership. Whereas, during hybrid vignette 4, two in-person children argued over who would control the two in-person robots. Sabet et. al. explored how enabling multi-user control of telepresence drones is more complex than merely adding a second controller [61]. We argue that robot distribution is a similarly unpredictable feature in tabletop telepresence robot systems for children, with small changes producing significant effects.

During hybrid, children displayed an overwhelming preference for robots at the in-person meeting location. Therefore, when using tabletop telepresence robots for hybrid collaboration, more robots should be provided where children are co-located. In contrast, during online design, two robots per location appeared to be sufficient, as pairs of robots enabled cooperation between remote children and ownership conflicts centered activities, not robots. We believe that these insights can be used as a jumping off point for distributing tabletop telepresence robots for children. However, *designers should budget ample time to explore and adjust robot distribution, as this is a critical yet unpredictable feature of tabletop telepresence robot platforms for children.*

6.2.3 Robot Form/Size. Children tend to conceptualize robots as anthropomorphic [44], and popular conceptions of physical telepresence are dominated by personal rovers [75]. However, our tabletop telepresence robots were abstract and small, which enabled flexibility in how children used them to create together [63]. As a result, children used a mix of remote control, direct manipulation, and crafting to closely collaborate with remote counterparts using the tabletop telepresence robots. Past work with adults researched how tabletop telepresence robots enable shared grasping and manipulation over distance [37], but children in our study are the first to explore how craft materials can be used to modify tabletop telepresence robots and their environment.

Craft is a foundational technique for participatory design with children [16, 19]. So, while it is unsurprising that combining crafts and tabletop telepresence robots came naturally to our child collaborators, it is noteworthy that the robots enabled shared ownership and elaboration of crafts over distance–especially because craft and play are significant to children's relationships, identity, problem solving, and learning [7]. Moreover, we observe that the blank-slate appearance of the robots enabled children to accessorize robots to mark ownership, and strengthen social presence of remote collaborators–consistent with Ma et. al.'s finding that telepresence robot accessories added to simple robots (like glasses) to "signify" remote colleagues increased social presence [43]. We reason that the creative flexibility [63] afforded by the robots' shape and size, impacted children's collaborations by providing opportunities for close collaboration, elaboration, and social presence between remote children. From this impact on children's design collaborations, we infer that small, blank-slate robots increase children's engagement with tabletop telepresence robot systems by providing opportunities to craft accessories and environments for the robots, collaborate to imagine scenarios for the robots, and decorate/customize their appearance to signify remote collaborators.

6.2.4 Robot Stewardship. Previously, researchers observed and interviewed child and adult users of physical telepresence systems to understand the social expectations and norms that developed during their use [10, 40, 62]. For instance, Newhart et al. interviewed homebound children who attended school via roving telepresence robot, finding that these platforms were socially enriching, but exposed children to increased bullying [53]. Meanwhile, Ahumada-Newhart and Eccles produced a theoretical model describing three levels of educational activity immersion enabled by telepresence robots from observations of children who used them to attend school [1]. In particular, past works have found that during longitudinal use of physical telepresence, social norms among physical telepresence users emerge as stable constructs [10, 53].

In our longitudinal study of children's use of physical telepresence robots during participatory design, we observe the emergence of a new social role: robot stewardship. Robot stewards manage robot connectivity, track who is controlling which robot, and help remote participants overcome collocation blindness by providing context and answering questions. Notably, this role emerged tacitly rather than being formally assigned, and was undertaken by both child and adult participants. Although we identified this role retrospectively and did not directly explore it during the study, its consistent recurrence suggests that stewardship is critical for effective child-centered tabletop telepresence robot systems. We recommend that facilitators work with child users to establish clear expectations for robot stewardship, including managing connectivity, tracking ownership, and offering contextual support. Once formalized, this role should be explicitly assigned—either shared between adults and children in intergenerational collaborations [83] or rotated among children in classroom activities. Formalizing and assigning this role can help ensure equitable participation, preventing undue burden on individual children that might otherwise detract from their engagement with peers.

7 Conclusion and Future Work

Improving telepresence for children makes education more inclusive [76], and supports bonds with faraway family [21, 81]. Also, tangible interfaces offer a promising avenue for child-computer interaction [3, 4, 18]. Although physical telepresence benefits online/hybrid collaboration [41, 65], and tabletop telepresence robots have emerged as versatile, portable, and low-cost physical telepresence platforms [37, 42], few studies have explored tabletop telepresence robots for children [30, 74].

In this study, we identified four key considerations of child-centred tabletop telepresence robot platforms: (1) Anonymous Robot Control (2) Robot/Material Distribution, (3) Robot Form/Size, and (4) Robot Stewardship. From this, we aim to guide future research efforts, highlighting opportunities to refine, compare, and evaluate these aspects of child-centered tabletop telepresence platforms. In particular, we hope researchers are inspired by our conclusion that tabletop telepresence robots represent a promising path to improving telepresence for children–and further this work by adopting child-centered tabletop telepresence robots to help children attending online/hybrid school connect socially with their peers.

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