Objects with Arms: How Robot Embodiment Shapes Perception in Physical Collaboration

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***Abstract*—Robots are entering everyday life in increasingly diverse forms, from mobile manipulators and humanoids to robotic furniture, objects, and spaces. We study how such embodiments shape user perception during physical collaboration through an exploratory Wizard-of-Oz study ($N = 16$), comparing object-embodied manipulation (a toolbox with arms, a kitchen bookstand with arms) with generic standalone arms, across mixed-initiative and human-initiative-only styles. Users characterized object embodiments as unified entities with contextual expertise (10 of 16 participants), whereas generic arms were perceived as separate tools. Object embodiments were rated more likable ($p = 0.049$), and perceived intelligence increased after collaboration only for object embodiments ($p < 0.01$). Initiative style did not significantly affect fluency, but participants valued assistance that fell into two functional categories cutting across styles, supporting user decisions through guidance and confirmation, and reducing user workload through anticipatory action, secondary assistance, and independent task contributions. These findings suggest that embedding robotic capabilities into task contexts can change how users conceptualize robot collaborators.**

***Index Terms*—Embodiment, Cooperation and Collaboration in Human-Robot Teams; Innovative Robot Designs**

I. Introduction

Robots hold the promise to transform everyday lives, offering a hand in daily routines such as food preparation and supporting physical activities, such as assembly. Such assistance can be embodied in various forms, from humanoids and mobile manipulators to household appliances.

Prior research has shown that when a robot's appearance (specifically human likeness) and social demeanor (playfulness) align with the context of use, cooperation improves and people are more willing to accept the technology [1]. To enable interactions with different robot forms, researchers in Human-Robot Interaction (HRI) and Human-Computer Interaction (HCI) have integrated robotic capabilities into existing environments by borrowing forms from what is already present. These investigations include robotic furniture [2], [3], architectural spaces [4], [5], and tabletop artifacts [6]–[8]. More recently, everyday objects themselves have been augmented with intelligence and tabletop locomotion to become physical AI agents that can infer user needs and proactively initiate assistance, such as a stapler approaching a user who is organizing paper packets, or kitchenware that moves into place during cooking [9].

Fig. 1. We augment task-centric objects, such as a toolbox, with robotic arms to become object-embodied collaborators.

These works suggest that future robots can take heterogeneous forms, integrating into existing environments and assisting users not only by following instructions but also by initiating assistance on their own. As robots enter everyday life, designers must choose what form each should take. These choices matter beyond aesthetics, since form can shape how users perceive and interact with the robot.

There are several open research questions. First, **how does integrating robotic capabilities into task-centric objects affect user perception during physical collaboration?** While prior work has established that appearance matters [1] and has developed various embodiments [3], [4], [6], [9], users' perceptual experience during hands-on collaboration with object-embodied robots remains unclear.

Second, **how does proactive robot behavior (i.e., it taking initiative) shape users' experience of collaboration, and what aspects of robot assistance do users value across different embodiments?** Prior work has studied whether and when robots should take initiative [10], but less is known about how initiative interacts with embodiment type, and initiative allocation alone may not capture what users value in collaborative assistance.

To investigate these questions, we conducted a Wizard-of-Oz study ($N = 16$) examining how embodiment type and initiative style influence user perceptions during collaboration in everyday physical tasks.

Through mixed-methods analysis combining questionnaires with semi-structured interviews, we contribute:

1) The concept of *object-embodied collaboration*, where robotic manipulation is integrated into *task-centric ob-*

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jects, and an investigation of how users perceive such embodiments during hands-on collaboration.
2) An examination of how collaboration shifts perception differently by embodiment.
3) Identification of two functional categories of valued robot assistance during physical collaboration, *supporting user decisions* and *reducing user workload*, which cut across initiative allocation.

II. Background

A. Integrating Robotic Capabilities into Existing Environments

Many robot embodiments integrate robotic capabilities directly into existing environments, including robotic furniture that reconfigures spaces and facilitates interactions [3]–[5], actuated tabletops [11], and desktop swarm robots [7], [8]. More recently, everyday objects are directly integrated with robotic movement [6] and re-imagined to become intelligent physical agents in everyday scenarios [9].

How users perceive these integrated embodiments during physical collaboration remains underexplored. The "matching hypothesis" suggests that aligning robot appearance with task context improves cooperation [1], but has primarily been studied with conventional robot forms. We study *how embodying robots in task-centric objects shapes user perception during hands-on collaborative tasks.*

B. User Acceptance Differs For Different Robots

A critical consideration for bringing robots into everyday spaces is user acceptance. While general-purpose robots, such as humanoids, are capable of rich manipulation, they remain unfamiliar in current environments, raising concerns about trust [12], perceived safety [13], and social awkwardness [14]. A recent study shows that many users currently prefer special-purpose robots like Roombas over humanoids [15], perceiving them as safer and more comfortable to be around. Robot appearance further affects friendliness [16], perceived danger [17], and human cooperation [1]. Additionally, repeated positive interactions improve perception [18], with familiarity as a contributing factor [19].

These findings motivate two of our hypotheses: that object embodiments, whose forms are already familiar in the task context, will be perceived more positively than generic arms (**H1**), and that hands-on collaboration will further improve perception for both embodiment types (**H2**).

C. Initiative Taking During Human-Robot Collaboration

Beyond forms, how robots and humans allocate initiative critically shapes collaboration dynamics. In human-initiative-only interaction, robots respond only to explicit commands, granting full control but increasing cognitive load as users must plan and instruct every action. In contrast, mixed-initiative interaction [20] allows both humans and robots to initiate actions [21], enabling robots to proactively assist with tasks [22]. Prior work has shown that proactive assistance from a robot can improve human-robot collaboration fluency [10]. Less is known, however, about how varying robot initiatives may influence user perception across different embodiments. In our work, we investigate initiative-taking jointly with robot embodiments. While we hypothesized that mixed-initiative collaboration would improve fluency (**H3**), we also explore what aspects of robot assistance users value across embodiment types.

III. User Study: How Do Embodiment and Initiative Influence User Perception?

We designed a 2 × 2 within-subjects Wizard-of-Oz study in which participants collaborated on everyday tasks (dessert-making, assembly) with robot collaborators differing in embodiment and initiative (Figure 2). Our study was approved by our institutional ethics board.

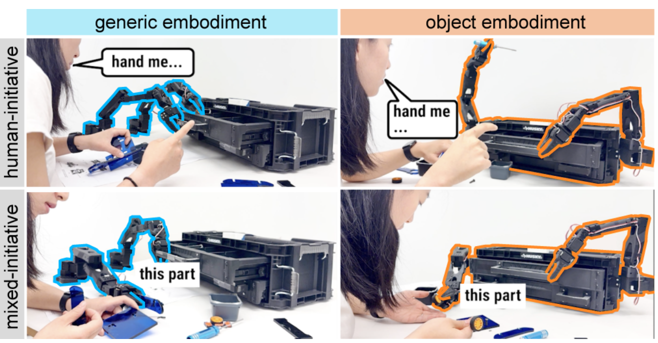

Fig. 2. Our independent variables were Embodiment (object vs. generic) and Initiative (mixed-initiative vs. human-initiated).

A. Hypotheses

Drawing on the matching hypothesis [1], prior work on exposure effects [18], and studies of proactivity in human-robot collaboration [10], we formed hypotheses about embodiment, exposure through interaction, and initiative:

H1: Participants will perceive *object* embodiments *more positively* compared to generic embodiments.

H2: Participants will perceive *both* embodiments more positively *after interacting* with them.

H3: Participants will perceive *higher collaboration fluency* for *mixed-initiative collaboration* than in human-initiative-only collaboration.

B. Study Design

We conducted a within-subjects experiment with a 2 × 2 factorial design. Our independent variables were Embodiment (object vs. generic) and Initiative (mixed-initiative vs. human-initiated), as shown in Figure 2. Each participant experienced all four conditions in counterbalanced order, with specific tasks (e.g., toy car vs. windmill, parfait vs. layered cake) counterbalanced across conditions so that no task was consistently paired with a particular embodiment or initiative style.

We employed a Wizard-of-Oz approach [23] to simulate robot autonomy. A hidden operator teleoperated the robotic arms, varying initiative-taking behavior while maintaining consistent domain knowledge across conditions (i.e., both embodiments know all task steps, where to find tools, etc.) and identical operation.

C. Tasks

Participants completed four tasks spanning two task types common in physical human-robot collaboration research: assembly [24] and food preparation [25]. We used two task types to broaden exposure and mitigate learning effects, not as an independent variable. Tasks were matched for robot reachability (Figure 3) and task difficulty (similar number of steps, subtasks, estimated completion time).

1) Assembly: In each assembly task, participants assembled a toy car or windmill following printed instructions, collaborating with either generic robotic arms or a toolbox with embedded robotic arms (Figure 3). We designed difficult steps (e.g., t-slot joints) to elicit help-seeking.

2) Dessert-Making: In each dessert-making task, participants prepared a no-bake dessert (strawberry Oreo parfait or layered berry cake) following printed recipes, collaborating with either generic robotic arms or a robotic kitchen bookstand with embedded arms (Figure 3).

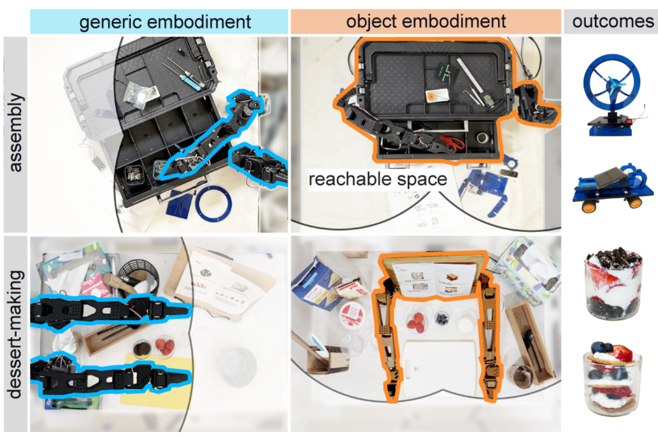

Fig. 3. We control for similar robot reachability of tools and ingredients across conditions.

D. Apparatus

1) Robotic Collaborators: We built two pairs of open-sourced robotic arms (SO101 [26]) as our two generic robotic collaborators, and adapted the design to integrate another two pairs of arms into the toolbox and bookstand to create object embodied collaborators. We built two pairs of SO101 leader arms for teleoperation.

2) Wizard Setup and Operation: We constructed a "Wizard's den" with one-way mirror film overlooking four task stations (Figure 4). The wizard observed participants and teleoperated robots without being seen.

In human-initiative conditions, robots idled with arms slightly raised and small ambient movements, similar to idle game characters. In mixed-initiative conditions, the wizard proactively initiated actions based on task context and observed participant needs. We compiled possible robot subtasks from prior HRC research [27]–[33], including: holding objects [29], [31], handing over objects [30], [33], organizing the workspace [31], tool use [27], and indicating objects to users [29], [32]. When participants interrupted with commands during robot-initiated actions, the wizard stopped and responded to the human request. The wizard followed standardized protocols developed during piloting.

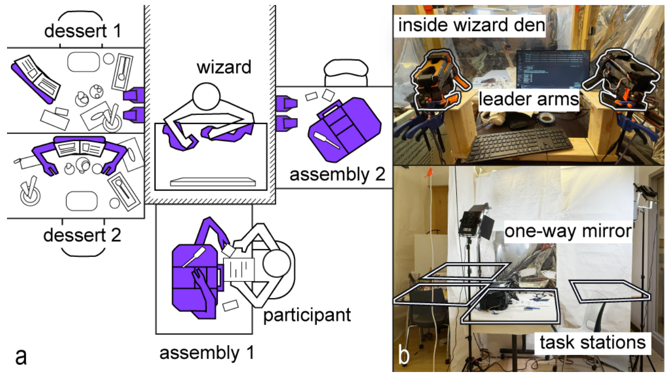

Fig. 4. (a) A "Wizard's den" overlooks four task stations through one-way mirror film. (b) A wizard teleoperated the robots inside using leader arms.

E. Procedure

After introducing participants to the study and obtaining their consent, we showed them the four task stations and introduced them to the two types of embodiments. Participants then completed a pre-study Godspeed questionnaire [34] rating their expectations for each embodiment.

Participants completed four collaboration tasks in counterbalanced order. Before each task, a study conductor explained the goal outcome, described the robot's capabilities ("can see and hear; knows task instructions; interact with it however you prefer"), and specified whether the robot would take initiative. Participants had 15 minutes per task and completed a post-task fluency questionnaire [35] after each.

After all tasks, participants completed a post-study Godspeed questionnaire and a semi-structured interview. Participants were asked which robot collaborators they would prefer for daily tasks and why, what they liked or disliked about each robot type, and what additional features they would want. We then disclosed the Wizard-of-Oz operation. Sessions lasted approximately 120 minutes.

F. Participants and Data Collection

We recruited 16 participants from local universities (age $M = 22.9, SD = 3.72$, 10 female, 6 male). Participants had varying experiences with robots ($M = 1.9$ months, $SD = 5.98$) and tangible interfaces ($M = 0.94$ months, $SD = 3.04$). Participants were compensated with $30 for their time.

We collected: (1) pre- and post-study Godspeed questionnaires [34] measuring perceptions of each embodiment type, (2) post-task HRC fluency questionnaires [35], measuring collaboration quality, (3) semi-structured interview responses, and (4) video recordings of all tasks.

IV. Study Results

We analyzed user perception using the Godspeed questionnaires and collaboration quality using the HRC fluency questionnaires, along with our interview data. For Godspeed measures, we used paired t-tests to compare object versus generic embodiments before and after the study, and to compare pre- to post-study changes for each embodiment. For post-task fluency measures, we used linear mixed models with embodiment and initiative as fixed effects and participant and task as random effects. We tested embodiment-by-initiative interactions on these measures, which were collected after each task and therefore capture the per-condition initiative manipulation.

To analyze the interview data, three researchers coded the transcripts using thematic analysis [36] and collaboratively resolved disagreements to inform our qualitative findings.

A. Embodiment Effects on Perception

Given our directional hypotheses (**H1** and **H2**) of planned pairwise comparisons, we used one-tailed t-tests for embodiment comparisons.

1) Likeability: Post-study, participants rated object embodiments significantly more likable ($M = 4.28, SD = 0.56$) than generic embodiments ($M = 3.96, SD = 0.91$), $\mathbf{p = 0.049}$ (Figure 5, Table I). This was the only Godspeed dimension showing a significant difference between embodiment types, providing initial support for **H1**.

Interview data help explain this difference. Ten participants (62.5%) described object embodiments as integrated, unified entities rather than robots attached to objects. P8: *"It's not a computer and two arms; it's like one body... one thing instead of two things."* P14 contrasted the toolbox as *"like having the toolbox itself give you stuff"* versus the generic arm being *"like having another person there."* This unified-entity framing suggests object embodiments felt like more natural, contextually appropriate collaborators.

2) Perceived Intelligence: Post-study intelligence ratings showed a similar directional pattern ($M_{object} = 4.17$, $M_{generic} = 3.84$) but did not reach significance, $p = 0.052$. However, perceived intelligence increased significantly from pre- to post-study for *object embodiments* ($p < 0.01$) but not for generic embodiments, despite identical wizard operation across conditions. This selective increase suggests that hands-on collaboration may reinforce perceptions of intelligence, specifically when the robot's form matches the task context. Qualitative data point to a possible explanation. Eight participants attributed contextual expertise to object embodiments. P14: *"It's like, it knows more... because it's part of the object."* Object embodiments may influence users to perceive domain knowledge. Through positive interactions with helpful robot assistance, perceived intelligence grows for object embodiments in a way that does not for generic embodiments.

3) Exposure Effect: Supporting **H2**, perceptions improved significantly from pre- to post-study across multiple dimensions for both embodiment types (Figure 5, Table I).

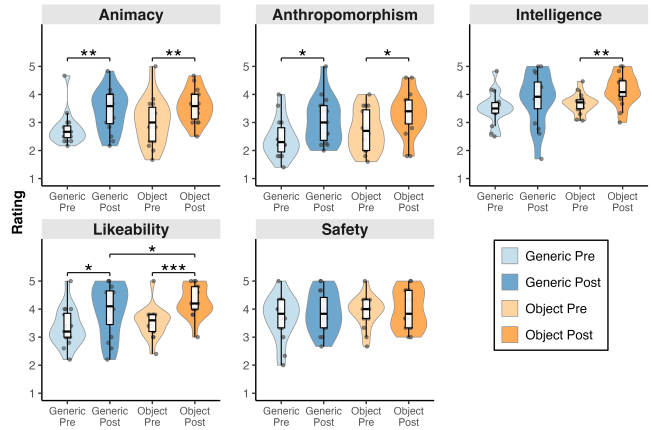

Fig. 5. Godspeed ratings by embodiment type, pre and post collaboration.

TABLE I
Paired one-tailed t-test results ($df = 15$).

	O>G (pre)		O>G (post)		Post>Pre (O)		Post>Pre (G)	
Measure	t	p	t	p	t	p	t	p
Likeability	1.52	.074	1.76	**.049***	4.29	**<.001**	1.98	**.033***
Animacy	1.69	.056	1.52	.075	2.90	**.006****	3.05	**.004****
Anthropomorphism	1.22	.121	1.30	.107	2.09	**.027***	2.10	**.027***
Intelligence	1.05	.155	1.73	.052	3.42	**.002****	1.27	.111
Safety	1.50	.077	0.60	.277	0.41	.344	0.94	.181

Animacy ($p < 0.01$), anthropomorphism ($p < 0.05$), and likability ($p < 0.05$) increased for both embodiments after collaboration. Safety showed no significant change for either embodiment. The selective increase in perceived intelligence for object embodiments only is reported above.

B. Cross-Initiative Assistance Types

We found no significant main effect of initiative or embodiment on fluency, nor a significant embodiment × initiative interaction, contrary to **H3**. However, post-study interviews revealed richer patterns about what participants valued in robot assistance.

While the quantitative measures did not distinguish between initiative conditions, participants in interviews described robot assistance behaviors that clustered into two functional categories: supporting user decisions ($N = 12$) and reducing user workload ($N = 10$) (Figure 6). These categories operated through distinct assistance behaviors and were valued for different reasons.

1) Supporting User Decisions (N=12): Participants valued assistance that helped them navigate uncertainty during tasks. This took two forms in our observations. Robots provided *guidance*, particularly when participants were distracted or unfamiliar with tasks. P15 was surprised to see the robot prompt "the next set of commands that I had to follow" while not focused on the manual. P11 similarly noted the robot *"showed me basically another way to approach it, so it handed me the tools, actually pointed to the [next step]."*

Robots also provided *confirmations and corrections*, validating user work or catching errors. This form of assistance was typically user-initiated (*"is this right?"*). P12: *"Just like having something to confirm with, like, oh is this enough food, or is this the right tool."* P1 described receiving robots' confirmations as *"emotional affirmation,"* suggesting that decision support served social as well as functional purposes.

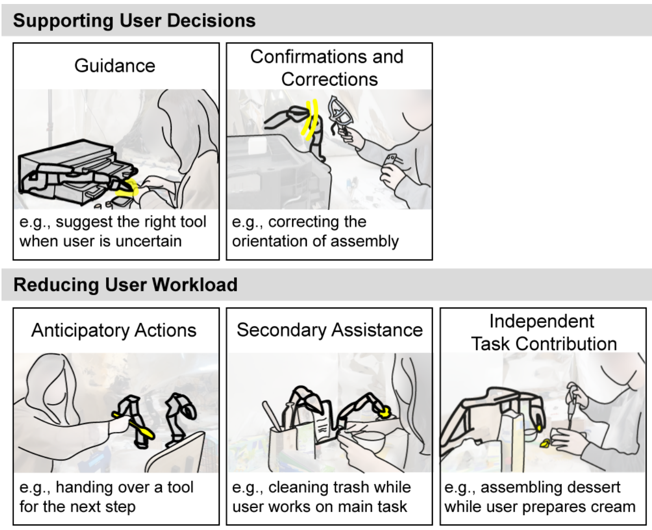

Fig. 6. Participants valued different assistance types, grouped into supporting user decisions and reducing user workload.

2) Reducing User Workload (N=10): Participants also valued assistance that offloaded effort, freeing them to focus on the primary task. This manifested in several ways. Robots *prepared for upcoming steps* before being asked, reducing coordination overhead. P2 valued that anticipation: *"I didn't have to look at the arms to let them know what I need."* P10 noted this enabled *"easy interaction"* without needing to monitor the robot. Robots *provided secondary assistance*: handling ancillary subtasks such as cleaning the workspace. P9: *"It was nice to have something doing the cleanup when the milk got all over me."* In a few cases, robots *independently advanced the main task*. P14: *"The robot built part of it, I didn't even notice until I got to that part... I'm very impressed."*

V. Discussion

A. Object Embodiment Shifts How Users Conceptualize Robot Collaborators

When robotic capabilities are integrated into an object that already belongs in the task context, users may reconceptualize what the robot is. Most participants described object embodiments as unified entities rather than robots attached to objects, a perceptual shift the likability difference supports quantitatively. The toolbox-with-arms becomes a toolbox that can help. Future work should test larger samples and additional object types to establish generality.

B. Contextually Appropriate Forms Amplify Perceptual Gains from Interaction

Repeated positive interactions generally improve perception of robots [18], [19]. The intelligence gain for object embodiments only suggests these forms further influence users to perceive domain knowledge through helpful assistance, perhaps by borrowing the identity of task-centric objects (toolbox to assembly). In scenarios where perceived expertise matters, such as guided assembly or physical learning, embedding robotic capabilities into task-relevant objects may build trust and improve collaboration. Future work can study this effect in isolation.

C. From Initiative Allocation to Assistance Function

While our initiative manipulation did not produce statistically significant differences on fluency measures, our qualitative data revealed that when participants described valued assistance, they focused not on who initiated the action but on what it accomplished. This points toward studying assistance types, such as the ones in Figure 6, as a complement to initiative allocation when designing collaborative robots.

VI. Limitations and Future Work

As an exploratory study with 16 participants, our findings require replication with larger and more diverse samples. Users' expectations for domestic robots may also vary across cultures and age groups, shaping how they perceive robot embodiment and autonomy. In addition, our Wizard-of-Oz setup does not account for autonomous perception, decision-making, and control. Future work can study effects of reintroducing partial autonomy, such as decision-making systems for user intention inference [37]. Subsequent studies could also complement subjective reports with objective measures such as reaction time, task completion time, and response latency.

The assistance types we identified offer a starting point for more targeted investigations. Future work could manipulate assistance type directly as an independent variable to examine whether users value these categories differently given contextual factors.

VII. Conclusion

Embedding robotic arms into task-centric objects positively shifts how users conceptualize the collaborator. Rather than a robot attached to an object, participants described unified entities whose identity and expertise derived from the object itself. Across initiative styles, what a robot helped with mattered more than who initiated the help. These findings point to embodiment not as a surface aesthetic but as a framing device that shapes how users interpret a robot's identity and expertise.

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