Exploring the Role of Social Robot Behaviors in a Creative Activity

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Robots are increasingly being introduced into domains where they assist or collaborate with human counterparts. There is a growing body of literature on how robots might serve as collaborators in *creative* activities, but little is known about the factors that shape human perceptions of robots as creative collaborators. This paper investigates the effects of a robot's social behaviors on people's creative thinking and their perceptions of the robot. We developed an interactive system to facilitate collaboration between a human and a robot in a creative activity. We conducted a user study (n = 12), in which the robot and adult participants took turns to create compositions using tangram pieces projected on a shared workspace. We observed four human behavioral traits related to creativity in the interaction: accepting robot inputs as inspiration, delegating the creative lead to the robot, communicating creative intents, and being playful in the creation. Our findings suggest designs for co-creation in social robots that consider the adversarial effect of giving the robot too much control in creation, as well as the role playfulness plays in the creative process.

CCS Concepts: • **Human-centered computing** → *Interaction design process and methods*; Collaborative interaction.

Additional Key Words and Phrases: Social robots, human robot collaboration, creative expression, creativity, interaction design, robot behavior design

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1 INTRODUCTION

Robots have been envisioned as tools, assistants, and collaborators across a wide range of collaborative domains from manufacturing to logistics. More and more of these applications involve *creativity*, and a growing body of literature in HRI has explored the use of robots in creative human activities [5, 6, 20–22, 27, 30, 35]. Prior work on collaborative robots has highlighted the importance of a robot's *social* capabilities for positive perception and acceptance [36, 43]. Although the literature indicates that social robots show significant potential in supporting creative activities for children [3–6], little is known about the effect on creativity in adulthood. This work investigates how the involvement of a social robot affects people's design ideation and the emerge of creative related behaviors in the collaboration.

Prior research has acknowledged two traditions of *creativity* research in psychology since the 1960s. The first tradition describes creativity as being intrinsic to human intellect and emphasizes the cognitive capabilities of individuals [17, 31]. Rather than viewing creativity as an individual endeavor, the second tradition situates creativity in a sociocultural

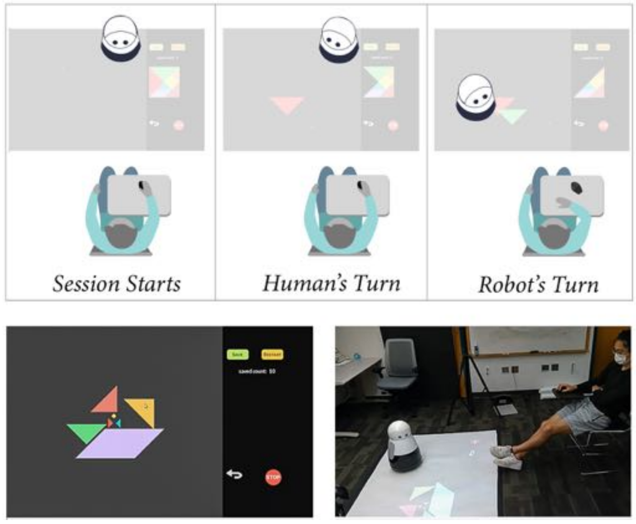

Fig. 1. In this paper, we investigated the effect of social robot behaviors on human creativity. An interactive experience in which participants constructed tangrams with a social robot enabled us to observe patterns of creativity-related behaviors.

context and suggests that the cognitive process for creativity is facilitated by interacting with other individuals and artifacts in the environment [1, 7, 12]. The multi-dimensional nature of creativity is also recognized by Sternberg and Lubart [39–41], who proposed *Investment Theory of Creativity* and viewed creativity as a compound of the six resources: intellectual abilities, knowledge, styles of thinking, personality, motivation, and environment. These early theories have paved the way for creativity research in the digital age, and a growing body of literature suggests that technological tools have the potential to advance creative problem-solving [11].

Ongoing research has explored various technological tools to support creative thinking. With the advancement of technology, more tools shift the focus from passive use to proactive participation in creative tasks such as drawing [6, 27], storytelling [18, 30, 35], and ideation [20]. While this body of work focuses on designing robot behaviors to directly support creative activities, this paper focuses on the robot's *social behaviors* exhibited during creative collaboration. Prior studies showed that social robots contributed to people's creative expressions in Zen rock garden [20], children's idea generation [3, 5] and figural creativity [4]. Therefore, we hypothesize that adults collaborating with a social robot will achieve more creative outcomes than with a nonsocial robot.

Our research questions are: *How do robots' social behaviors affect human idea generation in creative tasks? How do people perceive and collaborate with social robots in creative tasks?* To investigate these questions, we created an interactive experience in which people worked with a social robot in an idea generation task using digital tangrams (Figure 1). The activity was facilitated by an interactive system that projected a canvas on the floor and controlled a robot to move around in the projected area. The user and the robot took turns to create a composition out of tangram pieces. We conducted an in-person study that manipulated the robot's social behaviors during this creative task, using behaviors that were validated in an initial online study. We measured creativity using divergent thinking factors: *flexibility*, *originality*, and *elaboration* [16, 17, 44, 45]. We also measured participants' collaborative behaviors during the task, including their acceptance of the robot's contributions and their perceptions of the robot. We observed and categorized several human behavioral traits during the interaction and discussed their potential effects on creative thinking.

Our contributions are as follows.

- *Methodological contribution*: We present a novel use of social robots in situated and embodied creativity tasks involving co-creation and an interactive platform to study creativity in HRI. The robot actively engages in the co-creation with the user by navigating in the projected space and taking turns to manipulate the tangram elements.
- *Qualitative observations*: We identified four human behavioral traits related to creativity, including accepting robot inputs as inspiration, delegating a major role to the robot in the creation, communicating creative intents, and being playful in the interaction.
- *Insights and design/research implications*: On the one hand, participants' willingness to give away the control to the robot in idea generation revealed a shift of responsibilities in creation. On the other hand, playful interactions emerged as participants attributed personality to the robot and explored various means of communication. This raises questions on how playfulness in the interaction translates to meaningful creative outcomes in collaborating with a social robot.

2 RELATED WORK

2.1 Creativity and Creativity Support Tools

Human creativity has been a widely researched topic. Early work in this field has mostly viewed creativity as a dimension of human intelligence and emphasized cognitive skills for individuals [17, 31]. Guilford suggested four factors for divergent thinking [16, 17]: fluency, flexibility, originality, and elaboration, which were integrated into Torrance Tests of Creative Thinking (TTCT) for creativity measurements [44, 45]. The second wave of creativity research in the late 80s viewed that social and environmental factors played a crucial role in creative activities [7, 12]. Sternberg and Lubart [39–41] suggested multi-component models of creativity that considered intellectual abilities, knowledge, thinking styles, personality traits, motivation, and environment. Amabile [7] proposed the term "creative situation" in her work on the social psychology of creativity and defined it as "circumstances conducive to creativity". These views that external determinants affect creativity paved the way for later research in digital creativity tools in the late 20th century. Additionally, prior research proposed different frameworks of the creative process, such as "collect, relate, create, donate" suggested by Shneiderman [38] and "problem finding, ideational, judgemental/evaluation process" by Runco and Chand [34]. Various creativity support tools have been researched to support the different phases in the creative process [11].

Advancements in artificial intelligence in recent years enabled creativity support tools with more proactive roles. Emerging fields such as "co-creativity" arose as the tools were adopted as collaborators for human counterparts. They were developed to take part in human's creative process, such as drawing together with users [10], providing feedback or new ideas [26].

2.2 Robots and Creative Tasks

Prior research has utilized robots to collaborate with humans for early-stage design ideation by sketching on paper [27]. The robot improved the designer's exploration and engagement in the ideation process in comparison with a virtual agent. Law et al. investigated collaborative behaviors between the human and the robot [22]. Users collaborated with

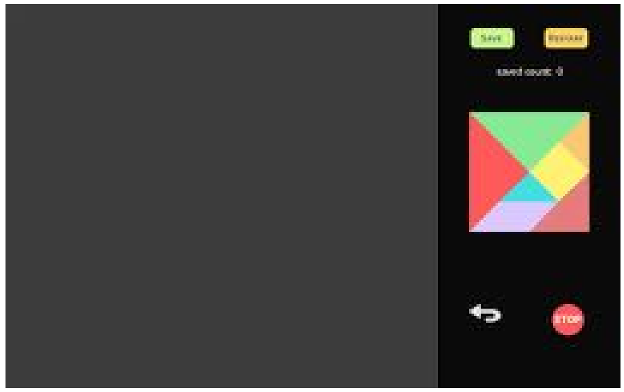

Fig. 2. The canvas software interface which participants and robot use to create shapes.

a robotic arm for a design configuration task and negotiated with the robot for both physical space use and design decision making.

Previous research has also used *social* robots to spark creativity in activities such as collaborative drawing [6], Japanese Zen garden making [20], and story creation [5, 21, 30, 35]. Alves-Oliveira et al. developed a creative social robot for children's storytelling and found that the robot with creative and social behaviors contributed to more of children's original ideas than without[5].

2.3 Social Robot Behaviors

Prior research has found that social robots with affective behaviors can improve children's second language learning [28], growth mindset development [33], and curiosity [15]. Besides speaking capabilities, nonverbal social behaviors such as facial expressions, gaze, and gestures are widely studied. Previous research found that nonverbal social cues of a robot assisted in children's learning of words [48]. Cues such as gaze were effective in conveying information without overloading the more complicated speaking channel in collaborative tasks [2]. With various available robot expressions, new issues emerged such as coordinating robot modalities into meaningful behaviors. To address this issue, existing work has developed learning companion robots with adaptive personalized features [32] and computational models to design and integrate robot behaviors [19].

2.4 Robots in Projection Systems

Projections create an interactive space where participants are immersed in rich external stimuli. Prior work has used projection to support a music-based puzzle game with Cozmo to foster collaboration and inclusion among children [13] and built an augmented reality interface with projection to access spectrographic performance [25]. The popularity of projection is in part because it is a convenient and versatile method for multimedia communication [37]. Many projection tools are adaptive to diverse surfaces and environments, enhancing researchers' ability to conduct studies in various spaces [9].

3 DESIGN OF THE INTERACTIVE SYSTEM

3.1 Design Overview

To explore how a social robot might facilitate idea generation in a creative activity, we designed and implemented an interactive experience that integrated a robot, an interactive tangram-construction platform, and a shared workspace with overhead projection.

3.1.1 The Social Robot. We chose the Kuri robot in the study because of its relatively strong social presence with human-like features. It has a height of 0.5 meters as shown in Figure 1. Its mobility enables task participation using physical movements in space. It also provides open access to the robot server for customized behavior development.

3.1.2 Interactive Game. Tangram is a puzzle that involves the use of seven pieces (five triangles, a square, and a parallelogram) to construct patterned shapes [47]. It encourages open-ended composition with simple shapes, while the limitation of seven pieces requires the user to think creatively to generate new compositions (Figure 2). Moreover, the step-by-step construction of compositions allows for multi-party collaboration with turn-taking.

3.1.3 Projection-based Shared Workspace. We placed the robot in a shared workspace that used an overhead projection to display tangrams on a projected canvas (Figure 1). This space enabled the robot to communicate with users through its movement on the canvas and to participate in the creative activity. In addition, we envisioned that the projection space would allow participants to physically engage in the system using their movements as input. In the current implementation, physical engagement is limited by space size and COVID-related restrictions.

3.2 Design and Implementation Details

3.2.1 Robotics System. In the study, we used a Kuri robot developed by Mayfield Robotics. The robot has built-in ROS services running on a Linux kernel that manages sensor information and controls the robot’s movements. For the robot’s navigation, we implemented a close-loop feedback control involving robot position tracking, planning, and execution. We obtained robot positions (x, y) using a global depth camera (Intel RealSense D435i), which is installed next to the overhead projector. We obtained robot orientations from its built-in IMU sensor. The robot pose is fed into a PID controller to compute linear and angular speeds for the robot to reach targeted waypoints. It is also used for social behavior development such as turning to the user or paying attention to the tangram placement on the canvas.

3.2.2 Tangram Platform. The tangram platform consists of a composition area and a tool panel as shown in Figure 2. In the tool panel, all seven tangram pieces are positioned in a square initially. The tool panel provides buttons to start a new round, stop the robot’s turn, and undo the pieces placed by the user or the robot. Users could arrange the tangram placement by moving, rotating, and resizing pieces.

The robot could participate in the user’s creative process in a turn-taking manner. It first moves towards an unplaced tangram piece and then selects the piece by standing on top of it. Next, it carries the piece to a designated destination computed based on the current positions of placed pieces. There are three steps to decide the robot’s placement. First, the piece is chosen randomly from all unplaced tangrams. Second, the piece’s new position will be aligned with either a corner or an edge of placed tangram pieces. This reference of alignment is picked randomly from placed tangrams in the center region of the canvas. Third, the new position, orientation, and scale of the piece will ensure the new piece does not overlap with the current composition.

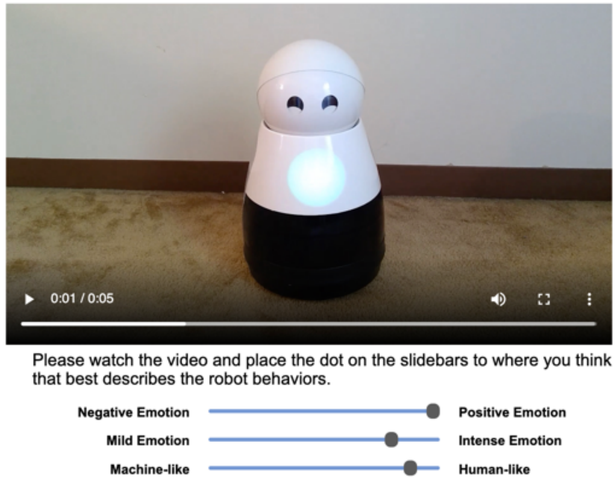

Fig. 3. In an online study, participants evaluated a robot's behaviors along different dimensions.

3.2.3 Robot's Social Behaviors. The robot displays social behaviors in three scenarios. First, the robot provides positive or negative feedback based on users' operations on canvas. Second, the robot expresses cheerfulness or confirmation when it finishes a new placement. Third, the robot tracks the user's movement of tangram pieces and occasionally makes eye contact with the user to communicate its attention during the user's turn. The robot's social behaviors integrate sound, chest light, body rotation, and eyes and head movements. They are selected from both built-in and customized robot behaviors. The built-in behaviors are created by the manufacturer of the robot platform and could be triggered via a ROS protocol. The custom social behaviors involve changing the robot's orientation with respect to the user and tangram pieces on the canvas. In some cases, the robot orients its body toward the participant before making eye contact, and in other cases, the robot rotates its head and points its eyes toward moving pieces on canvas.

3.2.4 Online Study for Behavior Evaluation. To validate and refine the design of social behaviors of the robot, we conducted an online study (Figure 3). Specifically, we sought to select robot behaviors with the appropriate level of intensity, and perceived negativity/positivity, sociability, and effectiveness in expressing attention for the three scenarios described above.

In the study, participants were asked to view 33 videos of the robot Kuri and answer questions regarding them. We had three groups of robot's social behaviors: (1) single robot features (color, sound, and eyes), (2) integrated robot's behaviors showing positive or negative emotions, (3) robot paying attention behaviors. Within each group, videos were randomized to minimize carryover effects. After viewing each video, participants were asked to evaluate the robot's social behaviors using two semantic differential scales. The first scale for the first 30 videos where the robot was alone included dimensions of *positivity of emotion* (negative to positive), *intensity of emotion* (mild to intense) and *human-likeness of the robot* (machine-like to human-like). The second scale for the last three videos for robot attention behaviors included *attentiveness* (distracted to attentive), *interactivity* (inert to interactive), and *human-likeness* (machine-like to human-like). The study included an attention-check task that asked questions about the color on the robot's chest in the previous video to ensure that participants were watching the videos in their entirety. We collected demographics information after the main survey questions. We recruited 129 workers from Amazon Mechanical Turk (AMT) and approved 98 workers, filtering out 31 unqualified responses due to failed attention checks. Among the

Table 1. Social behaviors for Online Study. PSI: positivity-socialness-intensity. ASI: Attentivity-Socialness-Interactivity. Selected robot behaviors are marked with "*." We assigned score of 0 to 100 to the semantic differential scale for measurement.

Anims Name	PSI (Mean)	Used Scenario
Colors - Blink		
red_blink*	40-46-47	When the user cancels the robot placement
green_blink*	66-51-48	When the user saves the robot placement
white_blink	61-49-41	
blue_blink	61-49-46	
yellow_blink	58-46-42	
Eyes Features		
double_blink*	53-47-38	The user saves the composition
neutral_eyes_close*	46-36-40	The robot closes eyes in the non-social condition
neutral_eyes_open	50-42-43	
Sound Features		
putdown_sound*	54-39-46	The robot places an element
pickup_sound*	62-48-52	The robot places an element
Integrated Behaviors		
gotit_docked_sound*	77-61-70	The user saves the composition
tickle_sound*	75-57-65	The user saves the composition
thank_you_1_sound	74-57-61	
giggle_3_sound	72-59-74	
proud_1_sound*	72-55-55	The robot places an element
bye_1_sound*	68-55-55	The robot places an element
photo_shoot_1_docked*	62-52-55	The robot places an element
yes_sound*	56-47-47	The user saves the composition / Robot places an element
huh2_sound	50-58-53	
lost_sound	46-57-64	
huh1_offline_docked_sound*	45-49-53	Stop, undo or relocate the robot's placement
live_frown*	43-53-49	Stop, undo or relocate the robot's placement
ponder_sad	39-60-52	
no_2_sound*	37-59-59	Stop, undo or relocate the robot's placement
twitch_1_sound	32-57-59	
Anims Name	**ASI (Mean)**	**Used Scenario**
Attentive Behaviors		
pay_attention_freq_0.2*	75-71-66	The robot pays attention to the user's action
pay_attention_freq_0.1	76-68-63	
pay_attention_freq_0.05	77-54-49	

approved participants ($age \in [19, 68], mean = 37, sd = 10.52; male = 65, female = 33$), the average level of experience with robots was 1.68 ($SD = 1.06$) on a five-point scale, which suggests that our participants had little experience with robots in general.

3.2.5 Social Behaviors Selection. The results from the online study informed our selection of robot's social behaviors as shown in Table 1. The first scenario is when users placed tangram pieces on canvas. If the user saved a new composition, the robot played behaviors with middle to high levels of positivity in order to provide encouragement with positive feedback. If the user stopped the robot or undid or relocated the robot's placement, the robot responded in a negative way. In this case, we selected behaviors with low positivity scores. Since strong negative feedback from the robot may discourage users from interacting with the robot, we avoided negative behaviors with a high average intensity score. If the robot placed tangram pieces on the canvas, all selected behaviors were positive with middle levels of intensity ($\in [45, 55]$) as an indicator of ending the robot's turn. During the user's turn, the robot occasionally establishes eye contact with the participant. We evaluated three frequencies of eye contact in the online study (every 5s, 10s, 20s) and found attentiveness scores for them to be similar. We chose a frequency of every 5s ($freq = 0.2$) as it had the highest average scores for sociability and interactivity.

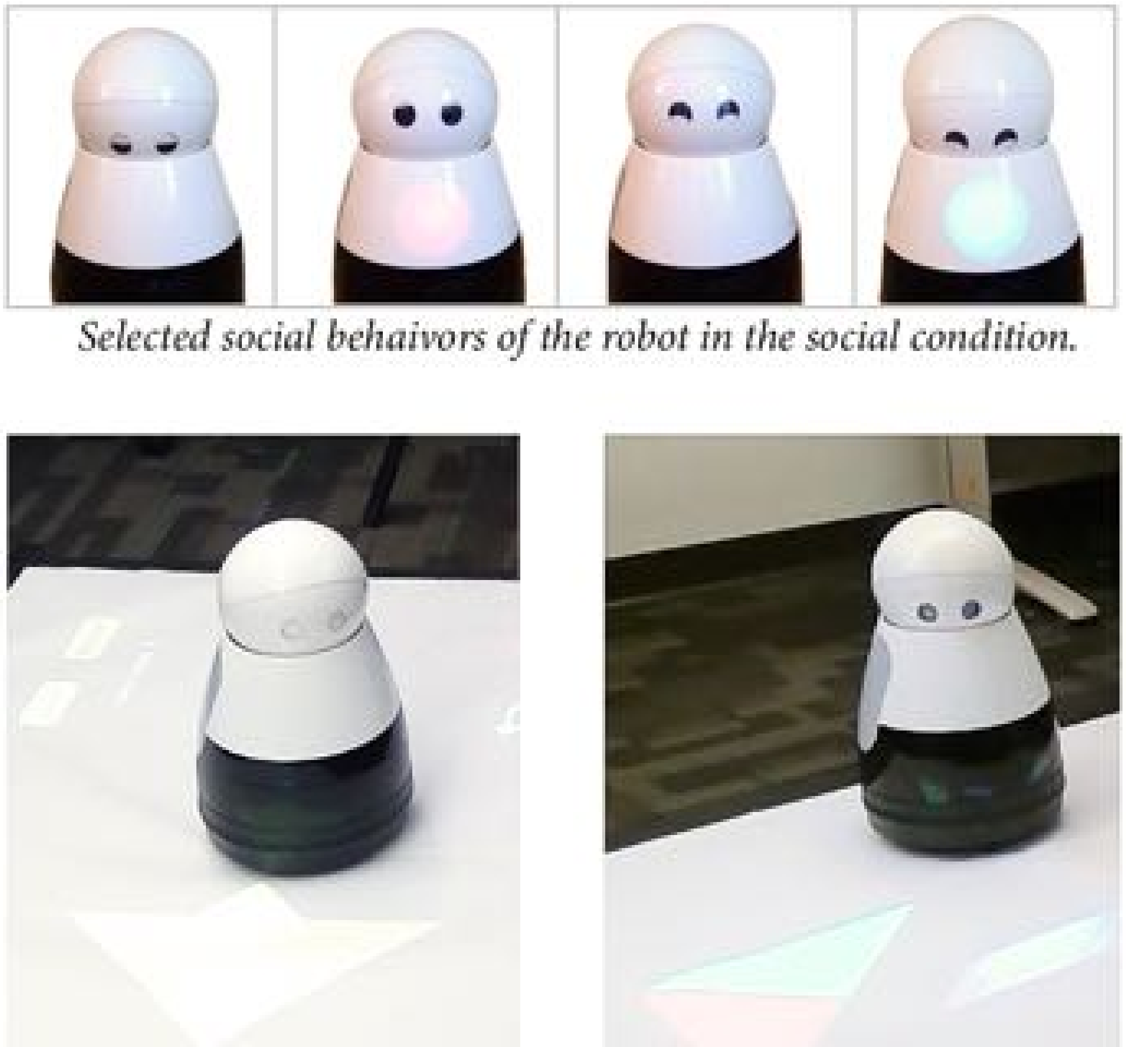

Fig. 4. During the in-person study, a Kuri robot exhibited social or non-social behaviors. Left: Non-social condition, the robot kept its eyes closed during the task. Right: Social condition, the robot attended to the participant's actions on the canvas.

4 EVALUATION

We designed an in-person experiment that used the interactive system to investigate the effects of a robot's social behaviors on creative collaboration. Our study explores the robot's effects on both humans' creative output as well as on their perceptions of the robot as a collaborator. Specifically, we examine how the robot's social behaviors affect people's creative idea generation output, perceptions of the robot's helpfulness, their willingness to accept the robot's contributions, and their view of the robot as an intentional agent. All our study and recruitment procedures were approved by an ethical institutional review board from Carnegie Mellon University.

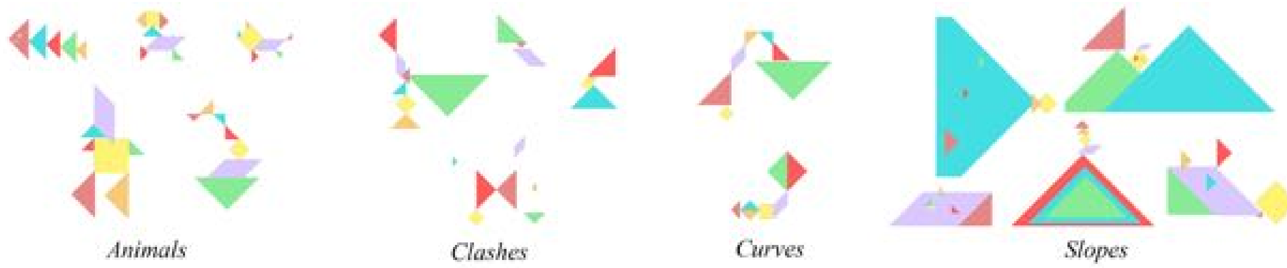

Fig. 5. One participant categorized the final fifteen shapes into four groups: Animals, Clashes, Curves, Slopes.

4.1 Hypotheses

We propose three hypotheses about how a robot's social behaviors will affect people's performance and perceptions in a creative collaboration.

H1. People collaborating with a social robot will *generate ideas with greater variation* than people collaborating with a non-social robot.
H2. People collaborating with a social robot will *accept more of the robot's creative input* than people collaborating with a non-social robot.
H3. People's overall subjective perceptions of robots will *be more positive* in social versus non-social conditions.

4.2 Participants

We recruited 13 participants, all of whom were either undergraduate or graduate students from local universities ($Female = 4$, $Male = 9$; average age= 22 years old, $Min = 18$, $Max = 28$, $SD = 3.76$). Their professional experience with robots and professional experience in design were diverse (robot experience: $Min = 1$ (never), $Max = 5$ (very often), $M = 2.08$, $SD = 1.26$; design experience: $Min = 1$ (never), $max = 5$ (very often), $M = 3.00$, $SD = 1.47$).

4.3 Study Design

The study had two parts: an idea-generation phase, in which people created compositions using the interactive tangram interface, and a categorization phase, in which people grouped compositions from the prior phase into conceptual categories. The study was between-subjects with one independent variable, robot's behaviors, which had two levels: *social* and *non-social*. In the social condition, the robot displayed social behaviors during the idea-generation phase, as described in Section 3.2.3; in the non-social condition, the robot kept its eyes closed and did not display any social behaviors during the idea-generation phase (Figure 4). Participants were randomly assigned to one condition.

4.3.1 Physical Setup. The experiment was conducted in the Human And Robot Partners (HARP) Lab at Carnegie Mellon University. Participants were seated at a desk approximately 1 meter in front of the interactive projection system (Figure 1). A white mat on the floor served as a screen for a mounted projector, which displayed the tangram interface. Participants controlled pieces of this interactive interface with a wireless computer mouse. At the start of the experiment the Kuri robot was placed at one corner of the white mat, and it rolled around on the mat during the interaction. A camera captured audio and video data for the study. As a part of our institutional guidelines for

COVID-19, we sanitized all equipment before each session, asked participants to wear a mask, and maintained social distancing during the study.

4.3.2 Procedure. Procedures for the two conditions are identical except for the robot's behaviors. After providing informed consent, participants watched an introduction video that described the task and provided instructions for using the interactive tangram interface. Then they experienced one practice trial that involved a few rounds of tangram construction with the robot to familiarize themselves with the system and the robot. After participants felt comfortable with the practice trial, they began the *idea-generation task*. Participants were instructed to use the tangram to create compositions that represented the concept of "motion" and encouraged to increase the variety of ideas as the goal of this creativity task. Each composition had to use all seven tangram pieces. Pieces could be moved, scaled, and rotated with the computer mouse. Once participants were satisfied with the placement of the tangram pieces for their composition, they clicked a button on the interface to save it. Each participant created 15 such compositions, which took approximately 30 minutes.

The robot would interject its creative suggestions by moving one of the currently unplaced tangram pieces onto the canvas. The robot took 30 turns in total with each participant and in their 15 rounds of composition, it took 1, 2, or 3 turns for every random 5 rounds respectively (The turns were distributed randomly in each round). It did so by rolling to the available piece and "dragging" it to the desired location. The location of the piece was autonomously selected by the algorithm described in 3.2.2. In response to the robot's creative contribution, participants could choose to undo the action using an "undo" button on the interface. They could also stop the robot mid-contribution by clicking a "stop" button. If stopped, the robot would drop the picked piece and return to the idle position.

After the idea-generation task was complete, participants moved on to the *categorization* task. In this task, participants were first asked to group their 15 compositions into conceptual categories of their choosing. They provided names for each category and were allowed to generate as many categories as they wished. One categorization example is shown in Figure 5. This allowed us to measure people's perceived variability of their own ideas. Next, they were asked to categorize another set of 15 compositions, which came from the participant before them. This allowed us to correlate people's perceived variability of their own compositions with the perceived variability of others' compositions. (The first participant categorized the compositions from the final pilot participant.) After completing both idea-generation and categorization tasks, participants completed a post-questionnaire and a short interview about their perception of the robot.

4.4 Measurement

Data collected in the experiment include (1) participants' categorizations of the final compositions, which were further analyzed for creativity, using Divergent Thinking factors *flexibility*, *originality* and *elaboration* [16, 17, 44, 45] (the factor *fluency* was not included as we specified the total number of creation to encourage more varieties of ideas instead of quantity), (2) a software log of participants' operations and robot's behaviors, (3) post-questionnaire responses about the robot, the interaction, and background information, and (4) interview responses about the robot's role.

Creativity Measurement. We measured creativity using the Divergent Thinking factors, *flexibility*, *originality* and *Elaboration*. *flexibility*, i.e., idea "variability", was measured by the number of unique categories created by each

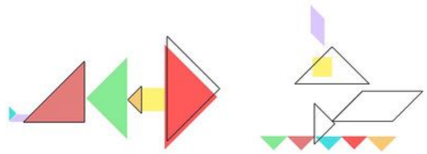

Fig. 6. Pieces in black lines are the robot's original placements. Left: one of the robot's placements is adjusted, but not moved far away. Right: all three robot's placements are changed greatly.

participant and a "variability score" [1] quantifying the physical distributions of shapes in compositions. *originality* was measured by the number of unique categories created by each participant. Two coders grouped all participants' categories by similarity and identified unique ones. *Elaboration* was measured by varieties of representation within each category. Two coders grouped similar images under each category by analyzing their visual strategies based on "shape," "composition," and "metaphor." Moderate agreement was reached between two coders for *originality* (Cohen's $\kappa = 0.590$) and *elaboration* (Cohen's $\kappa = 0.650$) and disputes were resolved with discussion.

Interface Actions. The software log includes the location, size, and orientation of each tangram piece every time it is manipulated, how often participants clicked to stop the robot's turn, and how often participants clicked to undo the robot's placed piece. *Explicit rejections* of a robot's input are defined as the number of times participants either clicked to stop or undo the robot's contribution. *Implicit rejection* defines cases where participants modified the robot's contribution by moving a piece after the robot had placed it (Figure 6). To calculate the frequency of implicit rejections, we identified how many rejections involved moves greater than the median threshold, as these represent more significant adjustments.

Post-Questionnaire Responses. The post-questionnaire contains two parts. The first part asks five Likert scale questions about participants' perception of the robot and the task, including to what degree do they perceive the robot as being helpful, distracting, inspiring, and having its own plan, and are they willing to collaborate with the robot again, and an open-ended question about their other thoughts when doing the task. The second part collects demographics information including age, gender, and experience with robots and design.

Interview Responses. After completing the post-questionnaire, we conducted interviews with four of the participants in the non-social group and six participants in the social group. (Two participants did not get interviewed due to unintentionally skipped experiment steps by the researcher.) The main interview question was "What do you think the role of the robot is?" A follow-up question was "Do you think it is a tool, collaborator, or peer?" These questions aimed to measure participants' perceptions of the role of the robot. Two coders transcribed interview scripts manually and indexed each sentence. Guided by Grounded Theory [23], each coder identified common themes related to the collaborative behaviors between the human and robot in the first pass. Then they presented the results and determined

[1]

$$V = \sum_{i=1}^{15} \sum_{j=1, j \neq i}^{15} (w_1 T(D_i, D_j) + w_2 R(D_i, D_j) + w_3 S(D_i, D_j))$$

The translation score $T(D_i, D_j)$ is the sum of the Euclidean distances between each piece's location in a pair of compositions D_i and D_j, in pixels. The rotation score $R(D_i, D_j)$ is a value indicating, for each piece, whether that piece was rotated between compositions (so maximum value was 7). The size score $S(D_i, D_j)$ is the sum of each piece's size difference between the two compositions, in pixels. Weights were introduced to balance effects among three scores related to shape transformation and computed as $w1 = 1$, $w2 = average_T / average_R$, $w3 = average_T / average_S$, respectively.

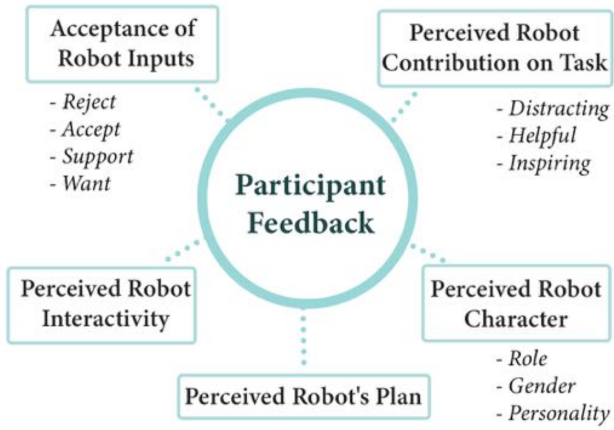

Fig. 7. The major themes that emerged in post-study interviews and post-questionnaire comments.

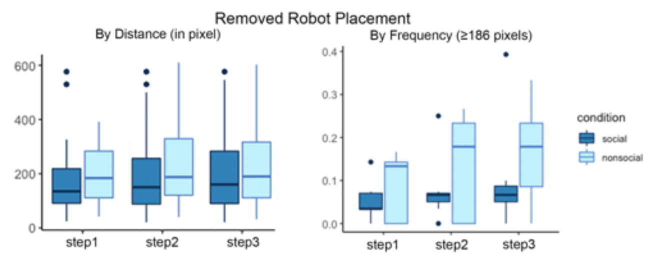

Fig. 8. Left: distances of robot's pieces that were moved one, two, and three steps after placement. Right: frequencies of robot's placements that were moved more than 186 pixels by participants in the following one, two, and three steps.

five major themes collectively. In the second pass, the two coders further identified common patterns under each theme, resolved disputes, and integrated all categories into a central paradigm as shown in Figure 7.

5 RESULTS

We evaluated our three hypotheses (Section 4.1) with a preliminary user study with 12 participants (7 in the social condition and 5 in the non-social condition). We excluded the data from one participant in the *non-social* condition, because the participant did not follow study procedures and randomly created compositions, rather than following to the theme of "motion." For all quantitative measures, we first tested the normality of our sample. We then used independent samples t-test and Mann-Whitney U Test for the normally and non-normally distributed data, respectively. The details for all statistical test are provided in Table 2. Our qualitative measures uncovered five major themes related to people's collaborative behaviors and their perceptions on the robot (Figure 7). The observations under each theme are reported in the following sections.

Table 2. A summary for our quantitative data analysis. *Social* and *non-social* conditions were denoted by *s* and *n*, respectively. Normality (N) was tested using the Shapiro-Wilk test. We used an independent samples *t*-test if both conditions were normally distributed. Otherwise, Mann-Whitney *U* Test was used.

Variable	N (s/n)	Mean (s/n)	Sd (s/n)	t/Df	U	P
Divergent Thinking Factors						
flexibility (self)	y/n	3.143/4.400	0.900/1.517		8.5	0.068
flexibility (other)	n/y	3.167/3.800	0.408/1.483		10.5	0.210
variability score	y/y	0.796/0.735	0.140/0.127	-0.787/9.304		0.451
orginiality score	n/y	0.714/1.600	1.113/1.140		9.5	0.101
elaboration score	y/y	0.833/0.607	0.363/0.326	-1.129/9.337		0.287
Acceptance of Robot Creative Input						
stop	n/n	0.028/0.013	0.040/0.029		13.5	0.249
undo	n/n	0.045/0.011	0.091/0.026		15	0.335
frequency step1	y/y	0.055/0.089	0.046/0.082	0.831/5.802		0.439
frequency step2	n/y	0.080/0.136	0.080/0.128		15	0.371
frequency step3	n/y	0.105/0.166	0.131/0.129		11.5	0.185
distance step1	n/y	169.620/197.407	132.319/108.659		316	0.079
distance step2	n/n	188.455/216.727	147.943/132.838		618	0.079
distance step3	n/n	201.508/216.727	153.810/128.963		929	0.122
Post-questionnaire						
helpfulness	n/y	3.286/3.000	0.488/0.707		13.5	0.247
distraction	y/n	2.429/1.800	1.618/1.304		13.5	0.271
having a plan	y/y	3.714/3.400	1.380/1.673	-0.345/7.631		0.739
collaborate again	y/n	4.143/3.600	0.900/0.548		11	0.150
inspiration	n/n	3.429/4.400	0.976/0.548		7.5	0.033*

5.1 Summary of Quantitative Results

Our preliminary analyses showed no statistically significant effect of the robot's social behaviors on *flexibility* (H1), *elaboration* and *originality*. Though participants in the non-social condition created marginally more idea categories from self-evaluation, which suggests more *flexibility* in the opposite direction to H1's prediction. The results showed that participants maintained marginally larger distance from the robot's placement within one step and two steps in the non-social condition than in the social condition, indicating higher acceptance of the robot with social behaviors than without (H2). Overall, the frequency and magnitude of implicit rejections were both slightly, though not significantly, higher for non-social robots than for social robots (Figure 8). Furthermore, participants rated the nonsocial robot significantly higher for the survey question, "Do you think Kuri robot has inspired you in the idea generation process," contrary to the prediction offered by H3. However, no differences were observed in participant perceptions of the robot's helpfulness, plan, and willingness to collaborate again across conditions. Overall, our quantitative analyses offer no conclusive support for any of our hypotheses, and the potential explanations for these findings are discussed in the Limitations Section.

5.2 Acceptance of Robot Inputs

We differentiated four different types of participants' acceptance attitudes towards the robot's contribution from the interview phrases. We observed an increasing level of need: reject, accept, support, and want. Participants in the social condition tend to describe their acceptance of the robot with a stronger desire to work together. For example, two participants mentioned that "*I expect her to build something together every time.*" (S12) or "*I'll go do your plan...sometimes I was trying to complement [for] his plan.*" (S11) In comparison, participants in the non-social group are more likely to accept the robot when they find the task is hard. Two participants mentioned that "*Sometimes I have no idea what shape I want but I just wanted it to help me decide it.*" (N8) or "*Sometimes it did help generate some ideas just because it was hard* *to make something just from the few shapes.*" (N7) Among all cases, the participants are likely to have mixed feelings of acceptance.

5.3 Perceived Robot Contribution on Task

In the interviews, 50% and 75% of the participants mentioned the robot's effects on the idea-generation task. Positive effects include being "helpful" and "inspiring," while negative effects include being "distracting" and "interfer[ing]." Overall, mixed responses are commonly observed: "*Sometimes the robot interfered my idea that I had so I ended up moving pieces it placed, but other times it helped generate an idea since it's hard to depict something with a few simple shapes.*" (N5) Negative phrases focused on the robot getting in the way: "*Sometimes the robot will distract me and makes me ignore the robot*" (S3) or "*Sometimes I find the robot was interfering with what I was thinking.*" (N7)

Positive phrases described three aspects of robot contributions: 1) give inspirations, 2) help to finalize the shape, and 3) take the major role to make decisions. Participants in both conditions described the robot as the source for inspiration and mentioned they have developed ideas out of the robot's input, such as "*It tries to inspire me of more thoughts of the creation*" (S1) or "*Sometimes it is helpful that he was able to like place a piece and then I can figure something else I can make out of the shapes.*" (N7) Some participants also viewed the robot's inputs as complement of their own ideas and mentioned "*Sometimes it helps you to finalize...at least two times, she has placed the piece exactly what I wanted.*" (S12) Furthermore, some participants delegated the major role to the robot and "*wanted it to help me decide it.*" (N8) or thought the robot "*was [a] relatively large part of [the] goal in constructing these shapes.*" (S11)

5.4 Perceived Robot's Plan

66.7% participants in the social group and 50.0% participants in the non-social group mentioned the robot had its own ideas or plans saying that "*it has some idea*" (S2) or "*it had its own plan*" (N7) for instance. Some participants described the robot's plan as "*strong,*" "*dominate,*" and "*I had no control.*" Some participants thought the robot's plan was confusing, saying that "*complicated to know,*" (S12) and "*I don't know what he was thinking.*" (S11)

5.5 Perceived Robot Character

We identified three aspects of the perceived robot character: robot gender, role, and personality. Participants in both conditions have attributed gender or peer role to the robot, but only two participants in the social condition attributed personality onto the robot using words such as "*sad,*" "*angry,*" "*happy,*" "*cute,*" and "*shy.*" 33% participants in the social group and 25% participants in the non-social group addressed the robot using he or she, such as "*He turned around and looked at me, he said he is not a tool,*" (S11) and "*I mean I know that he is agreeing, he is happy with what I...we are doing.*" (S12) 83% and 25% of the participants assigned the role of the robot as peer or collaborator when asked "*Do you think the robot is a tool, peer or collaborator?*" in the post-interview. Other participants did not provide a direct answer to this question.

5.6 Perceived Robot Interactivity

Participants in both conditions mentioned interactivity in the post-interviews. However, participants in the non-social condition focused more on the task-based interaction, while participants in the social condition tended to explore various means of communication with the robot. One participant in the non-social condition thought there was "*not too much*" interaction, saying that "*Sometimes it won't even do anything at all for one image, sometimes it places two pieces at once.*" (N7) Different from the limited interactivity perceived in the non-social condition, participants in the social condition expressed a stronger desire to communicate with the robot. Two people showed interests in verbal communication with the robot saying that "*You can ask me something, even if simple questions...maybe I want to talk to you? get to know what you are thinking, show me some of your logic.*" (S11) and "*What would it say if it could speak English?*" (S4) One participants intentionally moved away the robot's placement to make it look angry saying that "*Definitely it's been like more interesting in feeling her reactions than playing.*" (S12) Besides the verbal and nonverbal communications, one participant used the computer mouse cursor in the projection to "*pet*" the robot remotely in the social condition (S2).

6 DISCUSSION

Creativity is a multi-dimensional construct that requires both internal characteristics and external resources [39–41]. We identified several human behavioral traits in the collaboration that could indirectly contribute to or diminish people's creative thinking. Particularly, we present four observed patterns: accept robot inputs as inspiration, delegate the creative lead to the robot, communicate creative intents, and be playful in the creation.

Accept Robot Inputs as Inspiration. Participants in both conditions mentioned that they were inspired by the robot and developed ideas out of its input, where the robot's placements were computed based on existing elements on the canvas. This demonstrates a circular process where the participant's decision-making and the robot's inputs build on each other. This circulation is characterized as the conversational nature of design, that "usually held via a medium such a paper and pencil, with an other (either an "actual" other or oneself acting as an other) as the conversational partner," and is identified as a central feature of creativity [14].

Delegate the Creative Lead to the Robot. It is observed in both conditions that participants attributed a dominant role to the robot in the creation. One participant in the non-social condition expected the robot to help to decide when they had no idea, and another participant in the social condition created a category called "spontaneous," as he thought the robot "*was [a] relatively large part of [the] goal in constructing these shapes...I had no control in the situations.*" Sometimes the shift of responsibility in creation led to participants' free ride and losing track of their task goal. For example, some participants categorized compositions into "random" or "other" categories that do not represent coherent concepts. Prior research has shown that "free-riding" in idea generation can be caused by a lack of individual reward as the output is considered as a group endeavor [46]. As the willingness to take risks and overcome obstacles are viewed as key personality traits in creativity development [39–41], the act of free ride can adversely affect people's creativity as they give away the difficult thinking endeavor to the robot partner.

Communicate Creative Intents. The desire for mutual understanding of creative intents is observed in both conditions and our results showed a mixture of success and failure of communication. Some people perceived the robot to be able to understand their own intentions. A participant in the non-social condition said "*it seems like it was trying to see what I was making…*" Another participant in the social condition was impressed when the robot completed a piece exactly as the participant intended to create: "*...that's been like oh my god. How this is like possible. That's been amazing, two times, it happened.*" It's more commonly observed that participants tended to infer the robot's intents. In both conditions, participants thought the robot had its own plan but confused about the plan details. As suggested by Law et al. [22], the awareness of each other's intent is the foundation for negotiation. The success of communication contributes to collaborative decision-making, while the failure could detriment people's trust on the robot. For better communication outcomes, robots need to convey their plans clearly to people during collaborative tasks. Furthermore, the robot's social signals should avoid confusion, but contribute to the clarity of its intents.

Be Playful in the Creation. Prior research showed that playful disposition could augment the creative process [42] and people who characterized themselves as being playful have higher self-ratings for creativity [8]. Prior work also explored playful experience with robots with a ludic design approach [24]. We observed that some participants in the social condition tended to come up with playful ways to interact with the robot. One participant tried to "*make her angry*," saying "*that was more fun actually we get.*" Another participant used the projected computer mouse cursor to "pet" the robot remotely, saying that "*it is cute.*" Playfulness could be an important outcome of the robot's social behaviors and contribute to creative thinking.

6.1 Limitations & Future Work

A key limitation of our study is the small sample size utilized due to the preliminary nature of the study. A *post hoc* power analysis indicates a power of 0.11. Consequently, the quantitative findings are inconclusive and difficult to explain. A more comprehensive study with a larger sample size is necessary to establish a more conclusive quantitative understanding the effects of our manipulation. Another limitation of the presented work is that our study hypotheses drew from the human creativity literature, which may not have been appropriate for human-robot creative activities. For example, a social, compared to a non-social one, might have been perceived more as an independent agent pursuing its own goals [29] and thus might not have been perceived as a conduit to express creativity. More research is needed to better understand the relationships between human perceptions of robots and their interactions in creative activity.

7 CONCLUSION

This paper investigates the effects of a robot's social behaviors on people's creative thinking and collaborative behaviors in co-creation. We presented an interactive system that facilitates collaboration between a human and a robot, hosted an online study for robot behavior selection, and conducted a preliminary user study ($n = 12$). We observed creativity-related behaviors including accepting robot inputs as inspiration, delegating the creative lead to the robot, communicating creative intents, and being playful in the creation. As a multi-dimensional construct, creativity is a result of multiple correlated factors, including internal ones such as personality, motivation and knowledge, and external ones such as cultural and socioeconomic factors. Our study findings raise questions about the downstream effects of delegating the creative lead to technical artifacts as well as how the creativity-related behaviors such as playfulness can translate to meaningful creative outcomes.

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