Escape!Bot: Social Robots as Creative Problem-Solving Partners

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ABSTRACT

In this work, we explore the effect of a social robot's embodiment and creativity scaffolding on children's creative problem solving skills in the context of a digital creative problem-solving game called Escape!Bot. Children aged 5-11 years played the video game, which involved assembling contraptions to escape a digital world, and the robot Jibo acted as a collaborative peer that offered questions, reflective prompts, challenges, and ideas. In order to evaluate the role of the robot's co-presence and creativity scaffolding, we ran a 2x2 experiment to determine the factorial efficacy of the robot's embodiment and creativity scaffolding behaviors. We observed mixed results, with the robot's creativity scaffolding having a positive influence on the time taken to complete the game, but not on the overall use of novel objects or reuse of objects. We present the system design, user study and findings from Escape!Bot to investigate the feasibility of designing social robots to support creative problem solving.

CCS CONCEPTS

• **Human-centered computing** → **Collaborative and social computing devices**; **Collaborative interaction**; *User studies.*

KEYWORDS

child-robot interaction, creativity, divergent thinking, social robots, collaboration

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1 INTRODUCTION

Children's ability to think creatively, or generate novel, fluent, and valuable ideas, contributes to their learning and well-being [30]. Most current works explore creative expression in the context of open-ended creative activities, such as drawing or telling a story. Creativity has also been associated with problem solving and finding solutions, especially in education [39, 45]. These definitions of creativity fall under Creative Problem Solving (or CPS), "a framework which individuals or groups can use to formulate problems, opportunities, or challenges, generate and analyze many, varied, and novel options, and plan for effective implementation of new solutions or courses of action" [48]. In this work, we position our definition of creativity within the framework of CPS, focusing on fluent, novel and valuable idea generation to solve a problem.

In contrast with open-ended creative activities, CPS activities involve thinking creatively to work towards a *solution* to solve a given *problem*, often one that either has an unconventional solution, or multiple possible courses of actions. CPS involves understanding the problem, generating ideas, and planning for action [48]. Learning CPS helps children solve everyday problems using creative and critical thinking [16]. While the benefits of creativity and CPS abilities are well known, children's creativity drops around the age of 7 [46], which has been attributed to structured elementary school curricula that does not make space for creative thinking and play. As a result, educators and researchers have made efforts to leverage technology to foster creativity in children, and there has been an increased interest in designing, implementing and evaluating Creativity-Support Tools (CSTs), which are digital tools and interfaces that stimulate creativity in people [44]. A recent review of CSTs [18] in HCI found several tools focusing on children's creative learning [14, 25]. Given the social nature of creative expression, and the positive influence that collaboration has on children's creative expression, social agents, particularly social robots, have been posed as a potential tool for fostering children's creativity. Existing works in HRI focus on children and robots collaborating in open-ended creative activities, such as storytelling or drawing. While open-ended activities promote creative expression and divergent thinking, CPS empowers children to solve daily problems using creative approaches. Previous works in HRI have used robots in various collaborative scenarios, such as [19, 35]; however, the robot did not utilize social interactions. Social robots have the ability to be co-present collaborators that can express artificial creativity and socially interact with children in ways that stimulate creativity. As collaboration with robots increases, there is an opportunity to leverage social interaction with these robots to aid CPS.

In this work, we explore the feasibility of using social robots as effective creativity support partners for creative problem solving. In particular, we sought to determine the effect of the robot's embodiment and its exhibited creativity scaffolding behaviors on children's expressed creativity during gameplay. We present a case study, Escape!Bot, in which children engage in a digital creative problem solving game while collaborating with the social robot Jibo. Escape!Bot is a digital platform game that can be played on a tablet. The goal of the game is to assemble a series of objects that enables the game character to escape a room. There are infinitely many solutions to each level, using different combinations and

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placements of objects. In congruence with previous studies, we hypothesized that the robot's social interactions with children, as well as the behaviors combined with the robot's embodiment, would help foster creative expression in children. Creativity was measured by the number of unique objects used, using unique strategies such as reusing an object with multiple placements, and successfully completing the task.

We conducted a 2x2 randomized control trial, with the robot's embodiment and creativity scaffolding behaviors as independent variables. Children were randomly assigned to one of four groups: (1) physical robot exhibiting creativity scaffolding behaviors (E+C+), (2) virtual robot exhibiting creativity scaffolding behaviors (E-C+), (3) physical robot not exhibiting creativity scaffolding behaviors (E+C-), and (4) virtual robot not exhibiting creativity scaffolding behaviors (E-C-). We had mixed results, and found that neither the robot's embodiment nor creativity scaffolding behaviors had a significant influence on children's creativity during gameplay. Further, we found that while children could perceive the robot's expressed creativity, they did not find the scaffolding offered helpful.

In this paper, we investigate the effect of embodiment and creativity scaffolding on children's CPS skills. We present our design of the child-robot interaction in Escape!Bot. We present our experiment design, comparative user pilot study, and its results. We discuss the findings and their implications on using social agents as collaborators in creative problem solving tasks for children.

2 BACKGROUND

2.1 Eliciting Creativity in Children

Creative learning in young children occurs primarily through "questioning...manipulating, experimenting, and playing to find out in their own way the truth about things" [47]. Indeed, research has shown that having children question and reflect on their behaviors is beneficial to their creativity [22, 52]. Children learn through social mechanisms such as emulation, i.e. "[when] children achieve common goals to those modelled, but do so by using idiosyncratic means that were never observed" [9], especially in classroom environments. Similarly, collaboration is key to combining diverse perspectives and ideas, now understood to be a crucial factor in creativity [28]. For children in particular, friendship and peership is essential to fostering positive collaborative and creative relationships [32]. Teachers can also use several methods to stimulate creative expression in children, such as encouraging risk-taking behavior and divergent thinking [8]. Children's creativity, and CPS abilities are also positively influenced by positive affect [20].

2.2 Creativity Support Tools for Children

Benefits of creative thinking and observed decline in children's creativity as they enter elementary schools has motivated the development of several technological approaches that aim to stimulate children's creativity, especially in classrooms [6]. Most commonly, these included novel use of materials and interactions [26, 50]. Longitudinal studies indicated that integrating digital game-based tools increased children's creative skills and attitudes [10, 36, 37, 49], and can lead to both self-reported [1] and empirical [13] increases in problem solving skills. Play-based activities are effective mechanisms for exploring new concepts due to their high entertainment value, which keeps children engaged. Bowman et al. provided digital game players with sandbox-like environments that contain multiple solutions to a single problem [11]. Digital games are also highly interactive, and allow players "to experience novelty, curiosity and challenge", which stimulate learning [21]. Further, children learn creativity from social interactions with others, such as mentors and peers, in their environment. In this work, we designed the digital platform game Escape!Bot, which children play with the peer-like social robot, Jibo. Each level involves CPS by placing objects in a physical contraption to enable the game character to escape. Inspired by Bowman et al., Escape!Bot provides multiple ways to reach the final goal, and there is no one correct answer. All objects and levels are different, which was intended to stimulate novelty, curiosity and challenge.

2.3 Human-Robot Interaction and Creativity

Algorithms that enable robots to quickly adapt to varied human behaviors allow them to assist in creative problem solving tasks [19, 35]. Advancements in generative AI and computational creativity techniques enable human-AI collaboration that leverages computational agents as co-creative agents [24, 27]. In particular, the social capability of robots is highly promising for fostering human creativity due to the collaborative nature of creativity. Social robots have been used in a variety of co-creative tasks, such as, musical composition [23, 33], creating visual art [4, 29], creating a Zen rock garden, telling creative stories [5, 31], and even physical expressions such as dancing [34, 42] and improvisation [41]. Previous work has demonstrated the efficacy of the robot's verbal and non-verbal social behaviors upon children's verbal, figural and constructional creativity through social emulation of the robot [2, 5]. Children mimic the robot's behaviors, resulting in a positive effect on their own creativity. However, this was not true for all studies; Elgarf et al. found that a creative storytelling robot did not have a positive influence on children's creativity [17]. Previous works also found that the robot's presence alone (embodiment) did not have a positive influence on children's creativity [3, 7]. While previous work is largely situated in the context of open-ended creative tasks, little research has been conducted to study a robot's influence on children's creativity in CPS tasks. In this work, we evaluate whether playing a CPS game collaboratively with a robot would influence children's CPS abilities. While most existing work analyzed the influence of the robot's social interactions, or the robot's presence, we analyze the influence of both the robot's embodiment and creativity scaffolding behaviors on children's creative expression during gameplay. Embodiment's effect on creativity has been inconclusive; we believe that combining embodiment with creative scaffolding behaviors will lead to creativity gains.

3 SYSTEM DESIGN

3.1 Robotic Platform

The robotic companion in this study was the Jibo robot. Jibo is a socially expressive robot, with a three-axis body and a screen based face. It utilizes text-to-speech for speech generation and a microphone for speech identification, a speaker which outputs sound, cameras for image recognition, and tactile sensors to detect touch. Jibo uses body animations, face screens and audio effects to express emotions. We chose the Jibo robot since it has a playful character and has been used successfully in learning applications with children [12, 40]. Further, since the robot is designed to be used as a commercial and research platform, its robustness is well-suited for unattended autonomous studies, which was preferable since we were running the experiment remotely in participants' homes. The Jibo robot's software development kit includes a Java protocol, which enables applications developed in Java to communicate with Jibo by sending and receiving messages over WiFi. We developed a Java Package Archive (JAR) file that has the ability to connect with a Jibo robot based on its IP address, send a speech or animation command, receive information recorded. We made use of a JAR file for robot communication because the Escape!Bot Game was developed in the Unity Game Development Platform, which supported JAR plugins. This allowed for seamless communication between the robot and the tablet game (Figure 1), and the setup could be used straight out of the box with the participants' parents only involved in connecting the tablet and robot with their home WiFi. We presented an earlier version of our system design in [15].

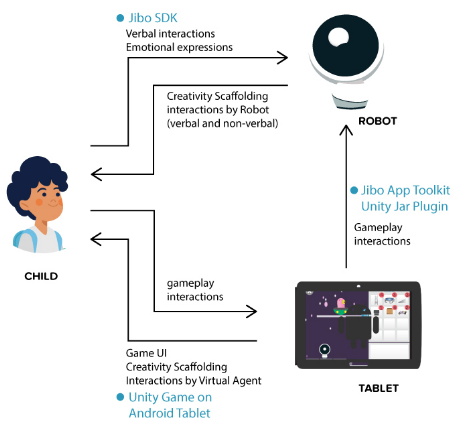

Figure 1: System diagram displaying the interaction between the child, tablet, and robot in the embodied conditions. In the virtual conditions, the robot is not present.

3.2 Escape!Bot Creativity Game

We designed the game Escape!Bot using the Unity platform to investigate the factorial influence of embodiment and creative scaffolding upon problem solving within gameplay. Escape!Bot is a sandbox-like game inspired by *The Incredible Machine* games, in which players assemble a series of contraptions to move a character to a goal. Escape!Bot offers an unlimited number of solutions to the player, but certain constraints are applied, such as a limited number of objects and a time limit. In the creative condition of the gameplay, the robot will inquire about and suggest possible solutions, and encourage the player.

The game is played on an Android tablet. Players tilt the tablet left and right to move the character around, and use a single finger drag to move objects into the game world 2. Once objects are in the game world, the character can use them to traverse in a logical manner. For example, ladders and trampolines are used to get to higher platforms, while catapults are used to go sideways. Objects can also be combined in logical manners; for example, ladders or trampolines could be placed on top of boxes or ramps, but not on top of catapults or vents. Purposeful placement of the objects is key, as they are limited in count and can be dropped or lost off the edge of platforms in the game world. As such, objects can be reused by dragging them to a different place in the game world, or dragged back into the inventory for later use. Players can also close the inventory to use the zoom feature, which allows them to get a wider perspective of the game world. They can also use a two finger drag to pan around the game world and identify possible paths to take.

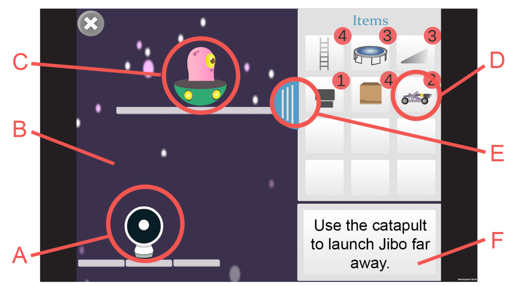

Figure 2: The game interface. A: The player character, a virtual Jibo. B: The game environment. C: An environmental enemy. D: A game object (catapult). E: The draggable object drawer. F: The text description of the selected object.

The intended object functionalities are as follows:

- Ladder: used to traverse medium vertical distance
- Trampoline: used to traverse medium to large vertical distance or medium horizontal distance
- Vent: used to traverse large vertical distance or medium horizontal distance
- Box: used to block enemies or obstacles, or as a base to stack other objects
- Ramp: used to traverse short horizontal distance, or as a base to stack other objects
- Catapult: used to traverse large horizontal distance

The following is a sample gameplay progressions followed by one participants while playing Escape!Bot:

Jasmine (name changed) started the game by viewing an interactive tutorial of how to move and use objects. In the Space level 1, she first decided to use a ladder to climb to the platform above the robot. The robot fell from the ladder twice. She then used a trampoline, that allowed her to jump two levels above. She used another trampoline, but that landed her robot in the pit, and the game restarted. This time, she started with the trampoline, and landed two platforms above and one platform to the right. She used a vent to jump all the way to the top. She attempted to move to the platform towards the robot's left, but fell into the pit again. After 5 more failed attempts, she used a combination of a trampoline, 2 ladders and a vent to finally reach the flag at the end of the level. Then, she progressed onto level 2.

4 INTERACTION DESIGN

The Jibo robot acts as an autonomous NPC who comments on events in the game as the child triggers them. Dialogues were pre-programmed for each trigger, and differed based on the creative vs. non-creative conditions. In the embodied condition, the robot will make affective responses based on the dialogue. For example, when exclaiming that the player is close to the escape door, Jibo will spin around joyfully; when commenting on the alien enemy, the robot will make a scared expression. Dialogues refresh upon reloading or losing the level.

4.1 Introduction

To begin the interaction, the researcher explains to the child that they will be playing this game with Jibo, and that Jibo will explain the instructions to them. When the child indicates that they are ready, the Jibo robot launches the tutorial stage.
ROBOT: [*with enthusiasm*] Hey there! My name is Jibo. What is your name?
CHILD: [*says their name*]
ROBOT: [*curiously*] Can you help me find the door out of this spaceship?
CHILD: [*responds yes*]
A box appears on the game stage a short distance away from Jibo.
ROBOT: Tilt the tablet left and right to move around. Make me run over to the box! [*pauses to let the child try*]
ROBOT: You should also use the objects in the toolbox to help you get places. The toolbox is on the right side of the screen. Press and drag the objects into the world to use them. [*pauses to let the child try*]
ROBOT: [*an arrow pointing at the toolbox appears*] You can drag the toolbox closed using this blue slider. [*pauses to let the child try, then the toolbox disappears*] When you close the toolbox, you'll find a zoom button in the bottom right. [*pauses to let the child try, then screen zooms out*] When you are zoomed out, you can use two fingers to pan around the scene. [*diagram of two finger pan appears*]
ROBOT: [*with enthusiasm*] Got it? [*spins around*] Let's go!

4.2 During Gameplay

4.2.1 Dialogue Triggers. The robot's dialogues are triggered by the following variables from the gameplay state:

- *Object usage*: If the player has used more than half of the available objects of a single object class, and has also used less than half of any other object class, this indicates that they have been relying heavily on a specific object (e.g. if a player has used all their trampolines, only one box, and none of the other objects) In all conditions, the robot will start its comment with "I see you've been using a lot of [object type]."
- *Object reuse*: If the player reuses a single object more than three times (defined by distinct placements within the game stage), in all conditions, the robot will start its comment with "I see you've been reusing a lot of [object type]".
- *Use of all objects*: If the player uses at least one of each of the available objects, in all conditions, the robot will start its comment with "Wow, we've used so many different objects".
- *Proximity to escape door*: Certain locations within the game stage allow the player to reach the escape door with a single object. When the player reaches a location, in all conditions, the robot will start its comment with, "It looks like we're close to the escape door!"

4.2.2 Dialogue Behaviors. The robot's dialogues varied between the creative and non-creative conditions. In the non-creative conditions, the robot would say something tangentially relevant to the triggered dialogue, but not particularly helpful to the gameplay. For example, if a player triggered an object usage based dialogue for trampolines, the robot would comment on how it likes bouncing on trampolines. If a player triggered a proximity based dialogue, the robot would comment on being excited to escape.

In the creative condition, the dialogues were divided into three categories, derived from Kahn et. al's 10 human-robot interaction patterns aimed to foster human creativity: demonstration (Pushing the Limits), inquiry (Consider the Alternative), and encouragement (Validate Decision) [29].

- *Demonstration*: Previous work has shown that social robots demonstrating creativity increased children's expressed creativity [2, 38, 51]. These dialogues were tied to the 'object usage' dialogue triggers. The robot would give an explicit example of a different object with a similar functionality (e.g. a ladder instead of a trampoline), or suggest combinations of objects (e.g. a trampoline on top of a box). For example, if the player is using a lot of boxes, the robot suggests putting a ladder or a trampoline on top of a box.
- *Inquiry*: Reflective question asking has been shown to benefit children's creativity [43]. These dialogues were tied to the 'object usage', 'object reuse', and 'proximity to escape door' triggers. Upon an 'object usage' or 'object reuse' trigger, the robot would suggest thinking of different objects with similar functionalities. On the 'proximity to escape door' trigger, the robot would ask questions prompting the participant to reflect on what object would complete the level (e.g. "What object do you think would propel us that far up?" for the vent).
- *Encouragement*: Research has shown that positive affect [20] and positive reinforcement [28] have beneficial effects on children's creativity. These dialogues were tied to the 'object reuse' and 'use of all objects' triggers. For example, upon activating reuse triggers, the robot would comment on how reusing objects is smart. Furthermore, on the 'use of all objects' trigger, the robot would comment that knowing how all the objects work is useful.

4.3 Gameplay End

If the child had not finished the game after 45 minutes, they were asked to close the game and answer the post-test questions. If they completed all three levels, they would encounter a win screen in which the robot thanked them for successfully returning it to its home.

5 STUDY DESIGN

5.1 Participants

56 participants in the 5-11 year-old age range were recruited for this study (22 female, 32 male, 2 non-binary). The average age of the participants was 8.71 (S.D. = 1.65). 23 were recruited from a previous study, and 33 were recruited from a department mailing list. The latter participants had primarily not been exposed to robots before, while the former had; they were split equally across test conditions. All participants and their guardians signed an informed assent and consent form to participate in the study and to permit us to collect demographic and assessment data. The recruitment materials, study protocol, and data collection protocol were reviewed and approved by the Institute Research Board at Massachusetts Institute of Technology. Three children experienced technical issues with their internet connection or the game itself, and five children were either too young to read and/or required a parent's help to play the game, resulting in 48 participants' data being included in the final analyses.

The study was conducted remotely due to the pandemic, and the researchers delivered robots and tablets as needed to the participants' addresses. The participants' parents were instructed to connect the Jibo robot to Wifi, but to not allow participants to play the game until their assigned 45 minute study slot. Tablets were password protected and passwords were emailed to the parents.

5.2 Study Conditions

We designed a 2x2 study with 2 experimental factors: creativity scaffolding and embodiment. Participants were counterbalanced and divided across conditions by gender and age.

- **E-C-**: Gender: M = 6, F = 7; Age: 8.40 ± 1.45, n = 13
- **E-C+**: Gender: M = 5, F = 4, NB = 2; Age: 8.73 ± 1.35, n = 11
- **E+C-**: Gender: M = 8, F = 4; Age: 9.08 ± 1.56, n = 12
- **E+C+**: Gender: M = 7, F = 5; Age: 9.5 ± 1.62, n = 12

5.2.1 *Creative (C+) vs Non-Creative (C-) Conditions.*

The difference between C+ and C- was wholly in the robot's dialogues, as described in Section 4.2.2. We validated that the C+ robot was indeed perceived as more creative in our post-test, in which a statistically significant number of participants in the C+ condition said that Jibo was creative as compared to the C- condition ($p = 0.0215$).

5.2.2 *Virtual (E-) vs Embodied (E+) Conditions.*

Participants in the E- condition played the game with only a virtual character who delivered dialogue through in-game speech bubbles, as shown in the left column of Figure 3. Participants in the E+ condition played the game with a physical Jibo robot who verbalized the dialogues through its custom speech API, and the virtual character was merely the means through which the player traversed the level.

5.3 Hypotheses

- **H1: Embodiment**: Participants interacting with the E+ agents will not express a significantly different level of creativity than participants interacting with the E- agents.
- **H2: Creative scaffolding**: Participants interacting with the C+ agents will express a higher level of creativity than participants interacting with the C- agents.

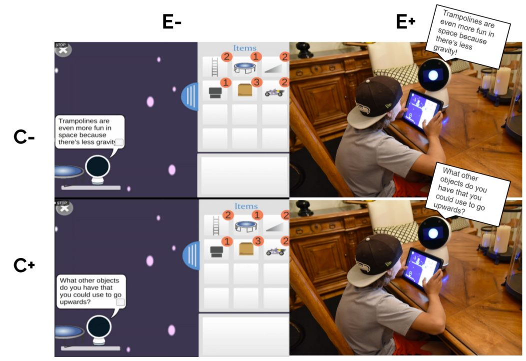

Figure 3: Diagram showing the difference between the four study conditions.

- **H3: Combined effect**: Participants in E+C+ will express higher levels of creativity than all other study conditions.

5.4 Data Collection and Measures

5.4.1 *Data Collection.*

We collected the following data points from logging built in to the game code:

- Objects used, reused, or interacted with by the character, where in the game world they were used, and timestamps
- Dialogues triggered
- Win and loss states

Because the study was run virtually, audio and video data were not collected over Zoom. The instructors merely observed the participants over video and helped them debug technical issues if they encountered any. After the task was over, a post-test questionnaire consisting of a mix of 5-point Likert scale, yes/no, and open ended questions was administered.

5.4.2 *Measures.*

We used the following measures as built-in evaluation of expressed creativity in gameplay:

- **Unique objects used**: In the C+ condition, Jibo encouraged the use of diverse objects. Using a wide set of objects demonstrates flexibility of thought and divergent thinking within the context of the game. For each of the objects participants used within across all attempts of a single level, 1 was added to their score, with a maximum score of 6 per level for the 6 object classes.
- **Object reuse**: Reusing objects was not explicitly specified as a game mechanic, and players had to discover it on their own, which demonstrated divergent thought in exploration. In the C+ condition, Jibo encourages reuse of objects, saying that it is smart because objects can be lost in the level. This comes in useful later in the game, when the player is given only one of each object class in the third level. For each of the individual objects that a player reused within their attempts at a single level, 1 was added to their score for that object. For example, within the four provided ladders, if they reused ladder-1 4 times and ladder-2 6 times, their total ladder reuse score would 4+6 = 10. This was done for all six objects, and their final scores were calculated by summing the object

scores together and dividing them by the number of turns (or attempts) the participant took for that level.

- **Completing the task**: As this was a CPS task, players would successfully demonstrate their flexibility and understanding by completing it. The time taken was also taken into account, with a lower time indicating a faster understanding of the problem. Quitting the game, defined as exiting the task before 35 (of 45) given minutes had elapsed, was counted against participants.

5.5 Results

5.5.1 In-game behaviors. The following results were collected from analyzing the participant log data files.

Unique object usage: We used a two-way ANOVA test to compare children's usage of unique objects across the study conditions. Accepting the null hypothesis, we found no significant differences between children in the E-C- condition (L1: 4.616 ± 1.446; L2: 3.6 ± 2.011; L3: 3.375 ± 1.847), the E-C+ condition (L1: 5.5 ± 0.756; L2: 5.125 ± 1.808; L3: 4.25 ± 0.957), the E+C- condition (L1: 5.3 ± 1.060; L2: 4.889 ± 1.965; L3: 4.333 ± 1.033), and the E+C+ condition (L1: 5.636 ± 0.809; L2: 5 ± 1.225; L3: 4 ± 0.894) across all levels (F(1, 44) = 0.204, p = .135). Neither independent variables, creativity (p = 0.19 (L1); 0.59 (L2); N/A for L3) or embodiment (p = 0.27 (L1); 0.59 (L2); N/A for L3) had a significant impact on children's usage of unique objects. Unique object usage uniformly went down across all conditions per level, perhaps indicating that participants learned which objects were most beneficial to their gameplay.

Object reuse We used a two-way ANOVA test to compare children's reuse of the same objects across the study conditions. Accepting the null hypothesis, we found no significant differences between children in the E-C- condition (L1: 4.988 ± 3.776; L2: 5.451 ± 3.451; L3: 4.096 ± 1.294), the E-C+ condition (L1: 6.268 ± 3.323; L2: 5.51 ± 2.106; L3: 4.096 ± 1.294), the E+C- condition (L1: 3.519 ± 1.811; L2: 4.00 ± 3.584; L3: 3.608 ± 2.803), and the E+C+ condition (L1: 5.023 ± 4.043; L2: 4.066 ± 2.845; L3: 1.834 ± 1.326) across all levels (F(1, 40) = 0.407, p = 0.527). Neither creativity (p = 0.94 (L1); 0.54 (L2); N/A (L3)) nor embodiment (p = 0.37 (L1); 0.36 (L2); N/A (L3)) had a significant impact on children's reuse of objects.

Winning We used a z-score test for two population proportions to determine statistical significance between conditions for the proportion of participants who won. For C+ (9/23 won) vs C- (13/25 won), there was no significant difference in the proportions (z = 0.894, p = 0.37). For E+ (9/24 won) vs E- (13/24 won), there was no significant difference in the proportions (z = 1.159, p = 0.25). We also calculated the total amount of time that participants who successfully completed the task took. There were no observable differences in the average win time for E+ vs E- (27.334 ± 8.313 vs. 28.076 ± 7.364). A Kolmogorov-Smirnov Test test indicated that the data was normally distributed (D = .16756). We used an unpaired t-test to compare the win times for C+ vs C- (23.111 ± 6.624 vs. 31 ± 6.816), and rejecting the null hypothesis, we found that C+ participants took significantly less time to win the game than C- (t(44) = 2.94, p = 0.009).

Quitting We used a z-score test for two population proportions to determine statistical significance between conditions for the proportion of participants who quit the game early. We defined quitting as leaving the task before 35 out of 45 of the allowed minutes had elapsed. For C+ (3/23 quit) vs C- (4/25 quit), there was no significant difference in the proportions ($z = -0.29$, p = 0.77). For E+ (7/24 quit) vs. E- (0/24 quit), there was a significant difference in the proportions (z = 2.862, p = 0.004), rejecting the null hypothesis. Participants that interacted with the physical Jibo robot were significantly more likely to quit the game early as compared to the group interacting with the virtual robot.

Behaviors following robot dialogue: In the C+ condition, the robot makes suggestions to the player for possible objects that they could use when they are running low on a particular object (the *demonstration* class of dialogues). To determine if the robot's embodiment had an effect on how many of these suggestions that participants took, we used a z-score test for two population proportions to compare the number of dialogues that participants E+C+ and the E-C+ conditions followed with the usage of the suggested object. In level 1, we found a significant difference between how many dialogues E+C+ followed (5 followed for 12 participants) vs. how many dialogues E-C+ followed (0 followed for 11 participants) with z = 2.42 and p = 0.016. However, in the following levels, we found no significant differences between E+C+ (L2: 2 dialogues followed for 8 participants; L3: 1 dialogue followed for 6 participants) and E-C+ (L2: 1 dialogue followed for 8 participants; L3: 0 dialogues followed for 4 participants).

Player styles: We observed that players used different gameplay strategies in their winning turns. We listed the game interactions for every player in the winning turn and identified 4 kinds of object usage strategies: (1) Using many objects with many repetitions, (2) Using many objects with few repetitions, (3) Using few objects with many repetitions, and (4) Using few objects with few repetitions. We also observed two kinds of planning strategies: (5) Frequent use of zoom in, zoom out and panning across the game for planning object placement, and (6) Infrequent planning strategy. The player strategies differed across conditions; for instance, most participants in E-C- used S3 (58.3%), those in E-C+ used S4 (40%), most in E+C- used S2 (62.5%), and most in E+C+ used S1 & S4 (75%). The robot's embodiment and creativity had a significant combined effect on participants selecting many objects in the winning strategy ($X^2 = 4.36, p = 0.037$). Post-hoc analysis revealed significant differences between the E+C+ vs E-C- and E+C+ vs E+C- groups. This finding was consistent with the participants following the robot's dialogues more in the E+ condition as compared to E-. No significant effect was found on the object reuse ($X^2 = 1.4817, p = 0.22$). Participants in the E+ conditions were significantly more likely to use the frequent planning strategy (5) (58.82%) as compared to participants in the E- condition (20%) ($X^2 = 5.89, p = 0.015$). Hence, embodiment had a significant impact on participants' planning strategy, but creativity behaviors did not.

5.5.2 Post-test findings. The following results were collected from participants' post-test answers.

Q1: On a scale of 1 to 5, how much fun did you have playing the game today? A 2x2 ANOVA test on participants' responses revealed no significant differences due to creative scaffolding (F(1,44) = 0.57, p = 0.454) or due to embodiment (F(1,44) = 1.426, p = 0.239).

Q2: Which of the objects in the game did you find useful? Of the six objects in the game, participants across all conditions considered the trampoline and the vent to be the most useful objects (Figure 4). Reasons given for this included the objects' relative versatility in where they can be placed, and the large distance that can be traversed when using them. Some participants also discussed objects they didn't find useful. Reasons given were that they couldn't figure out how to use them, or that the objects could not be rotated to face a different direction.

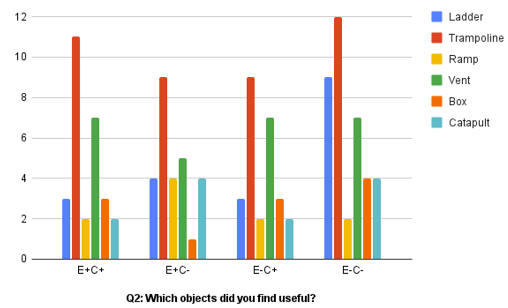

Figure 4: Objects that participants listed as useful across the four conditions.

Q3: Did you find any object really useful? Why? Participants across all conditions agreed that the trampoline was the most useful object in the game. Reasons given included the height boost, getting between platforms, and getting just the right amount of height.

Q4: On a scale of 1 to 5, how hard did you find the game? A 2x2 ANOVA test revealed that the creative scaffolding (F(1,44) = 0.437, $p = 0.512$) and embodiment (F(1,44) = 2.655, $p = 0.1103$) had no significant effect on the participants perceived task difficulty.

Q5: On a scale of 1-5, how helpful would you rate Jibo A 2x2 ANOVA test showed that embodiment had no significant difference on how helpful participants found Jibo (F(1,44) = 1.837, $p = 0.1822$). However, creative scaffolding had a significant difference (F(1,44) = 6.082, $p = 0.01762$). Participants in the C- condition rated Jibo more positively (3.36 ± 1.327) than participants in the C+ condition (2.531 ± 1.139). This may be because participants in the non-creative condition may have not perceived Jibo as trying to help them, and therefore gave ambivalent answers to the post-test question, whereas participants in the creative condition understood that Jibo was trying to help them, but didn't find him helpful nonetheless.

Q6: How do you think Jibo can be of more help? We used an inductive coding process to thematically group participants' responses. We recruited two objective coders blind to the study's hypothesis and the participants' study condition to categorize the responses. Conducting an inter-coder reliability test between the objective coders and our coding to validate the reliability of coding yielded a high correlation of 0.813. Many participants reported wanting more help from Jibo; 22.9% wanted more hints on how to use the objects, 14.6% wanted hints on what path to take through the level, 2.1% wanted Jibo to just give them the solution, and 12.5% wanted more hints in general. Participants also wanted changes to the game mechanics, including bigger text (4.2%), new mechanics (10.4%), and for Jibo not to repeat himself (12.5%). 6.3% of participants said that Jibo was already helpful.

Q7: Do you think Jibo had any creative ideas? (yes/no/ambivalent) A chi-square test of independence was performed to examine the relation between the robot's expressed creativity behaviors and children's perception of the robot as creative. The relation between C- and C+ was significant ($X^2 = 7.6754, p = .021543$). Children in the C+ condition were more likely to think of the robot as creative. Embodiment has no effect on children's perception of the robot as creative.

Q8: Do you think your ideas were more creative or Jibo's ideas are more creative? (mine/Jibo/ambivalent) A chi-square test of independence was performed to examine the relation between the robot's expressed creativity behaviors and children's perception of whose ideas were better. The difference between the non-creative and creative conditions was not significant ($p = .461192$). More children in the C+ condition reported that the robot's ideas were better as compared to the C- condition, but the difference was not significant. Similarly, the difference between the virtual and embodied conditions was not significant ($p = .731472$). Overall, participants across all conditions reported their own ideas to be better.

6 DISCUSSION

In this work, we presented the system design of Escape!Bot, a game-based collaborative and creative child-robot interaction. Through a user study, we evaluated the influence of a social robotic collaborative peer's embodiment and creativity scaffolding behaviors on children's creative expression in the Escape!Bot game. We hypothesized that the robot's embodiment would not have a significant effect on participants' creative expression, but creativity scaffolding social interactions, as well as embodiment and creativity scaffolding combined, would. Our findings indicate mixed results. In line with our hypothesis, participants that interacted with the robot expressing creativity scaffolding behaviors (C+) completed the game much more quickly than participants in the C- conditions. However, we found that the creativity scaffolding interactions did not have a significant influence on other aspects of children's creativity. With regard to E+ participants, while players in the E+C+ robot condition listened to the robot's suggestions more frequently, this did not yield significantly more wins when compared to E-C+. However, in the winning turn, E+C+ participants did significantly more spatial planning and commonly used multiple unique objects as the winning gameplay strategy. Hence, when the robot offered creativity scaffolding, embodiment had a positive influence on children's creativity, especially over time. However, while participants in the C+ conditions perceived the robot (both virtual and physical) to be significantly more *creative*, they did not find the robot to be more *helpful*. In this section, we discuss possible explanations for not seeing a more significant effect of the robot on children's creativity in the Escape!Bot task, and its implications on designing HRI patterns for fostering creativity.

6.1 Nature of the task

Creativity is influenced by external factors during a task, but is also influenced by the nature of the task itself. We observed that only 45.83% of participants could complete the game, and several participants found the game difficult. All participants had to make several attempts for all levels. While the complexity of task is essential for CPS, this game interaction was too complex for participants, which may have led them to find an external collaborator more distracting than helpful. Further, while the robot was posed as a collaborative peer, the game was not dependent on the robot, and could be played without it. We found that between the game and the robot, participants primarily focused on the game, only occasionally looking at the robot. Unlike open-ended creativity tasks, there was a win state within limited time, which led to participants being more motivated to win the game than to think creatively.

6.2 Role of the robot

Even though the robot is introduced as a "collaborative peer", it could have been perceived as a non-player character, or a spectator, rather than as a collaborator. In the post-test, one participant said that they wished the robot would just "tell them the solution", and did not view the robot as a collaborator to work *with* to figure out the solution. Participants in the creative conditions could perceive the robot's high creativity, but they still found the robot to be less useful. A possible explanation for this could be the timing of the scaffolding interactions offered by the robot; while the robot interaction patterns were contextual to the object being used, they were triggered immediately after the player uses an object. This design did not offer the player any autonomy over when they wanted to interact with the robot, and there was no way for the player to ask for the robot's input. Further, the fixed timing of the interactions made them repetitive, and we observed that over time, participants stopped following the robot's dialogues. This is different from scaffolding offered by human peers, which takes into account the participants' interactions, the number of attempts made, and participants' expertise. Post-test findings indicate that the children found the robot to be distracting, and the social interactions to be overall unhelpful. Unlike previous work, the robot's interactions were autonomous, with the nature and triggers of interactions being determined by researchers and grounded in creativity theory and previous work in HRI and creativity. The proposed interactions may not have been well suited for this task, and modeling the interaction patterns on a human collaborator's interaction data could be helpful.

Finally, it is imperative to consider that the study was conducted remotely, and while we attempted to make the setup seamless for participants, it was still unfamiliar. Not being given enough time to familiarize with the robot in their environment before the activity may also have resulted in the participants not viewing the robot as a peer. For the participant group that interacted with the physical robot, we also observed significantly more quitting midway. The difficulty of the task was stated as the most common reason for quitting; however, the distraction due to the robot's speeches may play a role. Between getting used to a complex task, having limited time to complete the game, and familiarizing with a new robot, the cognitive load placed on the participants in the task was high. This can be mitigated by designing robot interactions to set common ground before the game begins. While participants looked at and listened to the robot, there was little space to speak with the robot. Interactions such as asking questions, or asking for feedback on the robot's ideas, such as, "What do you think of that idea", and utilizing participants' ideas to reform scaffolding could be more beneficial.

We also observed that, across all conditions, participants' unique object usage reduced, and so did their following of the robot's suggestions. This could be a result of the participants forming a game strategy that works for them and requiring the collaborative input less frequently. Future work could consider progressively reducing the scaffolding as participants gain expertise with the game.

7 CONCLUSION AND FUTURE WORK

As the use of robotic collaboration in workplaces grows, opportunities emerge for robots to support CPS - a crucial workplace skill for generating valuable solutions for novel problems. We proposed social robots, proven to be effective creativity aids, as a CST in problem solving. We designed robot interaction patterns geared towards enhancing children's creativity in a collaborative CPS game. The robot offered creativity support by demonstrating creative thinking, asking reflective questions, and providing positive encouragement. We observed mixed results, and the robot's social interactions did not have a significant influence on children's creativity overall, as we hypothesized prior to the study. We attribute our findings to the nature and complexity of the task and the design and timing of the robot's social interactions. Unlike previous work, that modelled the robot interactions on human instructors' interactions [2], we automated the timing of the robot's scaffolding to be triggered by game actions. The triggers for creative interactions were grounded in creativity theory, but not grounded in player preference or data from a human collaborator. Future work could utilize a reactive scaffolding model, instead of a proactive one, where the robot could offer help when the player asks for it. Another approach could utilize a Wizard of Oz scaffolding model, where the frequency of interactions depends on the human collaborator's interaction patterns. In this work, we also kept the virtual and physical character same, and they had the same social interactions, which could be confusing for the robot condition. In future work, we could use different physical and virtual characters and observe whether the results replicate. The current study was also conducted remotely due to the COVID-19 pandemic. Future user studies could be conducted in person, allowing for a more controlled environment and larger sample sizes. One limitation of this work is the broad age range, since it was more difficult to recruit for a remote study. Future studies with narrower age ranges could inform the effectiveness of the robot's creativity scaffolding for different age groups.

We contribute the system design of a game-based collaborative creative child-robot system, a user study demonstrating the combined effects of the robot's creativity scaffolding and embodiment on children's creativity, and the implications of our findings on designing child-robot interaction for creativity support.

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