Escape!Bot: Child-Robot Interaction to Promote Creative Expression During Gameplay

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ABSTRACT

Children's creativity plummets as they enter elementary school. Social interactions with peers and playful environments have been shown to foster creativity in children. Digital pedagogical tools often lack the creativity benefits of co-located social interaction with peers. In this work, we leverage a social embodied robot as a playful peer and designed Escape!Bot, a game involving child-robot co-play, where the robot is a social agent that scaffolds for creativity during gameplay. We aim to investigate the factorial extent to which the robot's embodiment (the co-presence of a peer-like social embodied agent), and scaffolding (the expression of creativity scaffolding behaviors by the social agent), influence children's creativity during gameplay. We contribute a novel social robotic interaction paradigm that aims to foster creative expression during gameplay.

CCS CONCEPTS

• **Human-centered computing** → HCI design and evaluation methods; • **Applied computing** → Psychology; • **Computer systems organization** → Robotics.

KEYWORDS

Embodiment, Creativity scaffolding, Child-robot interaction, Creativity

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1 INTRODUCTION

The importance of creativity cannot be understated. Generally referred to as the ability to produce novel yet appropriate solutions to a problem [22], creativity has been shown to improve children's problem solving and adaptability skills. Playful learning methodologies employed in early childhood education lay the foundation for creative thinking skills [25]. However, studies show that there

is a "discrepancy between teachers' claims of valuing creativity and the realities of their classrooms" [6]. The Torrance Test of Creative Thinking (TTCT) [28] showed a statistically significant slump in children's creative thinking abilities in fourth grade. [29]. Creativity has been recognized as an essential skill for children growing up in the 21st century [7] as the world evolves into a new technological age.

Researchers, educators, and game designers have utilized digital games and play-based learning techniques to foster creativity [27, 30]. Furthermore, children's social interactions with peers have been shown to influence their creativity [14]. While playing games can be beneficial to fostering creativity [9, 16, 23, 31], most games lack the element of co-present social interaction with a peer, preferring virtual agents. In this work, we explore whether social robots can promote higher creative expression than virtual agents, due to their unique ability to act as intelligent peers, as well as their capability for social emotional expression [5, 18]. To this end, we designed a game-based child-robot interaction aimed at fostering children's creativity. It employs a digital tablet-based game that affords creative problem solving, and is played alongside a co-present robotic peer that offers scaffolding for creative expression through verbal and non-verbal interactions. In designing this child-robot interaction to foster creativity in children, we utilize three key factors: an embodied agent, a play-based activity, and creativity scaffolding behaviors.

In order to evaluate the factorial efficacy of the robot's embodiment and social interactions in enhancing children's creativity, we designed a 2x2 study in which we will vary the modality of the social agent (a virtual agent vs. an embodied robot) as well as the behavior expressed (non-creative vs. creative scaffolding), and assess the differences in interaction and expressed creativity.

There are several frameworks for defining characteristics of creativity, such as generating novel ideas, divergent thinking, lateral thinking, and making unusual connections [4, 8, 12, 17]. For this work, we limit the definition of creativity to fluent generation of many novel ideas, flexibility in idea generation, expression of original ideas, and debugging problems with ambiguous solutions.

2 BACKGROUND

2.1 Agents and Creativity

While children have varying levels of intrinsic creativity, extrinsic factors, such as social interactions with teachers and peers, also influence a child's creativity [14]. In this work, we utilize Jibo, a social robot which has both embodied and virtual representations for the purpose of comparing modalities within our study, as a co-present peer equivalent. Social robots represent a scalable method

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of promoting positive cognitive behaviors within the classroom, especially in a virtual learning environment. In addition, the use of creativity scaffolding behaviors by social agents has been shown to enhance creativity [1, 15]. The creative behaviors expressed by the robot in this work are inspired by Kahn et. al's 10 human-robot interaction patterns aimed to foster human creativity, and consist of three categories: demonstration (*Pushing the Limits*), encouragement (*Validate Decision*), and inquiry (*Consider the Alternative*) [15].

Previous work has demonstrated how interaction with a social robot can lead to an increase in engagement with creativity tasks and help generate more creative ideas [15]. Social robots have also proven to be effective learning peers that lead to measurable learning gains [3, 21]. Research in human-robot interactions has demonstrated how interaction with social robots can promote positive learning behaviors in children through social emulation, such as curiosity, verbal creativity, and growth mindset [1, 10, 24].

While previous research exploring embodiment's effect on creativity has been inconclusive [2], we believe that the combination of embodiment with creativity scaffolding behaviors will lead to creativity gains. In our work, we compare an embodied version of a creatively scaffolding social robot to a virtual representation of the same robot, a juxtaposition which has not been made previously.

2.2 Play and Creativity

Activities presented in a game-like fashion, as well as play-based learning tools, have been shown to promote creativity [30]. Digital games, which incorporate many facets of play, provide players with a unique outlet to discover many creative solutions within a single play space [11]. Digital games are also effective vehicles for creative learning [20], and a long term study done on students playing digital games showed that it appreciably increased their creative skills and attitudes [23].

For this study, we designed Escape!Bot, a digital game in which the player must utilize a toolbox of objects to help Jibo find the escape door. We intend for players to utilize the freedom of the game mechanics to find a multitude of solutions. The game has three levels with increasing amounts of constraints, and we expect that the levels will require increasing amounts of divergent thinking, measured by the metrics described in section 4.3.

3 EXPERIMENTAL DESIGN

The child-robot interaction consists of three major agents: the child, the robot and the game on an Android tablet (Fig. 1).

3.1 Robotic Platform

The social robot used in this work was Jibo, a socially expressive companion robot that has a three-axis body and a screen based face[13]. Jibo uses text-to-speech for speech generation, a speaker to output sound, a microphone to identify speech, cameras to detect images, and tactile sensors to detect touch. Jibo responds to the player's actions during gameplay. The robot communicates with the tablet using Robot Operating System (ROS), where the tablet game and robot SDK are both connected to a ROS server through an IP address. Certain user actions in the game trigger messages that are sent to a local machine running ROS, and are then forwarded

to Jibo (Fig. 1). This communication involves no perceivable delay. Depending on the scaffolding condition (creative vs. non-creative), Jibo's dialogues differ, but are triggered by the same game logic.

Figure 1: System components. The child communicates with Jibo as they play the tablet game. The tablet sends messages to Jibo upon certain triggers in the game logic, which prompts Jibo speeches.

3.2 Escape!Bot Creativity Game

To understand how embodiment and creative scaffolding affect children's creativity, we designed Escape!Bot, a sandbox style tablet game for Android, where players must get the character to an end marker by placing combinations of tools that act as physical contraptions within the game space (Fig. 2). The game affords an unlimited amount of solutions to allow for creative problem solving.

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.

3.2.1 Game Mechanics. Players tilt the tablet to move the player character horizontally, and use a single finger drag to move the toolbox and objects. The objects used to traverse the level can be placed on the in-game platforms for the player character to interact with and use. Objects are limited in count and purposeful placement is encouraged, since they can be dropped or lost. They can be reused or placed back in the inventory, and be used in ways unique to their properties; for example, ladders can be climbed, and trampolines can be used to bounce vertically. Objects can also be combined in any logical manner - for example, players could put a ladder on top of a box. There are three levels that subsequently increase in difficulty by constraining the time limit and the number of available objects respectively. Each level also has a zoom-out feature to get a full view of the game scene.

3.2.2 Design. Escape!Bot was inspired by *The Incredible Machine* [26], a game in which players construct Rube Goldberg contraptions to get from one end of the level to the other. Escape!Bot was designed to constrain the types of objects a player can use, but to offer freedom in the routes and object combinations they can use to traverse the level. During gameplay, Jibo acts as a collaborative peer that offers creativity scaffolding by demonstrating different solutions, inquiring about alternate solutions, and encouraging use of varied objects.

3.2.3 Strategy. The most optimal strategy is to use the zoom-out feature to plan a route beforehand, and then zoom back in to place the objects for traversal. The less optimal strategy is to explore the level until seeing the end marker, which relies heavily on reusing objects. In later levels, where less objects are provided, players run the risk of dropping the objects and not having enough to complete the level with.

4 STUDY DESIGN

The study follows a 2x2 between-subjects design with the modality of the robot (embodied vs. virtual) and the scaffolding condition (creative vs. non-creative) as independent variables. We will independently test the effects of these variables on participants' expressed creativity. The four experimental conditions constitute participants playing the Escape!Bot game while interacting with one of the following:

- **E-C-:** Virtual Jibo that is not offering creative scaffolding
- **E-C+:** Virtual Jibo that is offering creative scaffolding
- **E+C-:** Embodied Jibo that is not offering creative scaffolding.
- **E+C+:** Embodied Jibo that is offering creative scaffolding.

80 participants (ages 6-10) will be split evenly across the four balanced experimental conditions.

4.1 Hypotheses

During gameplay, the Jibo robot (physical or virtual) serves as a peer, making suggestions on how the participant can progress through the level. The two independent variables in our experimental design are embodiment and creativity scaffolding behaviors exhibited by the robot. We hypothesize that the robot's embodiment alone will not influence children's creativity, whereas creativity scaffolding behaviors will influence children's creativity. Further, embodiment coupled with creativity scaffolding behaviors will have the highest

influence on children's creativity. Hence, we expect embodiment to be a significant catalyst of children's creativity, but only in the presence of creativity scaffolding behaviors. We hypothesize the effects of the two variables as follows:

H1: Embodiment

- (a) Participants interacting with the E+C- robot will express the same level of creativity as participants interacting with the E-C- robot.
- (b) Participants interacting with the E+C+ robot will express a higher level of creativity than participants interacting with the E+C- robot.

H2: Creative scaffolding

- (a) Participants interacting with the E-C+ robot will express a higher level of creativity than participants interacting with the E-C- robot.
- (b) Participants interacting with the E+C+ robot will express a higher level of creativity than participants interacting with the E-C+ robot.

H3: Combined factors

- Participants interacting with the E+C+ robot will express higher levels of creativity than all other study conditions.

4.2 Testing Procedures

4.2.1 Experimental set-up. Participants will be playing the game on an Android tablet, and with a Jibo robot (virtual or embodied). The experimental condition and participant ID are input by the researcher before starting the game.

4.2.2 During task. Participants will be briefed on the game controls. Then, Jibo gives a short introduction to the game by saying *Hey there! I'm Jibo. What's your name? Can you help me find the escape door?* Participants have twenty minutes to complete the first level, and the latter two levels have time limits of ten minutes each.

4.2.3 Robot Interaction. When certain conditions in the game are met, a Jibo dialogue is triggered. These conditions are classified into two categories: *Toolbox object usage* and *Proximity to in-game object*. An example of a *Toolbox object usage* condition would be if the player is using an abundance of one object and neglecting the others, and an example of a *Proximity to in-game object* condition would be if the player is close to an enemy or the end of the level. The creative dialogues are classified as *demonstration*, *encouragement*, or *inquiry*, and are described in section 2.1 (Fig. 3).

4.2.4 Post-test. After finishing all three levels, or exceeding the cumulative 40 minute time limit, the game task will end and participants will be asked a series of post-test questions on how they felt the robot companion affected their creativity. They will then be debriefed on the task, the system design, and the purpose of the study, at a level suitable for middle school understanding.

4.2.5 Data Collection. Audio and video data of the interaction will be collected using an overhead GoPro camera, and the video will be transcribed by personnel blind to the study. We collect timestamped gameplay data using tablet interaction logs, including all gestural interactions and manipulation of objects on the game screen.

Jibo Dialogues				
Category	Behavior	Condition	NC	C
Usage	Demonstrate	Half the ladders in the toolbox have been used	I see you've been using a lot of ladders to go upwards. I'm glad we're in space, because climbing ladders on Earth is hard!	I see you've been using a lot of ladders to go upwards. Why don't you try combining it with other objects? I bet you could put a ladder on top of a ramp! Or on top of a box!
Proximity	Scaffold	Escape door can be reached by a catapult	It looks like we're close to the escape door! Just a little farther until we escape this spaceship...	It looks like we're close to the escape door! What object do you think we could use to launch ourselves sideways?
Usage	Encourage	Player has used at least one of each object	Wow, we sure have used a lot of different objects.	Wow, we've used so many different objects. That's great, keep it up! Knowing how all the objects work is useful!

Figure 3: Three behaviors represented in Jibo's dialogues.

4.3 Methods of Evaluation

4.3.1 *Creativity Measures.* The following four components of participants' creativity would be measured:

- **Fluency:** The number of distinct object combinations that the participants attempted.
- **Flexibility:** The variance in the play styles that the participant demonstrated for each level. For this game, we have identified four distinct play styles: *Heavy usage of few key objects*, *Heavy reuse of few key objects*, *Broad usage of all objects*, and *Broad reuse of all objects*. For each play style that a participant is observed to demonstrate, a point will be added to their flexibility score for that level.
- **Originality:** The number of unique object combinations a participant generated, as compared to other participants in the study. If n total participants within the experimental condition used a particular object combination, a participant would receive an originality score of $\frac{1}{n}$ for their usage of this combination, and the summation over all their object combinations equals their total originality score.
- **Debugging:** The number of different solutions a participant tried when an initial solution failed.

For instance, below is an example gameplay scenario of a participant who played through the first level of the game:

1. Triggered introductory dialogue → 2. Used ladder to traverse medium vertical distance → 3. Used trampoline to traverse large vertical distance → 4. Attempt to use trampoline to traverse large vertical distance; fell to lower level → 5. Triggered "too many trampolines" dialogue → 6. Reused trampoline to traverse large vertical distance → 7. Attempted to use ladder to traverse medium vertical distance; fell to lower level → 8. Reused two trampolines and a ladder to traverse large vertical distance → 9. Reused ladder to traverse medium vertical distance → 10. Trigger "catapult to end" dialogue → 11. Used catapult to traverse large horizontal distance → 12. Finished level

From the game log data, we learn that the participant used four distinct object combinations (actions 2, 3, 8, and 11), so their *fluency* score for this level was 4. They demonstrated two distinct play styles (heavy usage of few key objects; heavy reuse of few key objects), so their *flexibility* score was 2. Assuming 20 total people in this participant's experimental condition: say that all 20 participants

demonstrated actions 2 and 3, 14 demonstrated action 11, and this participant was the only one to demonstrate action 8. This participant's *originality* score would calculate to: $\frac{1}{20} + \frac{1}{20} + \frac{1}{14} + \frac{1}{14} = 1.171$ (for distinct actions 2, 3, 8, and 11 respectively). Two of the participant's solutions failed on initial attempt (actions 4 and 7), and for these two attempts, they tried a different solution 1 time (for action 7), making their *debugging* score 1.

4.3.2 *Data Analysis.* For each level that a participant completes, they will be assigned individual *Fluency*, *Flexibility*, *Originality*, and *Debugging* values. These values will be averaged across all the levels that they complete, giving participants a single score for each of the creativity measures. These scores will then be summed to calculate the participant's final overall creativity score.

Using each participant's individual *Fluency*, *Flexibility*, *Originality*, and *Debugging* scores as well as the overall creativity score, we plan to perform statistical hypothesis tests between each pair of conditions to test our hypotheses. This will enable us to evaluate the influence of the robot's embodiment and scaffolding behaviors on children's creativity. We plan to analyze participants' video and audio data for utterances of creative expression (reflection, ideation and question-asking) and affect during gameplay.

5 DISCUSSION

In this work, we introduce a novel child-robot interaction aimed at fostering creativity in young children. Previous work in HRI has demonstrated how a robot's creativity scaffolding behaviors were beneficial to children's creativity as compared to a screen-based interaction. However, previous studies did not evaluate the factorial influence of the robot's embodied co-presence and the robot's creativity scaffolding behaviors on children's creativity. We expect to discover the individual influence of these factors by conducting a novel 2x2 study where we vary embodiment (comparing with a virtual agent) and creativity scaffolding offered by the robot (comparing with a non-creative scaffolding robot). We aim to show that embodied agents imbued with creativity scaffolding behaviors can be more effective than identical virtual agents in stimulating creativity in children.

We hope to form design recommendations for game designers, researchers, and educators designing for fostering creativity. We position social robots as a creativity support tool in a game-based environment. These implications are vital in the new age of digital remote learning. Social robots are rapidly becoming a highly scalable technology, have witnessed higher engagement than tablets and computers [19], and are promising embodied pedagogical tools for classroom learning [3]. Lastly, we also introduce a game-based child-robot interaction that can be used as a creativity assessment tool for children.

6 FUTURE WORK

After running the described study, we plan to use the results to form initial conclusions on the factorial extent to which embodiment and creative scaffolding influence children's creativity. We intend to use these conclusions to form design guidelines on creativity for game designers and researchers, and hope to demonstrate the pedagogical potential of embodied social robots, as well as inform the future of HRI and children's game research.

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