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Gameplay With a Socially Supportive Virtual Robot Enhances Children's Global Self-Esteem, Peer Relationships, Interest and Engagement

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***Abstract*—Self-esteem plays a crucial role in children's psychological well-being and social development. However, traditional interventions cannot provide consistent and engaging support. Recently, game-based learning has shown promise in fostering self-reliance and social confidence. Notably, socially supportive robots, offering consistent, adaptive, and peer-like reinforcement, have emerged as potential tools for enhancing children's self-esteem. Nevertheless, their effectiveness in improving self-esteem remains unexplored. In this study, we investigated the role of a socially supportive virtual robot in boosting children's self-esteem, social engagement, and motivation through game-based interactions. Specifically, we examined whether positive reinforcement from the robot influenced children's global and social self-esteem, the quality and quantity of their friendships, and sustained engagement with the game. Twenty-three children in India participated in a video game with and without the virtual robot across three 30-minute sessions over a month. Results indicated that children who interacted with the virtual robot showed significant improvement in global self-esteem, enhanced quantity and quality of friendships, and sustained interest and enjoyment in the task. However, no considerable change was observed in social self-esteem between the experimental and control conditions. These findings provide valuable insights into the potential of robot-mediated interventions for boosting children's self-esteem and social engagement.**

***Index Terms*—Human-robot collaboration, social HRI, robot companions, human-centered robotics.**

I. INTRODUCTION

SELF-ESTEEM is generally defined as the awareness of the absolute value of one's personality or dignity [1]. Its development begins at five years of age and continues to fluctuate until around age 12. After this period, it becomes more stable and less susceptible to change [2], [3]. Individuals with high self-esteem are often psychologically resilient, healthy, socially active, optimistic, and generally happier [1], [4]. In contrast, those with low self-esteem are more likely to experience loneliness, depression, social withdrawal, eating disorders, and a more pessimistic outlook on life [1], [4]. Self-esteem is commonly conceptualized as comprising two key constructs: global self-esteem, defined as an individual's overall evaluation of their worth or value as a person [5], and social self-esteem, a domain-specific form of self-esteem that reflects how individuals perceive their value and acceptance in social contexts, such as their relationships with peers or their sense of belonging in a group [6], [7]. Given the long-term impact of self-esteem on psychological well-being and social development, fostering healthy self-esteem during childhood—particularly between the ages of six and 12—is crucial for developing a well-adjusted personality [2], [8].

Notably, interactive and engaging experiences that provide consistent positive reinforcement effectively foster self-esteem in children. Games, when designed with supportive elements, have demonstrated potential in promoting self-efficacy, social interaction, and confidence-building in children [9], [10], [11], [12]. In recent years, physical and virtual social robots have emerged as promising tools for positively influencing children's behavior by acting as peers or companions [13], [14]. However, to our knowledge, no prior studies have specifically investigated the role of robots in improving children's self-esteem. Traditional self-esteem interventions typically rely on human facilitators, such as teachers and caregivers. Although these methods can be effective, they often face limitations, including inconsistent feedback, difficulties in sustaining children's engagement, and challenges in providing peer-like social interactions or nonverbal communication [10], [11], [15], [16]. In contrast, robots offer the potential for consistent, tireless, and adaptive support, making them a promising alternative for fostering self-esteem in children [17], [18].

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This study investigated the impact of a socially supportive virtual robot in a game-based setting on children's self-esteem, interest, and engagement. In this article, the term "Socially Supportive Virtual Robot" refers to an on-screen agent that engages in positive reinforcement behaviors. These include providing verbal and non-verbal praise, maintaining eye contact for joint attention, and offering assistance during gameplay. Based on this, we propose the following hypotheses:

Hypothesis 1: Gameplay with a socially supportive virtual robot boosts children's self-esteem.

- *Hypothesis 1a:* Positive reinforcement from a virtual robot boosts children's global self-esteem.
- *Hypothesis 1b:* Positive reinforcement from a virtual robot boosts children's social self-esteem.
- *Hypothesis 1c:* Positive reinforcement from a virtual robot improves the quantity and quality of children's friendships.

Hypothesis 2: Gameplay with a socially supportive virtual robot sustains children's interest and engagement over time.

II. RELATED WORK

A. Gaming Interventions to Boost Self-Esteem in Children

Various strategies have been explored to boost children's self-esteem, with gaming interventions emerging as a promising approach. Commercial off-the-shelf video games have garnered significant attention, particularly in educational settings. For example, Miller et al. [9] studied the effects of Dr. Kawashima's Brain Training on 71 children (ages 10–11 y) over 10 weeks. The video game group showed considerable improvements in math skills, test completion time, and global self-esteem, i.e., an individual's general perception of their own worth, whereas a decline was observed in the control group. No changes were observed in the physical activity group. Likewise, Man-Man, a mobile game incorporating interactive narratives and mini-games, substantially improved global self-esteem in 30 children (aged 8–10 y) [11]. These improvements were observed both post-intervention and at follow-up. Similarly, in a related study involving 59 children (aged 10–11 y), RAPUNSEL, an educational game that integrates coding lessons with avatar customization, boosted both self-esteem and programming self-efficacy, particularly among girls [19]. "Programming self-efficacy" is a concept introduced by the authors [19] as an extension of the general notion of self-efficacy, defined as an individual's belief in their ability to successfully perform specific tasks or handle particular situations, applied specifically to learning and performing programming tasks. Additionally, game-based therapeutic interventions, such as the Self-Esteem Games for Children by Dr. Deborah Plummer [12], also promote positive self-esteem through role-play and storytelling.

However, many of these interventions focus on global self-esteem while neglecting its social dimension, which is crucial to promoting a sense of self-worth among children. Moreover, they often lack peer-like social interactions, which are essential for emotional processing and fostering a sense of belonging. Furthermore, these games tend to overlook non-verbal cues, such as body language and empathetic responses, which are vital for emotional regulation and social connection. Like traditional methods that rely on human facilitators, these games struggle to sustain long-term engagement. Without adaptive mechanisms to maintain motivation, children's interest in these games tends to diminish over time [10], [11], [15], [16].

B. Social Robots as Behavioral Change Agents

Social robots can drive behavioral changes by meaningfully engaging users and influencing their actions. Research has demonstrated their effectiveness in educational and therapeutic contexts. For example, Robota, a simple imitation robot, promoted social skill development in autistic children through imitation and joint attention (the shared focus of two individuals on the same object or task) [20]. Similarly, KASPAR, a minimalist humanoid robot, facilitated greater social awareness and physical engagement among low-functioning autistic children [21]. Robots have been shown to improve learning outcomes in education. Kanda et al. found that children who interacted with tutoring robots for over nine days demonstrated considerable improvements in their English-speaking skills [22]. In the health domain, DragonBot promoted better nutrition choices among children, with effects lasting beyond the study period [23]. These studies demonstrate that social robots effectively drive behavioral changes across various tasks by providing motivation, fostering new behaviors, and encouraging lasting changes.

Although much research emphasizes physically embodied robots, the relative effectiveness of virtual versus physical robots depends on task context. Recent work shows that virtual agents can fulfill similar educational and behavioral roles in child–robot interaction specifically for screen-based interactions that do not require physical environmental manipulation, as in the current study. They also offer benefits like lower cost, remote access, and fewer logistical challenges [24]. Shahab et al. [25] reported the successful use of virtual robots in music education, whereas Abdelmohsen and Arafa [26] reported their successful application in social skills training for children with ASD. Dietz [27] points to their scalability in STEM education, while Calvo-Barajas and Castellano [28] found that repeated interaction fostered trust and emotional bonds with children, even in the absence of physical embodiment. These findings underscore the promise of virtual agents, especially when physical robots are impractical.

III. METHODOLOGY

A. Snowventure: Love 'n' Learn – the Game

To sustain engagement in gaming interventions, we incorporated principles from Computers as Social Actors (CASA) [29] and Media Equation Theory [30], which suggest that humans perceive digital interfaces as social entities. CASA, extensively applied in human-robot interactions (HRIs) [31], complements gamification principles—such as narrative, relatable themes, clear goals, rewards, and social interaction—to foster player–robot collaboration and sustained participation [31]. Building on this framework, we developed a gamified intervention to boost children's self-esteem.

1) Technology Used: The game was developed using the Godot 2D engine, integrating three adapted games from Dr. Deborah Plummer's framework into a cohesive narrative [12]. The visual assets were designed in 2D-pixel art, with narrative

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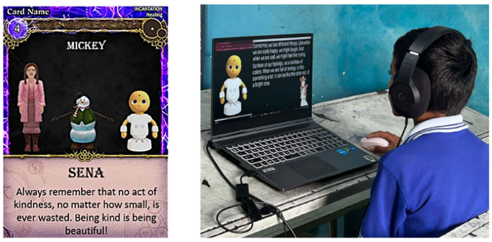
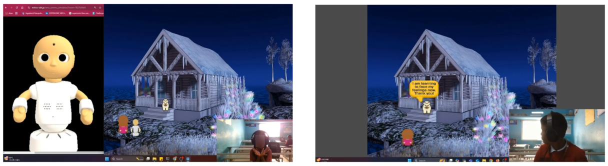


(a) (b)

Fig. 1. (a) A badge (game element) displaying the avatars of the player, character, and robot. (b) Experimental setup showing a child interacting with the system.



(a) (b)

Fig. 2. (a) Child interacting with the virtual robot and the game in the experimental condition, and (b) Child losing interest and looking away from the screen in the control condition.

sequences animated in Alice 3. The backgrounds were created using Adobe Photoshop and Inkarnate. To reduce cognitive load, the controls were simplified to arrow keys and mouse clicks.

2) Levels: Each level, based on Plummer's framework [12], fosters self-esteem and emotional awareness. In **Level 1**, players engage in a modified *Pass the Shell* game, searching for six hidden white roses within 90 s. The virtual robot provides positive reinforcement and fosters a sense of achievement. **Level 2**, is inspired by the *If Feelings Were Colors* game, wherein players navigate three mazes of three different colors; each color representing an emotion (e.g., red for love). After the completion of each maze, the virtual robot explains the emotion to the players. In the final maze, it models shared play, showcasing teamwork and mutual support. **Level 3**, which is the final level, adapts the *Emotions* game. Players act out both positive and negative emotions as directed by the virtual robot and then "release" these emotions by shaking their hands and legs. This level teaches emotional resilience by encouraging players to release negative emotions and focus on positive ones.

3) Game Elements: The game includes three core elements designed to enhance player experience and maintain motivation throughout gameplay. The **CommU Button (Help)** is available at all levels. This button allows the virtual robot to repeat instructions at any point in the game, ensuring that players do not feel overwhelmed. The **Treasure Chest** represents points. Upon completing each level, players earn "gems", which represent their progress and achievements, offering an intrinsic reward system. Finally, after successfully finishing a level, players are awarded digital **badges** featuring the virtual robot, the character associated with that level, and a personalized avatar. Each badge includes an encouraging quote related to the theme at that level (Fig. 1(a)).

B. The Virtual Robot

For this study, we used a computer graphics (CG) version of the *CommU* robot [32]. As discussed in Section II-B, prior research indicates that children perceive virtual robots as comparably socially engaging to their physical counterparts, in screen-based interactions, while offering advantages such as lower cost, easier deployment, and design flexibility [24], [25], [33]. The virtual robot's commands were written in Python, with real-time communication between the game (hosted on Game Jolt) and the robot managed by an external Python server. Displayed alongside the game, the virtual robot featured 13 degrees of freedom (DoF), tracked the user's cursor and adjusted its gaze accordingly. At certain levels, it followed the player's avatar, while during idle moments, it exhibited subtle behaviors such as blinking and hand movements. The virtual robot interacted with players in English using text-to-speech, providing randomized, pre-programmed feedback with slight delays for a natural response. Its dialogues and behaviors were designed on process-based praise and joint-attention principles from child psychology literature [34], [35], [36], and were carefully tailored to each level and player action. At the start of the game, players input their names, enabling personalized encouragement (e.g., "Excellent, [Player Name]! You are mastering this level!"). This robot provided process-based verbal praise (e.g., "I see you worked hard today, and I'm proud of that."), nonverbal rewards (such as high fives and clapping for correct answers), and patting gestures for incorrect answers. Additionally, the virtual robot maintained joint attention, periodically shifting its gaze between the player and the game to reinforce engagement and guidance. The supplementary video (S1) demonstrates excerpts of the robot's behaviors and dialogues across all three levels.

C. Procedure

To evaluate the impact of a socially supportive virtual robot on children's self-esteem, interest, and engagement, participants were divided into two groups: Experimental and Control. Under the Experimental condition, the virtual robot appeared on half of the screen alongside the game (Fig. 2(a)), providing continuous guidance, encouragement, and verbal praise. In the Control condition, the game occupied the full screen, maintaining the same size as in the Experimental 1 condition, but without the robot's visual presence (Fig. 2(b)). However, the robot's voice was still used for providing instructions and guidance. Each child played individually on a laptop with headphones in a classroom setting, and the researcher observed them from a distance to minimize interference (Fig. 1(b)). Each session lasted 30 minutes and was conducted once per week for three weeks, resulting in a total of three sessions per participant. To assess changes over time, the children completed the questionnaires (refer to Section III-E) at two time points: prior to the first session (pre-test) and following the final session after the three-week intervention period (post-test), in both conditions.

D. Participants

A total of 23 children (13 girls, 10 boys) aged 10–11 years (mean (M) = 10.69, standard deviation (SD) = 0.47) were recruited from a school in Bangalore, India. Children from Grades

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4 and 5 were randomly selected from different classrooms of the same school by the school principal based on their willingness to participate. The only exclusion criterion was the absence of parental or participant consent. Participants were randomly assigned to either the "experimental" ($n = 12$) or "control" ($n = 11$) group. To minimize bias, children were not told about the robot's presence or absence and were simply informed that different versions of the same game would be played. They were also asked not to discuss the study with classmates. However, since the study spanned three weeks, cross-condition communication could not be fully controlled and is acknowledged as a limitation. The study was approved by the ethics committee for research involving human subjects at the Graduate School of Engineering Science, Osaka University (31-5-3), and conducted in accordance with the Declaration of Helsinki (DOH). Verbal and written informed consents were obtained from both the participants and their parents, ensuring the confidentiality and anonymity of all data.

E. Measures

Children's self-esteem was assessed using the Piers-Harris Children's Self-Concept Scale 2, a standardized 60-item questionnaire with binary (yes/no) responses that measures how children perceive themselves across several domains [37]. Global self-esteem was evaluated using the Total (TOT) score (range: 0-60), which reflects an individual's overall self-worth and general self-concept. Social self-esteem was assessed using the Popularity (POP) subscale (range: 0-12), a 12-item component focusing on a child's perceived popularity, peer acceptance, and quality of interpersonal relationships. This scale was selected for its strong psychometric properties and widespread use in developmental research, offering a reliable assessment of self-esteem across social, academic, and behavioral domains [38].

Children's friendship quality and social connectedness (quantity) were explored through a short set of open-ended and categorical questions: How many friends do you have? (observed range: 1-25) What do you like to do with them?; How easy is it for you to talk to your friends? (Easy/Difficult); How easy is it for you to share things with your friends? (Easy/Difficult). These questions provided both quantitative and qualitative insights into how children's peer relationships transformed through the intervention.

Sustained interest and engagement during gameplay were analyzed using two behavioral indicators, coded from video recordings covering the entire experiment duration, for all participants in both conditions, across three gameplay sessions (Sessions 1, 2, and 3). The ELAN software [39] facilitated transcription and annotation. The two indicators were "Look-away frequency (interest)" and "Valence expressions (engagement)". Look-away frequency (observed range: 0-30) was defined as the number of times children averted their gaze from the screen, with fewer look-aways indicating greater engagement [40]. Valence expressions (observed range: -3 to 44) were analyzed to assess emotional responses [41], where positive expressions (e.g., smiling, laughter) indicated engagement, and negative expressions (e.g., frowning, frustration) indicated disengagement. Valence was quantified using a weighted formula [41] (refer to Equation (1)). Two researchers independently coded the videos, and after initial coding, they compared the results and resolved discrepancies to reach a final agreement. Inter-rater reliability was assessed using an intraclass correlation coefficient (ICC) with a two-way mixed effects model and absolute agreement. Reliability was strong for both indicators: Look-away frequency (ICC = 0.690, 95% CI [0.535, 0.829]) and valence expressions (ICC = 0.867, 95% CI [0.780, 0.932]). The average measures ICC was 0.930 (95% CI [0.874, 0.967]) for look-away frequency and 0.975 (95% CI [0.955, 0.988]) for valence expressions, indicating excellent agreement between the raters.

$$\begin{aligned}\text{Valence} &= \text{Smile} + 2(\text{Laughter} + \text{Excitement} + \text{PosVerb})\\ &\quad - (\text{Startle} + \text{Frown}) - 2(\text{Shrugging} + \text{NegVerb})\end{aligned} \tag{1}$$

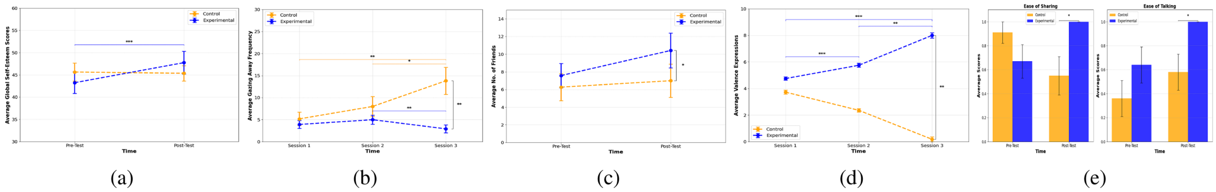
IV. RESULTS

This study aimed to examine the impact of a socially supportive virtual robot on children's self-esteem, interest, and engagement in gameplay. All statistical analyses were conducted at a significance level of $\alpha = 0.05$. For clarity, statistically significant results are illustrated using graphs (refer to Fig. 3(a)–(e)), whereas non-significant findings and descriptive statistics are detailed in the text. Data normality was assessed via the Shapiro–Wilk test, visual inspection of the Q–Q plots, and skewness and kurtosis values. The homogeneity of variance was examined through Levene's test. Parametric tests were conducted for normally distributed data with equal variances, and non-parametric tests were applied for the other cases. Type I errors were controlled by applying the Bonferroni correction to account for multiple pairwise comparisons.

A. Global Self-Esteem

To assess the effects of socially supportive virtual robots on children's global self-esteem, as measured by the Total Self-Esteem Score (TOT), we tested Hypothesis **H1a**. A two-way mixed analysis of variance (ANOVA) was conducted to examine the effects of time (pre-test vs. post-test) and condition (control vs. experimental) on the TOT scores. The results revealed the following: There was a significant main effect of time - $F(1, 21) = 9.74, p = .005, \eta_p^2 = 0.32$ (large effect), with the mean global self-esteem scores being higher post-test ($M = 46.61$, $SD = 7.49$) compared to pre-test ($M = 44.39$, $SD = 7.55$). A significant interaction effect was observed between time and condition - $F(1, 21) = 12.41, p = .002, \eta_p^2 = 0.37$ (large effect). There was no significant main effect of condition - $F(1, 21) = 0.00, p = 1.000, \eta_p^2 = 0.00$.

Simple main effects analyses further revealed that there were no considerable differences in TOT scores between the groups both for the pre-test ($p = .462$) and post-test ($p = .458$). No notable changes were observed in the control group ($p = .818$) with scores remaining relatively stable from pre-test ($M = 45.64$, $SD = 6.70$) to post-test ($M = 45.36, SD = 5.68$). However, in



(a) (b) (c) (d) (e)

Fig. 3. (a) Increase in self-esteem post-test in the experimental group. (b) Interest increased in the experimental group and decreased in the control group over time. (c) Experimental group reported more friends post-test. (d) Engagement increased over time in the experimental group. (e) Experimental group found it easier to talk and share with friends post-test.

the experimental group, TOT scores substantially increased from pre-test to post-test ($F(1,11) = 35.64, p < .001, \eta_p^2 = 0.76$), with descriptive statistics showing an increase from $M = 43.25$, $SD = 8.38$ (pre-test) to $M = 47.75$, $SD = 8.95$ (post-test), with a Cohen's $d = 0.52$ (medium effect). These results support **H1a**, as evident from the significant increase in global self-esteem of the experimental group (Fig. 3(a)).

B. Social Self-Esteem

To assess the effects of a socially supportive virtual robot on children's social self-esteem, as measured by the Popularity Score (POP), we tested Hypothesis **H1b** by again conducting a two-way mixed ANOVA. The results revealed the following: There was a significant main effect of time: $F(1,21) = 27.24, p < .001, \eta_p^2 = 0.57$ (large effect) with the mean social self-esteem scores being higher post-test ($M = 9.00$, $SD = 2.04$) compared to pre-test ($M = 7.48$, $SD = 1.75$). There was no significant interaction effect between time and condition: $F(1,21) = 0.68, p = .419, \eta_p^2 = 0.03$. There was no significant main effect of condition: $F(1,21) = 0.37, p = .549, \eta_p^2 = 0.02$.

Regardless of the condition, the children's social self-esteem increased substantially, as evident from the increase in M from 7.48 (pre-test) to 9.00 (post-test), with a large effect ($d = 0.80$). These findings led us to reject **H1b**, as the improvement in social self-esteem occurred independent of the condition.

C. Quantity and Quality of Friendships

To assess the effects of a socially supportive virtual robot on children's quantity and quality of friendships, we tested hypothesis **H1c**.

1) Change in Number of Friends (Quantity): We analyzed responses to the open-ended question, "How many friends do you have?", and a Mann–Whitney U Test showed a significant difference between the groups in the change in the number of friends from pre to post-test: $U = 36.00, Z = -2.05, p = .041$. Compared to the control group ($M = 0.73$, $SD = 1.62$), the experimental group exhibited a significant increase ($M = 2.83$, $SD = 3.86$), with a medium effect size ($d = 0.71$).

2) Ease of Talking With Friends (Quality): Children's perceived ease of communication with peers was assessed using a binary scale (1 = Easy, 0 = Difficult) and analyzed using chi-square tests. There were no notable differences in the proportion of "Easy" and "Difficult" responses between the groups pre-test: $\chi^2(1) = 1.11$, $p = .292$. However, there was a notable difference between the groups post-test, with the experimental group showing a significantly higher proportion of "Easy" responses, as confirmed by Fisher's Exact Test ($p = .037$).

3) Ease of Sharing Things With Friends (Quality): Similarly, the ease of sharing things with peers was analyzed using Fisher's Exact Test of binary responses. There were no considerable differences in the proportion of easy and difficult responses between the pre-test groups ($p = .317$). However, there was a significant difference between the post-test groups, with the experimental group showing a markedly higher proportion of easy responses, as confirmed by Fisher's Exact Test ($p = .014$).

These findings support **H1c**, with the experimental group demonstrating a greater increase in the number of friends and more positive perceptions of communication and sharing (refer to Figs. 3(c) and (e)).

D. Interest and Engagement With the Intervention

To assess the impact of the virtual robot on children's interest and engagement, we tested Hypothesis **H2**.

1) Interest in the Intervention: A two-way mixed ANOVA analysis was conducted, which revealed the following: Mauchly's Test of Sphericity was significant ($\chi^2(2) = 6.38, p = .041$). Therefore, the Huynh-Feldt correction ($\epsilon = 0.88$) was applied to correct the DoF. There was a significant main effect of time - $F(1.76, 36.89) = 11.09, p < .001, \eta_p^2 = 0.35$ (large effect). A significant interaction effect was observed between time and condition - $F(1.76, 36.89) = 19.91, p < .001, \eta_p^2 = 0.49$ (large effect). There was a significant main effect of condition - $F(1,21) = 4.98, p = .037, \eta_p^2 = 0.19$ (large effect).

Simple main effects analyses further revealed the following: At sessions 1 and 2, no considerable differences were found between the groups ($p = .482$ and $p = .234$, respectively). However, in session 3, the experimental group exhibited considerably fewer look-aways than the control group ($p = .005$), with a large effect size ($\eta_p^2 = 0.50$). In the control group, look-away frequency significantly increased over time, $F(2,20) = 15.66, p < .001, \eta_p^2 = 0.61$, with notable increases between all the time points. In contrast, in the experimental group, look-away frequency substantially decreased over time, $F(2,22) = 6.24, p = .007, \eta_p^2 = 0.36$, with a substantial decrease observed between sessions 2 and 3 ($p = .006$).

Follow-up analyses further revealed the following: In the control group, the look-away frequency increased from Session 1 ($M = 5.18$, $SD = 5.00$) to Session 3 ($M = 13.82$, $SD = 10.16$), with substantial increases between sessions 1 and 3 ($p = .003$, Cohen's $d = 1.08$) and between Sessions 2 and 3

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($p = .015$, Cohen's $d = 0.64$). In the experimental group, the look-away frequency decreased from Session 1 ($M = 3.92$, $SD = 3.15$) to Session 3 ($M = 2.92$, $SD = 3.09$), with a significant decrease from Session 2 to Session 3 ($p = .006$, Cohen's $d = 0.63$) (Fig. 3(b)).

2) Engagement With the Intervention: The two-way mixed ANOVA revealed the following: Mauchly's Test of Sphericity was significant ($\chi^2(2) = 28.91, p < .001$). Therefore, the Greenhouse-Geisser correction ($\epsilon = 0.57$) was applied to correct the DoF. There was a significant main effect of time - $F(1.13, 23.81) = 15.62, p < .001, \eta_p^2 = 0.43$ (large effect). A notable interaction effect was observed between time and condition - $F(1.13, 23.81) = 8.51, p = .006, \eta_p^2 = 0.29$ (large effect). There was a significant main effect of condition - $F(1, 21) = 6.62, p = .018, \eta_p^2 = 0.24$ (large effect).

Simple main effects analyses further revealed that in sessions 1 and 2, no considerable differences were found in valence expression between the groups ($p = .252$ and $p = .138$, respectively). However, in session 3, the experimental group exhibited a markedly higher valence expression than the control group ($p = .009$), with a large effect size ($\eta_p^2 = 0.28$). In the control group, the valence expression did not change significantly over time: $F(2, 20) = 0.64, p = .536, \eta_p^2 = 0.06$. In contrast, in the experimental group, valence expressions considerably increased over time: $F(2, 22) = 32.92, p < .001, \eta_p^2 = 0.75$ (large effect), with substantial increases observed between all the time points.

Follow-up analyses further revealed the following: Control group's valence expressions decreased from Session 1 ($M = 3.73, SD = 6.45$) to Session 3 ($M = 0.18, SD = 3.12$), though not significantly. Experimental group's valence expressions increased from Session 1 ($M = 4.75$, $SD = 8.84$) to Session 3 ($M = 8.00$, $SD = 13.27$), with notable increases between sessions 1 and 2 ($p < .001$, Cohen's $d = 4.85$), Session 2 and Session 3 ($p = .001$, Cohen's $d = 4.79$), and Session 1 and Session 3 ($p < .001$, Cohen's $d = 6.88$) (Fig. 3(d)).

These findings support **H2**: the socially supportive virtual robot successfully maintained the children's interest and engagement with the intervention over time.

V. DISCUSSION

While previous research has demonstrated the role of positive reinforcement from human-human interactions in enhancing self-esteem in children, little is known about the effects of robotic interactions. This study investigated whether positive reinforcement from a virtual robot can induce similar effects. Below, we summarize the key findings from the tested hypotheses.

A. H1a: Positive Reinforcement From a Virtual Robot Boosts Children's Global Self-Esteem

Previous research identified three key behaviors that promote self-esteem in children: verbal and nonverbal praise with encouragement, consistent attention, eye contact, and guided assistance. Process-based verbal praise, such as acknowledging efforts (e.g., "I can see you worked hard, and that makes me proud of you"), has been shown to boost self-esteem when provided periodically [34], [35], [36]. Similarly, appreciation and encouragement enhance motivation and self-esteem [36]. Nonverbal reinforcement, such as clapping and high fives, also significantly supports self-esteem development [34], [35]. Consistent attention and the Hawthorne effect, where children feel seen and accepted, have been linked to increased self-esteem [42], [43]. Guided assistance in completing tasks also boosts confidence, intrinsic motivation, and self-esteem [44], [45], [46].

A virtual robot was designed to incorporate these behaviors. The observed increase in global self-esteem is consistent with findings from human-human interaction studies, suggesting that verbal and non-verbal reinforcement contributed positively. The consistent eye contact from the virtual robot mimicked an observing presence, reinforcing self-esteem, and its guided assistance in solving a maze likely further supported this effect.

B. H1b: Positive Reinforcement From a Virtual Robot Boosts Children's Social Self-Esteem

Positive reinforcement strategies, including praise, encouragement, and consistent attention, have been previously associated with increases in both global and social self-esteem [34], [35], [36]. However, in this study, an increase in social self-esteem was observed under both conditions, suggesting that factors beyond the intervention may have contributed to this increase. A key difference from previous studies was the measurement tool used. While earlier research typically employed the Coppersmith Self-Esteem Inventory, Self-Perception Profile for Children, and Rosenberg Self-Esteem Scale, this study used the POP sub-scale from the Piers-Harris Self-Concept Scale for Children 2, which focuses on social challenges, such as peer exclusion, bullying, and sports performance [2], [47], [48]. It is possible that a reduction in perceived social challenges influenced an increase in POP scores. Additionally, some items in the POP scale may introduce gender biases, as boys tend to rate sports-related items more positively, while girls typically assign higher ratings to popularity-related items [47], [48]. These biases could inflate POP scores without reflecting genuine improvements in self-esteem. Therefore, children with co-morbidities in peer interactions may still show high POP scores, indicating that the measure has limited sensitivity in detecting true changes in self-esteem. Future research should explore alternative assessment tools to better understand the development of self-esteem.

C. H1c: Positive Reinforcement From a Virtual Robot Improves the Quantity and Quality of Children's Friendships

Having more friends, sharing personal experiences, and feeling comfortable in conversations are key to social self-esteem [2], [47], [48]. The number of friends reflects friendship quantity, with more friends typically linked to higher self-esteem [2], [48]. Friendship quality, assessed using scales such as the University of Michigan Youth in Transition Study and the Barrera scale, measures the comfort in confiding and conversing with friends [2], [47], [48]. By including variables

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like "number of friends", "ease of talking to friends", and "ease of sharing with friends", alongside the POP scale, we gained a more comprehensive understanding of how interventions, such as that proposed in this study, affect social self-esteem.

Previous studies on self-esteem interventions with positive reinforcement, such as verbal praise and encouragement, have been shown to enhance both global self-esteem and friendships [2]. Our study observed an increase in the number of friends in the experimental group which was consistent with previous results. Shared activities such as reciprocal communication and feedback foster trust and intimacy and improve friendship quality [49], [50]. In our study, the virtual robot's involvement in shared play and feedback was associated with children in the experimental group engaging in activities such as playing and watching movies with friends post-intervention—activities that had not been reported before participation, as indicated by qualitative responses to open-ended questions. No such changes were observed in the control group. As the number of friends in the experimental group increased, the frequency of these activities likely fostered greater communication and trust.

D. H2: Gameplay With a Socially-Supportive Virtual Robot Sustains Children's Interest and Engagement Over Time

Human–human self-esteem interventions often face engagement challenges, with children losing interest over time due to the repetitive and predictable nature of these interactions, leading to minimal long-term impact [10], [11], [15], [16]. In this study, a similar decline in interest was observed in the control group. While embodied agents can engage children and assist in task completion [51], engagement tends to fade as the novelty diminishes [52], [53]. To maintain long-term interests, robots should include strategies such as one-on-one engagement, prosocial behaviors (e.g., eye contact, joint attention, and empathy), and personalized interactions [51], [52], [53].

In this study, the children interacted individually with the virtual robot to minimize group distractions and ensure focused engagement. The robot addressed the children by name and used pre-programmed dialogues dynamically selected from a wide range of responses, adding variation and personalization. Joint attention further supported engagement, with the virtual robot shifting its gaze between the child and the game while tracking the cursor movement, simulating consistent attention. These design elements contributed to sustained and increased interest in and engagement with the experimental group, demonstrating the effectiveness of a socially supportive agent in maintaining motivation and involvement throughout the study.

VI. CONCLUSION AND FUTURE WORK

This study investigated the potential of a socially supportive virtual robot in enhancing children's self-esteem, social engagement, and motivation through shared gameplay. Conducted with 23 children in India, who were assigned to either the experimental (virtual robot present during gameplay) or control (no virtual robot) groups, our study suggests that the presence of the robot positively impacted global self-esteem, the quantity and quality of friendships, and sustained engagement with the task. However, no substantial differences were observed in social self-esteem between the conditions, which may be attributed to limitations in the assessment tools used. The results indicated that verbal and nonverbal reinforcement, coupled with the consistent attention-giving and adaptive behaviors of the virtual robot, considerably influenced the children's self-esteem and social connections. While the positive effects on global self-esteem were evident, the impact on social self-esteem was less pronounced, highlighting the need for refined measurement approaches in future studies. Previous research has focused on the role of robots in education, physics, and social interaction. However, none has directly targeted the enhancement of self-esteem. Our findings indicate that robots can play a significant role in supporting children's self-esteem and social development, highlighting their potential for educational and therapeutic use. This study opens new avenues for interdisciplinary research in psychology, education, and robotics.

Although this study provides valuable insights, certain limitations should be considered. This study was conducted in a single school, focusing on a specific age group and cultural context, which may limit the generalizability of the findings. Future studies should explore whether similar effects are observed across different educational settings, age ranges, and cultural backgrounds. Another limitation is that, the pre-programmed nature of the virtual robot's interactions may have influenced engagement dynamics, and the short study duration restricted conclusive evidence about the long-term effects. Additionally, several social and contextual factors were not systematically controlled between conditions, which may have influenced the results. For example, peer bonding across groups, prior familiarity with robots, and varying levels of family support. To build on these findings, future studies should expand the sample size and incorporate real-time adaptive responses and diverse reinforcement strategies to enhance the interaction capabilities of the virtual robot. Moreover, integrating objective measures such as parental or teacher observation, will provide a more comprehensive understanding of behavioral changes linked to self-esteem and social development. Furthermore, future work should examine how social and contextual factors beyond the direct child–robot interaction affect children's engagement and learning outcomes and future studies could benefit from validating the robot's dialogues with clinical experts to optimize the effectiveness of the intervention. Finally, a longitudinal study is planned to investigate the sustained impact of robot-mediated interventions on children's emotional and social well-being.

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