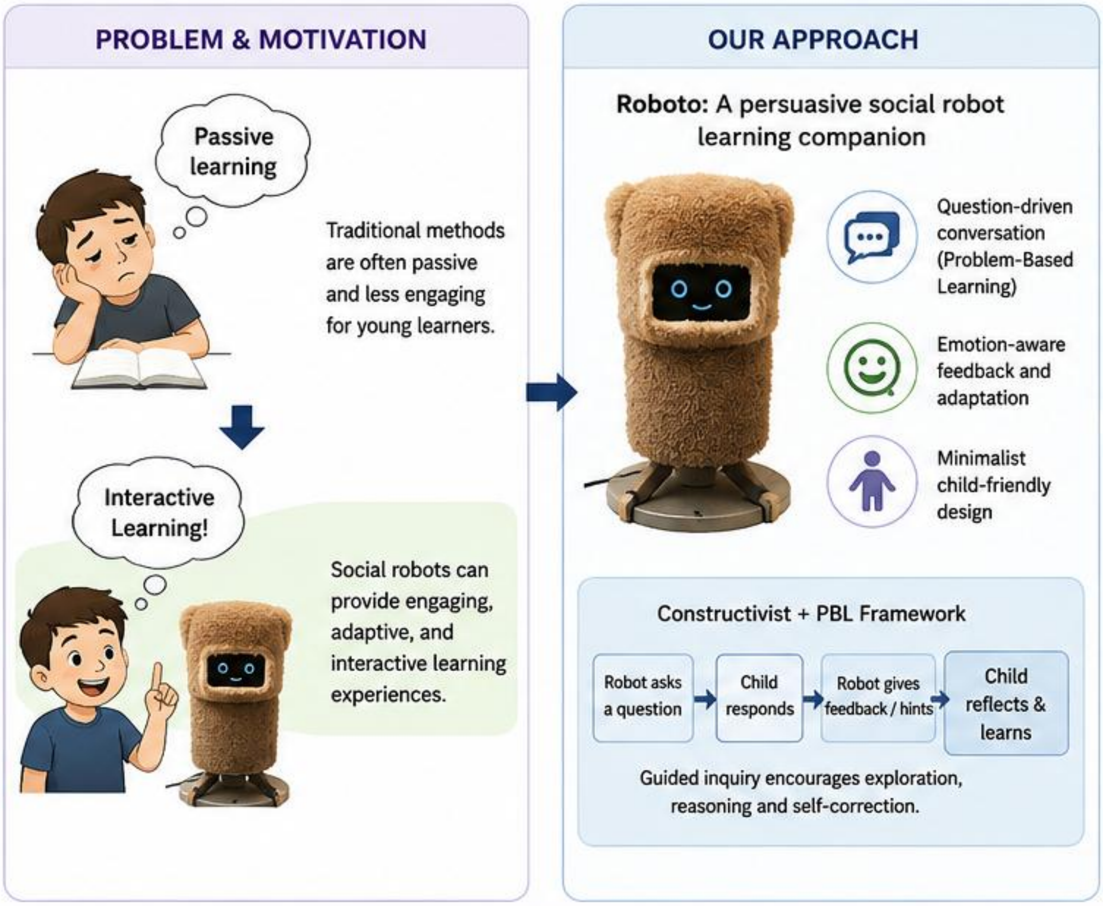
Developing a Persuasive Social Robot as a Learning Companion

D. A. A. Deepal[1], Y. Samarakoon[2] and P. R. S. De Silva[3]

[1]Department of Scientific Computing, Faculty of Computing, University of Sri Jayewardenepura, Gangodawila, Sri Lanka
[2]Centre of Robotics and Intelligent Systems, Faculty of Applied Sciences, University of Sri Jayewardenepura, Gangodawila, Sri Lanka
[3]Department of Computer Science, Faculty of Applied Sciences, University of Sri Jayewardenepura, Gangodawila, Sri Lanka

Date Received: 26-03-2026 Date Accepted: 25-06-2026



Abstract

This study presents the design and evaluation of a persuasive social robot, *Roboto*, developed as a learning companion to support early second language (L2) acquisition in children aged 4–8. While prior research in robot-assisted learning has largely emphasized interaction design and short-term engagement, limited attention has been given to integrating pedagogically grounded frameworks such as constructivist learning and Problem-Based Learning (PBL) within child–robot interaction.

To address this gap, Roboto employs a question-driven conversational model that facilitates active learning through guided inquiry and incremental feedback. The system incorporates multimodal interaction, including speech, visual cues, and emotion-aware responses, to enhance engagement and adaptability. An experimental study was conducted with 18 participants across three interaction scenarios: conversational learning, storytelling, and repeated longitudinal sessions. Data were

*Correspondence: deepal@sjp.ac.lk

collected using questionnaire-based evaluations and observational measures, and analyzed using non-parametric statistical methods, including Chi-square and Wilcoxon signed-rank tests.

The results indicate high levels of user engagement and acceptance, with all participants expressing willingness to interact with the system. Statistical findings show that the PBL-driven questioning model significantly enhances perceived learning support. Furthermore, longitudinal analysis reveals a significant increase in positive emotional engagement and improved task efficiency over repeated sessions, suggesting the development of interaction familiarity. Despite these promising findings, the study is limited by a small sample size and the absence of a control group. Overall, this work demonstrates that integrating constructivist pedagogy with persuasive and emotionally adaptive interaction design can effectively support learner engagement and perceived learning support, providing a foundation for future research in educational social robotics.

Keywords: *Constructivist learning, Conversation model, Learning companion, Minimalistic design, Persuasive social robot*

**Correspondence:* deepal@sjp.ac.lk

1. Introduction

Learning a second language (L2) at an early age plays a significant role in enhancing children's cognitive and academic development, including improvements in memory, problem-solving abilities, and critical thinking skills (Hosseini et al., 2012). Early exposure to language is particularly effective due to the high neural plasticity during childhood, enabling faster and more natural acquisition compared to adulthood (Kuhl, 2004; Jacqueline et al.,1989), (Johnson & Newport, 1989). In addition, early language competence is strongly associated with improved literacy, communication skills, and long-term academic performance (Hulme et al., 2020).

Despite these benefits, traditional language learning approaches for young children often rely on passive instructional methods, which may limit engagement and reduce opportunities for active participation. Studies suggest that children learn more effectively in interactive environments where communication, feedback, and social engagement are central to the learning process (Kuhl, 2004; Chandra et al., 2016). In particular, the presence of an interactive partner plays a crucial role in language acquisition by encouraging active dialogue and reinforcing understanding (Li & Jeong, 2020).

In this context, social robots have emerged as a promising tool for education due to their ability to provide interactive, adaptive, and engaging learning experiences (Belpaeme et al., 2018; Mubin et al., 2013; Toh et al., 2016). Unlike conventional digital systems, social robots offer physical embodiment, enabling multimodal interaction through speech, gestures, and visual cues. This embodiment enhances attention, motivation, and user engagement, making robots particularly suitable for child-centered learning environments (Neumann, 2020). Social robots can function as tutors, peers, or companions, supporting both cognitive and social development (Chen et al., 2020).

A key concept in this domain is **persuasiveness**, which refers to the ability to influence user behavior through interaction and reasoning rather than coercion (Siegel et al., 2009; Dillard & Pfau, 2002). Persuasive social robots can motivate children to participate in learning activities, sustain attention, and improve task engagement. In child-robot interaction (CRI), this effect is amplified as children often perceive robots as social entities, enabling more natural and meaningful interaction (Belpaeme et al., 2013).

However, existing research has largely focused on interaction design and engagement strategies, with limited attention to integrating structured pedagogical approaches such as **Problem-Based Learning (PBL)** within a **constructivist framework**. Constructivist theory emphasizes that learners actively construct knowledge through experience, exploration, and interaction (Bada & Olusegun, 2015). PBL aligns with this perspective by encouraging learners to solve problems independently, promoting deeper understanding and critical thinking.

To address this gap, this study proposes **Roboto**, a persuasive social robot designed as a learning companion for children aged 4–8. The system integrates constructivist learning principles with PBL-driven interaction, enabling children to engage in language learning through guided conversations and storytelling. Roboto incorporates a minimalist physical design, a conversational model, and emotion-aware feedback to enhance engagement and perceived learning support.

The primary objective of this research is to design and evaluate a persuasive social robot that facilitates early language learning through interactive and emotionally responsive experiences. The study also investigates how children adapt to repeated interactions with the robot and how such interactions influence emotional engagement and learning behavior.

The main contributions of this work are as follows:

- A **minimalist social robot design** optimized for child interaction
- A **PBL-driven conversational model** grounded in constructivist learning theory
- Integration of **emotion recognition and adaptive feedback**
- An **empirical evaluation** of child-robot interaction across multiple scenarios

*Correspondence: deepal@sjp.ac.lk

Despite the growing interest in robot-assisted learning, existing studies predominantly emphasize interaction design and short-term engagement, with limited focus on integrating pedagogically grounded learning frameworks and evaluating their longitudinal impact. In particular, the application of constructivist and Problem-Based Learning (PBL) principles within persuasive social robots for early language acquisition remains underexplored. This study addresses this gap by proposing and empirically evaluating a learning companion robot that combines structured pedagogical design with socially interactive and emotionally adaptive behavior.

2. Related Work

2.1. Social robots as learning companions

Socially assistive robots serve as a means of providing support and assistance through non-contact, social interactions, with the primary aim of promoting and enhancing social interactions among users (Langer et al., 2019). These robots have shown potential in various applications, including education and rehabilitation for children on the autism spectrum, as well as children with social and cognitive disorders or speaking disabilities (Langer et al., 2019). Social robots can come in different forms, such as humanoid, semi-humanoid, or even pet-like, with fur and skin coverings. Many social robots function as personal assistants or helpers, engaging with humans in unique ways. A fundamental requirement for social robots is their ability to engage in natural communication during interactions with users. Within the Human-Robot Interaction (HRI) community, there is a distinction between the external and internal aspects of interaction (Beer et al., 2014). The external aspect focuses on the user's response when the robot interacts with a human, another system, or another robot. The internal aspect pertains to the sensory behavior, decision-making, and control mechanisms of the robot during interpersonal interactions. While various aspects of HRI receive attention, significant emphasis is placed on the design of robots in the field of Social Robotics. Social Robotics combines a more human-centered approach, drawing from the social sciences and humanities. The development of social robots often involves testing in realistic environments, not only to refine algorithms but also to understand the impact of human-robot interaction on society and the behavior of children (Salter et al., 2008).

When considering the role of robots in education, Chaidi et al. conducted a pilot educational research study to assess the impact of educational robotics in primary education, specifically emphasizing its potential to foster inclusion for students with special educational needs (Chaidi et al., 2021). The study gave positive results, underscoring the advantages of educational robotics in enhancing inclusion for students with special educational needs. The authors highlighted the significance of employing a blended teaching approach, incorporating both in-person and remote learning, to implement a robotics curriculum in a school that facilitates integration. According to Drigas et al., robots can contribute to the enhancement of empathy through the establishment of natural cooperation and communication between robots and humans (Drigas & Papoutsi, 2023). In their theoretical examination of empathy and its connection to technology, they also address the influence of technology on empathy and explore its potential to bolster empathy in diverse settings. Moraiti et al. authored an article that centers on the role of educational robotics and programming in nurturing students' computational thinking, a vital aspect of critical thinking (Moraiti et al., 2022). The article underscores the potential of educational robotics and programming tools in enabling educators to prioritize the development of essential 21st-century skills, such as teamwork, problem-solving, innovation, project management, planning, and communication. Nevertheless, it emphasizes the significance of teachers possessing the requisite knowledge to effectively impart this information, considering the ubiquitous presence of technology in our daily lives. Most of these studies suggest that encouraging children to use social robots as learning companions is effective when supported by professionals such as human teachers or tutors.

*Correspondence: deepal@sjp.ac.lk

2.2. Persuasive robots and the ability to persuade children

Only a limited number of studies have explored people's responses to persuasive attempts made by social robots. For instance, Ghazali et al. investigated the social responses evoked by persuasive social robots and the social cues they exhibited (Ghazali et al., 2018a). Their findings indicated that a robot displaying minimal social cues, such as a neutral face and blinking eyes, as well as a robot with enhanced social cues, such as facial expressions, head movement, and emotional intonation in the voice, elicited lower levels of psychological reactance compared to when the same persuasive messages were presented as text-only without a robot present (Ghazali et al., 2018a). Another study from Ghazali et al. reported that a persuasive robot with enhanced social cues actually triggered higher levels of psychological reactance than a persuasive robot with minimal social cues (Ghazali et al., 2018b). In the research of Baroni et al. about designing a robot to motivate children to eat fruits and vegetables, they found that using words was more effective than using physical cues (Baroni et al., 2014). The reason might be that the robot focuses on encouraging children with words to lead a healthier lifestyle. Jaap Ham et al. investigated the impact of gazing and gestures on the persuasiveness of a storytelling robot (Ham et al., 2015). They found that gazing significantly increased the robot's persuasiveness, indicating that it is an important persuasive strategy for storytelling robots.

It was reported in a study by Saunderson et al that when the robot assumes a friendlier role (peer role), the user can experience a higher level of persuasive power compared to when the robot assumes an authoritative role (Saunderson & Nejat, 2021). The study also discovered that the persuasiveness of the robot increases when users receive rewards instead of penalties. Ahtinen and Kaipainen conducted a 4-month user experience study of a social and persuasive robot for learning in a primary school (Ahtinen & Kaipainen, 2020). They found that the robot's physical embodiment, non-verbal communication methods such as lights and sounds, and special movements contributed to an increased level of persuasiveness exhibited by the robot. Studies reveal that social robots' persuasiveness varies with different social cues. Comparing text-only to robot-presented messages, the latter mitigates psychological reactance. Words are effective for children's motivation, while gazing and gestures enhance robot persuasiveness. Role and rewards influence persuasion, and long-term studies emphasize physical embodiment and non-verbal communication's impact.

2.3. Constructivism in learning

Constructivism is the theory that says learners construct knowledge rather than just passively take in information (Bada & Olusegun, 2015). According to this constructivist framework, children are active learners who construct their knowledge by formulating and testing their own theories and beliefs. Through play, children explore the tangible world, organize their thoughts, and engage in logical operations (Yilmaz, 2008). This primarily occurs in relation to concrete objects rather than abstract concepts. Inquiry learning serves as a valuable tool in facilitating a more structured exploration of abstract ideas, often incorporating physical touch or connection. Based on previous research, it can be concluded that persuasiveness can be achieved through constructivist learning. PBL fulfills the imperative of promoting lifelong learning by engaging learners in question-based and constructivist approaches.

Theory of Mind (ToM) is a fundamental social cognitive ability that allows one to understand the state of mind (mental state) of others. As an example, understanding others' current thoughts, intentions, beliefs, and feelings (Bamicha & Drigas, 2022). Constructivist Learning approaches can be used to facilitate the development of the ToM by providing opportunities for children to engage in social interactions, collaborative problem-solving, and perspective-taking activities that promote the understanding of others' mental states.

Drawing upon prior research, it is possible to devise a constructivist learning approach by incorporating the ToM concept and employing PBL approaches. This constructivist approach, in turn, enables the attainment of persuasive learning outcomes. The summarized findings of this literature concerning persuasive learning are illustrated in Figure 1.

*Correspondence: deepal@sjp.ac.lk

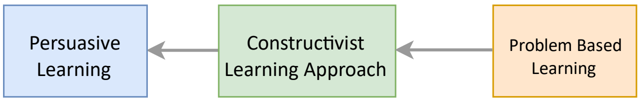


Figure 1: The utilization of constructivist learning approaches, through the integration of the application of PBL methodologies, facilitates the accomplishment of persuasive learning objectives.

2.4. Design approaches for social robots in education

In the realm of designing robots for educational companionship, prior research has employed a range of approaches, including the utilization of pre-existing commercial robots and the creation of novel robotic systems. Within this landscape, several scholars have opted to employ well-known social robots such as Pepper, Furhat, and Nao as tools for engaging with children in activities like language teaching and storytelling (Ahtinen & Kaipainen, 2020; Calvo et al., 2020; De Carolis et al., 2021). These robots consist of advanced capabilities like human-like facial expressions, intricate hand gestures, autonomous locomotion, and facial recognition. Notably, a majority of these studies have enlisted participants aged eight years and older, individuals with the cognitive capacity to comprehend intricate tasks and acquire advanced language proficiencies. However, when the focus shifts to interactions with younger children (under eight years of age), these advanced functions can inadvertently divert attention from the core research objectives.

The development of an innovative robot with minimalist functionalities emerges as a compelling strategy for engaging with young children. A prime example of this approach is exemplified by the Personal Robots Group at the MIT Media Lab's creation, Tega, a robot designed to foster connections with children and facilitate early childhood education (Westlund et al., 2016). Tega's design features a blue exterior adorned with soft fur, imbuing the robot with a cuddly aesthetic that encourages tactile interaction, allaying any apprehensions of harm (Phillips-Brown et al., 2023). Furthermore, the Personal Robots Group's Dragonbot stands as another testament to this approach, being tailor-made for sustained interactions (Setapen, 2012). Likewise, Kaspar, conceived at the University of Hertfordshire, stands out as a social robot designed specifically as a therapeutic tool for children with Autism Spectrum Disorder (ASD) (Wood et al., 2021). Kaspar presents a child-like, realistic face characterized by simplified features, intentionally designed to furnish a more approachable and less intimidating interface for young users. Collectively, the aforementioned researches underscore the advantages of diverging from commercially available robotic platforms in favor of designing purpose-built robots, characterized by minimalist design and requisite functionalities. The literature review has revealed a lack of robot-related research focusing on the PBL approach derived from constructivism theory for teaching an L2. To address the above challenges, we have developed a persuasive social robot as a companion. This robot has the ability to tailor its interactions and constructive conversations according to the individual skill level of each child. Furthermore, the companion robot is designed in a minimalistic way to engage in long-term interactions with children, ensuring consistent support and continuity. The primary objective of this robot is to enhance a range of skills in children. It focuses on improving language and literacy skills, fostering effective communication abilities, nurturing social-emotional development, and enhancing analytical thinking skills. By integrating these various skill-building components, the robot serves as a comprehensive learning companion for children, supporting their holistic development in multiple domains.

3. Methodology

This study adopts a **design-and-evaluation research methodology**, focusing on both the development of a persuasive social robot and its empirical assessment in a real-world learning context. The approach is grounded in **constructivist learning theory**, with **Problem-Based Learning (PBL)** serving as the primary interaction paradigm. The objective is to design a system that promotes active

*Correspondence: deepal@sjp.ac.lk

learning by encouraging children to construct knowledge through guided interaction rather than passive instruction.

3.1 Research Questions

To guide the study, the following research questions are formulated:

- **RQ1:** Does a PBL-driven conversational model improve perceived learning support in early second language acquisition?
- **RQ2:** How does interaction with a persuasive social robot influence children's emotional engagement over repeated sessions?
- **RQ3:** Can a minimalist robot design effectively sustain engagement in child–robot interaction?

3.2 Interaction Framework

The interaction framework follows a structured and progressive learning approach, as illustrated in Figure 2. The robot initiates interaction by presenting a question and allowing the child to attempt an independent response. If the child is unable to answer correctly, the system provides incremental hints, guiding the learner toward the correct solution.

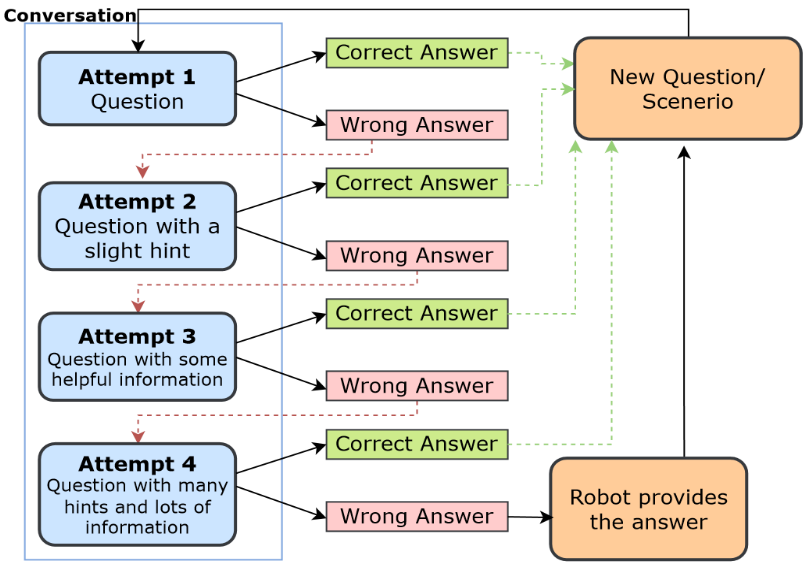


Figure 2. The constructivist learning approach behind Roboto is incorporated with the PBL.

The above mechanism operationalizes the principles of PBL by emphasizing exploration, reasoning, and self-correction. Rather than delivering direct answers, the robot facilitates learning through guided inquiry, enabling children to actively construct knowledge in alignment with constructivist theory.

Language learning is implemented through a conversation-driven model, where interaction occurs through dialogue rather than explicit instruction. In storytelling scenarios (Figure 3), the robot presents narratives in segments and introduces context-based questions to maintain engagement and reinforce comprehension. This interaction style simulates a peer-like learning environment, which has been shown to enhance motivation and participation in early learners.

*Correspondence: deepal@sjp.ac.lk

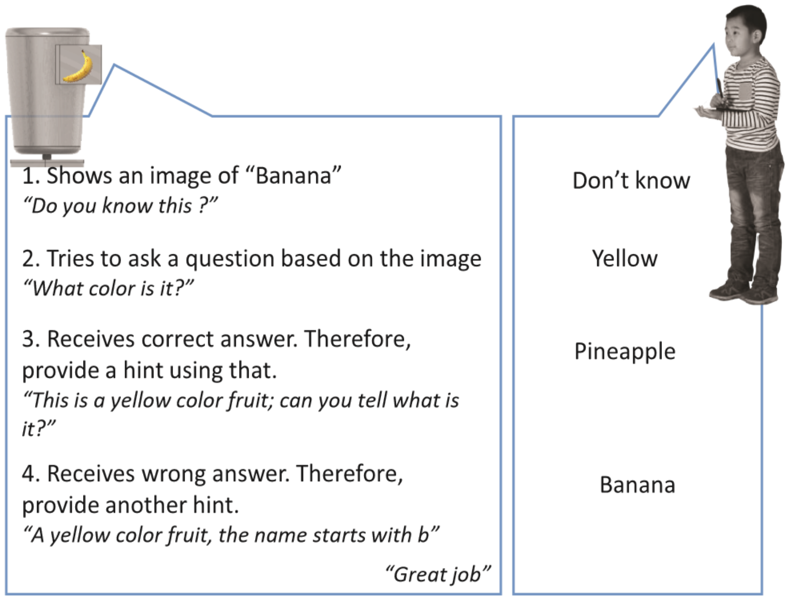


Figure 3. A basic illustrative dialogue between Roboto and a child, in which the robot provides cues, encouraging the child to learn independently.

3.3 Robot Design

The physical design of the robot follows a minimalist and child-centric approach, aimed at reducing distraction while maintaining engagement. The system is implemented as a tabletop device with limited movement capabilities, such as controlled head rotation, to guide user attention without overwhelming the learner.

Figure 4. Left: 3D design of the robot created by Fusion 360, Middle: Final design of the robot, Right: Physical appearance of the robot with emotions

*Correspondence: deepal@sjp.ac.lk

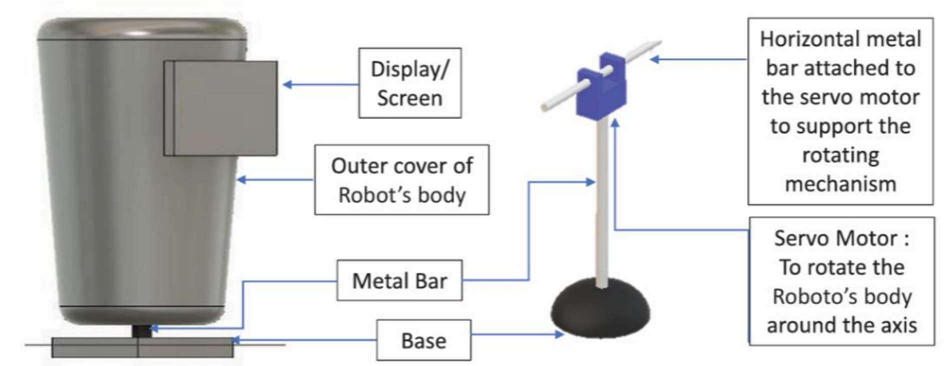


Figure 5. Left: Outer structure of the robot, Right: Internal structure of the robot for the rotation mechanism

Visual feedback is provided through a display that presents emotional expressions and learning content (Figures 4 and 5). This simplified embodiment prioritizes usability and interaction clarity over physical complexity. The design choice is informed by prior research (Kozima et al., 2009; Korn, 2019) in human–robot interaction, which suggests that minimalistic robots can effectively engage young children while avoiding cognitive overload associated with highly complex humanoid features (Reichardt et al., 2015). To enhance its appeal as a child-friendly companion, a fur cover was added, giving the robot a teddy bear-like appearance (Westlund et al., 2016; Saldien et al., 2010).

3.4 System Architecture

The system architecture integrates multimodal input and adaptive output generation, as illustrated in Figure 6. Audio input is captured through a microphone for speech-based interaction, while visual input is obtained via a camera for head tracking and basic emotion detection. These inputs are processed through a conversational framework that maps user responses to interaction intents, enabling context-aware dialogue generation. The system produces outputs in the form of speech, visual feedback, and limited physical movement, creating a coherent and interactive learning experience.

To enhance expressiveness, speech output incorporates variations in tone and pacing, while visual feedback reflects the system's interpretation of the child's emotional state. This integration supports adaptive and personalized interaction, allowing the robot to respond dynamically to user behavior.

3.5 Emotional Interaction Mechanism

An effective interaction mechanism is incorporated to enhance user engagement. The system detects basic emotional states, such as happiness, neutrality, and negative expressions, through visual input. Emotion recognition was implemented using facial-expression analysis based on computer-vision techniques that classify visible facial expressions into broad emotional categories. The detected emotional state was used solely to adapt the robot's interaction style, visual feedback, and conversational responses. Since emotion recognition was incorporated as a supporting interaction mechanism rather than the primary focus of this study, an independent validation study of recognition accuracy was not conducted. Therefore, the emotional measurements reported in this study should be interpreted as approximate indicators of user engagement rather than precise psychological assessments. Based on these states, the robot adapts its conversational tone, feedback strategy, and visual expressions (Figure 7).

*Correspondence: deepal@sjp.ac.lk

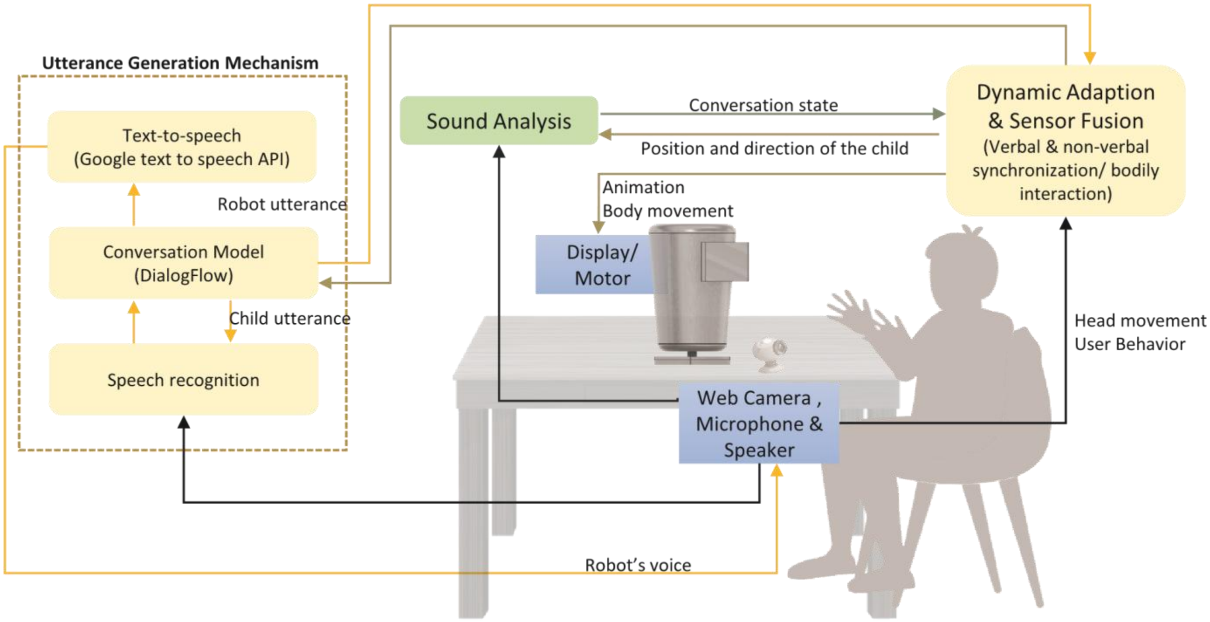


Figure 6. Overall Processing Architecture for Roboto: The robot receives input using a Camera and a microphone. The way it generates responses involves three main parts: speech recognition, a conversation model created with Dialog Flow, and Text-to-Speech using the Google Text-to-Speech API. The robot displays body movements based on the child's position, and emotions are shown through an LCD display.

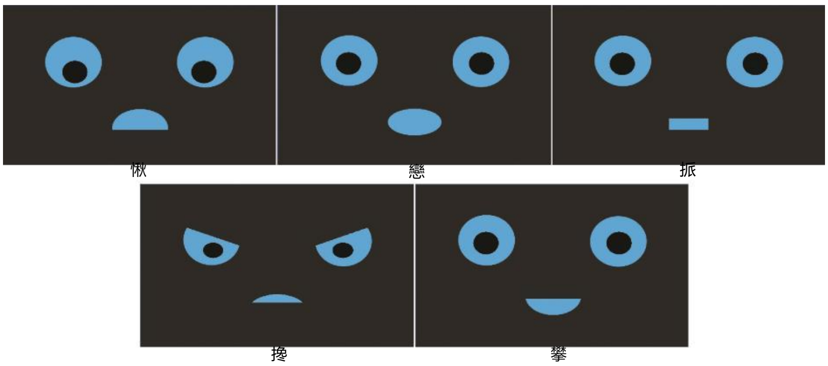


Figure 7. Emotions of the robot. a) sad, b) surprised, c) natural, d) angry, e) happy

This feedback loop enables the system to respond in a socially appropriate manner, reinforcing positive engagement and reducing potential frustration. The incorporation of emotional adaptation supports the development of a more natural and relatable interaction, which is particularly important in child–robot interaction contexts.

The proposed methodology integrates constructivist learning principles, PBL-driven interaction, and emotionally adaptive feedback within a unified system design. By combining pedagogical grounding with interactive and affective capabilities, the approach aims to enhance engagement and perceived learning support.

*Correspondence: deepal@sjp.ac.lk

4. Experimental Protocol

4.1. Experimental Setup

The study involved 18 children aged 4–8 years in Colombo, Sri Lanka. Research suggests that 50% of learning ability develops by age 4, with an additional 30% by age 8–10 (ParentCo, n.d.; Trafton, n.d.), making early L2 introduction beneficial. In Sri Lanka, English is typically introduced in primary school, emphasizing activity-based oral English to enhance vocabulary and sentence structure (Sri Lanka National Institute of Education, n.d.). Participants had basic English skills, and the robot's vocabulary and stories were aligned with the national syllabus.

Given the exploratory nature of this study and the practical and ethical considerations associated with recruiting young children for child–robot interaction research, the participant sample was intended to provide an initial evaluation of the proposed system rather than establish broadly generalizable learning outcomes. Accordingly, the primary objective was to assess the feasibility, user acceptance, and interaction characteristics of the robotic learning companion. The longitudinal component involving seven participants was designed as a preliminary investigation of interaction trends over repeated sessions, providing initial insights to guide future large-scale controlled studies.

Children were introduced to Roboto before the experiment and engaged in conversations and storytelling sessions. Feedback was collected via questionnaires completed by parents, teachers, or investigators. Figure 8 illustrates children interacting with the robot.

Figure 8. Children engaging in interactions with Roboto

4.2 Ethical Considerations

Ethical considerations were carefully addressed throughout the study. **Informed consent** was obtained from parents or guardians before participation. The study was conducted in accordance with institutional ethical guidelines, ensuring the safety, privacy, and well-being of all participants. No personally identifiable data was recorded or disclosed.

*Correspondence: deepal@sjp.ac.lk

4.3 Experimental Scenarios

The experimental design consists of three scenarios, each targeting a different aspect of interaction:

Scenario 1 – Conversation Model and Companionship

Participants engaged in individual conversational sessions with the robot, covering topics such as letters, colors, numbers, fruits, vegetables, and verbs. The interaction followed a PBL-based questioning approach, where the robot provided hints when participants were unable to respond correctly.
This scenario evaluates the effectiveness of the conversational model in supporting learning and engagement.

Scenario 2 – Storytelling Function

Storytelling sessions were conducted in small groups of 2–4 children. The robot presented stories in segments and asked context-based questions to assess comprehension. Participants provided individual feedback following each session.
This scenario focuses on evaluating engagement and learning support in a collaborative setting.

Scenario 3 – Continuous Use and Progress

A subset of seven participants engaged in repeated interaction sessions over three separate weeks. Each session involved storytelling followed by question-based interaction.
This longitudinal scenario evaluates **emotional adaptation and interaction consistency** over time. Stories used in this scenario included *The Three Little Pigs*, *The Ugly Duckling*, and *Little Red Riding Hood*, ensuring consistency across sessions.

4.4 Data Collection

Data was collected using a combination of questionnaire-based feedback and observational analysis. Post-session questionnaires were designed to accommodate young children (under 9 years) by using simplified response options: Yes, No, or Neutral, instead of Likert scales, in line with established guidelines for child-centered survey design (Bell, 2007). Questions were phrased using simple and direct language, avoiding negations and complex qualifiers to minimize confusion and improve response reliability (de Jong et al., 2020). In addition, facial expressions were recorded during storytelling sessions to assess emotional engagement. Observational data, including interaction duration and behavioral responses, were also collected to support the analysis. To minimize recall bias, questionnaire responses were obtained immediately after each interaction session.

4.5 Evaluation Criteria

The evaluation framework combines both **quantitative and qualitative measures**:

- **User Feedback:** Scenario-specific questionnaires assess interaction quality, engagement, and perceived learning support.
- **Emotional Analysis:** Facial expressions are analyzed to evaluate changes in emotional engagement across sessions.
- **Statistical Analysis:** Non-parametric tests, including the **Friedman test** and **Wilcoxon signed-rank test**, are used to identify significant differences in repeated measures data.

Non-parametric statistical methods were selected because of the relatively small sample size and the ordinal nature of the questionnaire responses. Unlike parametric methods, non-parametric tests do not require assumptions of normality and are widely recommended for human–robot interaction studies involving limited participant groups and categorical response data. Accordingly, Chi-square

*Correspondence: deepal@sjp.ac.lk

goodness-of-fit tests were employed to examine response distributions, while Wilcoxon signed-rank tests were used to evaluate differences across repeated interaction sessions.

4.6 Experimental Validity

To ensure consistency and comparability, all participants were exposed to the same interaction structures, question formats, and storytelling content. This controlled design allows for meaningful comparison across scenarios and sessions.

However, the absence of a control or comparison group limits the ability to attribute the observed outcomes exclusively to the proposed robotic system. Consequently, the findings should be interpreted primarily as evidence of feasibility, user acceptance, emotional engagement, and perceived learning support rather than causal proof of learning improvement. Future studies should incorporate controlled experimental designs and objective language assessments to establish comparative effectiveness.

5. Results and Discussion

5.1. Overview of Analysis

The experimental evaluation of the proposed robotic system was conducted using questionnaire responses (Tables 1 and 2) and observational data (Figures 9 and 10), supported by non-parametric statistical analysis (Table 3). To provide a more rigorous interpretation, the questionnaire data were further examined using comparative and score-based analyses derived directly from the observed responses.

Table 1. Summarized the results of the questionnaire to evaluate the conversation model based on user experience

Questions	Yes	No	Neutral
English Learning Is learning the English Language hard?	66.67%	33.33%	0.00%
Do you like to talk to a person in English?	77.78%	22.22%	0.00%
Experience Is the design of the Robot cute?	94.44%	5.56%	0.00%
Does the size of the robot suit you?	88.89%	0.00%	11.11%
Does the questioning model help to get a better understanding?	83.33%	11.11%	5.56%
Are robots’ conversations clear enough to understand?	66.67%	22.22%	11.11%
Do animations/emotions help to build a good conversation?	94.44%	0.00%	5.56%
Is robot movement distracting?	44.44%	22.22%	33.33%
Engagement and Acceptance Do you enjoy having a conversation with the robot?	100%	0.00%	0.00%
Would you use this robot again?	100%	0.00%	0.00%
Do you think Roboto is a useful companion for English learning?	100%	0.00%	0.00%

*Correspondence: deepal@sjp.ac.lk

Table 2. Summarized the results of the questionnaire to evaluate the effectiveness of the storytelling function of the robot

Questions	**Yes**	**No**	**Neutral**
Do you like to listen to stories in English?	55.56%	44.44%	0.00%
Does asking questions help you understand the story easily?	83.33%	16.67%	0.00%
Do you enjoy listening to the story with the robot?	100%	0.00%	0.00%
Would you use this robot again to listen to stories?	100%	0.00%	0.00%

Table 3. Session visited P-value given by the pairwise Wilcoxon signed-rank test

Sessions	**S1**	**S2**
S2	0.1830	-
S3	0.0063	0.0108

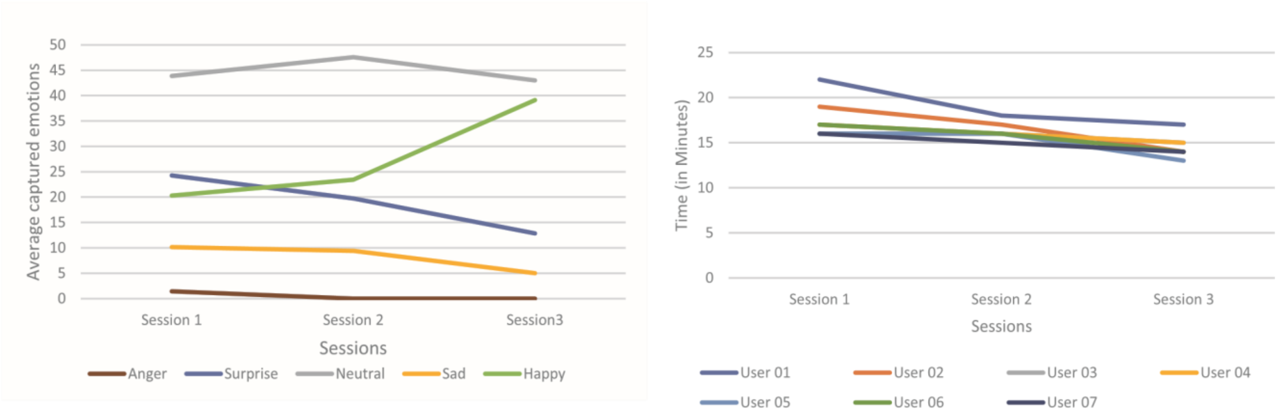


Figure 9. Left: Variation of facial emotions across three sessions. Right: Session-wise comparison of time spent by each user.

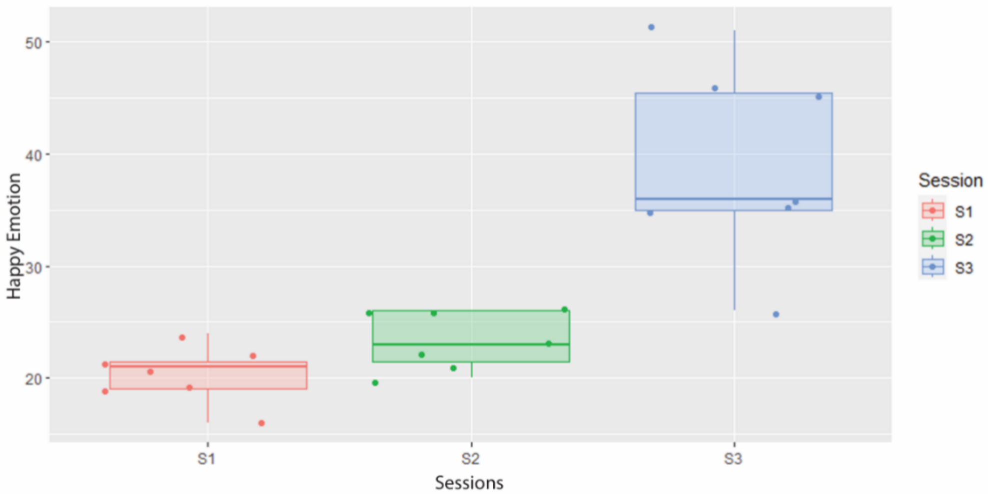


Figure 10. Box plot of happiness levels across sessions.

**Correspondence: deepal@sjp.ac.lk*

5.2. User Experience and Conversation Model Analysis

The results from Scenario 1 (Table 1) indicate that while a majority of participants (66.7%) perceive learning English as difficult, a higher proportion (77.8%) expressed willingness to engage in English conversation. This suggests that although learners face linguistic challenges, they remain intrinsically motivated to participate when supported by an interactive system.

The robot's physical design received strong positive feedback, with 94.4% of participants indicating that the robot is visually appealing and 88.9% confirming that its size is appropriate. These findings highlight the effectiveness of a minimalist, child-centric design in facilitating acceptance. This aligns with prior research in human–robot interaction, which suggests that simplified embodiments can enhance engagement by reducing cognitive overload while maintaining social presence.

From a learning perspective, 83.3% of participants reported that the question-driven interaction model improved their understanding. A Chi-square goodness-of-fit test further confirmed that this positive response distribution is statistically significant ($\chi^2 = 8.0$, $df = 1$, $p < 0.05$), indicating that the observed effect is unlikely to be due to chance. This finding provides empirical support for the integration of Problem-Based Learning (PBL) within a constructivist framework. The questioning model encourages active participation, self-reflection, and incremental problem-solving, which are key mechanisms through which learners construct knowledge rather than passively receive information.

However, conversation clarity received comparatively lower agreement (66.7%), suggesting that language comprehension remains a limiting factor. This may be attributed to variations in participants' English proficiency and highlights the need for improved speech adaptation and linguistic simplification in future iterations.

Notably, all participants (100%) reported enjoying interaction with the robot and expressed willingness to use it again. While this indicates a high level of engagement and acceptance, these findings should be interpreted with caution due to the potential influence of novelty effects commonly observed in child–robot interaction studies.

The exceptionally high positive responses observed for enjoyment and re-use intention may partly reflect the novelty associated with interacting with a social robot for the first time. While the longitudinal findings suggest that positive engagement was maintained across repeated interactions, larger and longer-term studies are required to determine whether these perceptions persist beyond the initial exposure period.

5.3. Comparative Analysis of Interaction Scenarios

A comparative evaluation of Scenario 1 (conversation) and Scenario 2 (storytelling), as summarized in Table 4, reveals consistently high levels of engagement, perceived learning support, and re-use intention across both interaction modes.

The comparable performance between the two scenarios suggests that the effectiveness of the system is not strongly dependent on the type of instructional content but rather on the underlying interaction design. In both cases, the robot employs a question-driven conversational strategy, reinforcing the role of guided inquiry as a central mechanism for engagement and learning. This indicates that the integration of PBL principles contributes to a flexible interaction framework capable of supporting multiple learning contexts.

Table 4. Comparative analysis of user experience across Scenario 1 (conversation) and Scenario 2 (storytelling).

Evaluation Metric	Scenario 1 (Conversation)	Scenario 2 (Storytelling)
Positive engagement (enjoyment)	100%	100%
Perceived learning support	83.3%	83.3%
Re-use intention	100%	100%

*Correspondence: deepal@sjp.ac.lk

5.4. Score-Based Analysis of Questionnaire Responses

To provide a quantitative interpretation of user perceptions, questionnaire responses were transformed into ordinal scores (Yes = +1, Neutral = 0, No = −1), as presented in Table 5.

The results show that engagement and reusability achieved the highest mean scores (1.00), followed by robot design and emotional interaction (0.89). Learning support through the questioning model also demonstrated a strong positive score (0.72), reinforcing its effectiveness as a pedagogical mechanism.

In contrast, conversation clarity yielded a lower mean score (0.44), identifying it as a key limitation of the system. This suggests that while the interaction design successfully promotes engagement and perceived learning, its effectiveness is partially constrained by linguistic accessibility. Addressing this limitation through adaptive language generation and proficiency-aware dialogue strategies may further enhance overall system performance.

Table 5. Score-based analysis of key questionnaire items.

Metric	Mean Score
Enjoy interaction	1.00
Re-use intention	1.00
Robot design (cuteness)	0.89
Emotional interaction support	0.89
Learning support (question model)	0.72
Conversation clarity	0.44

Mean scores were calculated using a simple ordinal transformation (Yes = +1, Neutral = 0, No = −1).

5.5. Emotional Engagement Analysis

The analysis of emotional responses across repeated sessions (Figure 9) indicates a clear progression toward more positive emotional states over time. Initial interactions were characterized by a mixture of emotional expressions, including surprise and occasional negative responses. However, subsequent sessions showed a reduction in negative emotions and a consistent increase in positive expressions, while neutral states remained relatively stable.

Statistical analysis using the Wilcoxon signed-rank test (Table 3) supports these observations. No significant difference was found between Session 1 and Session 2 ($p = 0.183$), whereas significant improvements were observed between Session 1 and Session 3 ($p = 0.0063$) and between Session 2 and Session 3 ($p = 0.0108$). These results indicate that emotional adaptation occurs progressively rather than immediately.

This trend suggests the presence of a habituation effect, where repeated exposure to the robot reduces uncertainty and enhances user comfort. Over time, the robot transitions from a novel entity to a familiar interaction partner, contributing to increased trust and emotional engagement. These findings are consistent with existing literature in human–robot interaction, which emphasizes the importance of longitudinal interaction in developing sustained engagement.

5.6. Task Performance Analysis

Task performance across sessions, as illustrated in Figure 9 (right), demonstrates a decreasing trend in the time required to complete interaction tasks. This indicates that participants become more efficient with repeated exposure to the system.

The observed improvement in task efficiency can be attributed to increased familiarity with the interaction process and reduced cognitive effort required to engage with the robot. This suggests that repeated interaction not only enhances emotional comfort but also contributes to improved behavioral performance.

Although a direct causal relationship between emotional engagement and task efficiency cannot be established within the current study, the concurrent improvement in both dimensions indicates a

*Correspondence: deepal@sjp.ac.lk

potential interdependence. Future research incorporating controlled experimental designs would be required to further investigate this relationship.

5.7. Integrated Discussion

The combined findings from questionnaire data, observational analysis, and statistical testing provide a coherent understanding of the system's effectiveness. The results indicate that the proposed robotic system successfully supports user engagement, perceived learning, and emotional adaptation. The effectiveness of the system can be attributed to the integration of constructivist learning principles with a PBL-driven interaction model. By encouraging learners to actively construct knowledge through guided questioning, the robot facilitates deeper engagement compared to passive instructional approaches. Furthermore, the incorporation of persuasive interaction elements, such as emotional feedback and conversational dynamics, enhances user motivation and sustained participation.

The findings also demonstrate that a minimalist robot design, when combined with appropriate interaction strategies, can achieve high levels of acceptance and engagement without relying on complex humanoid features. This highlights the importance of interaction design over physical complexity in educational robotics.

Several limitations should be considered when interpreting the findings. First, the relatively small sample size, particularly within the longitudinal component, limits statistical power and generalizability. Second, the absence of a control or comparison group prevents causal attribution of observed effects to the robotic intervention alone. Third, learning-related outcomes were assessed primarily through participant perceptions and engagement measures rather than standardized language proficiency assessments. Finally, emotional-state measurements were derived from automated facial-expression analysis and should be regarded as approximate indicators of engagement. Future research should employ larger participant groups, objective language assessments, validated emotion-recognition procedures, and controlled experimental designs.

Despite these limitations, the study provides preliminary empirical evidence that integrating pedagogically grounded interaction models with socially adaptive robotic systems can positively influence learner engagement and perceived support during early language-learning activities. Unlike prior work that primarily emphasizes engagement, this study demonstrates that embedding structured learning frameworks such as PBL within robot interaction can contribute to perceived learning effectiveness.

6. Contribution to Knowledge

This study makes several significant contributions to the fields of human–robot interaction and robot-assisted language learning.

Firstly, it introduces a novel integration of Problem-Based Learning (PBL) within a constructivist framework for the design of a persuasive social robot targeting early second language acquisition. Unlike prior work that predominantly emphasizes engagement and interaction design, this study explicitly embeds a pedagogically grounded learning model into the interaction process, demonstrating its measurable impact on perceived learning support.

Secondly, the study provides empirical evidence that a minimalist robot design, when combined with structured conversational strategies and affective feedback, can achieve high levels of engagement and acceptance among young children. This challenges the prevailing assumption that complex humanoid features are necessary for effective educational interaction.

Thirdly, the research offers new insights into longitudinal emotional adaptation in child–robot interaction. The findings reveal that positive emotional engagement and interaction efficiency improve progressively over repeated sessions, highlighting the importance of sustained interaction in building familiarity, trust, and learner engagement.

Finally, the study contributes methodologically by employing a multi-dimensional evaluation framework that integrates questionnaire-based feedback, observational analysis, and non-parametric statistical testing. This approach enables a more comprehensive understanding of both subjective user

*Correspondence: deepal@sjp.ac.lk

perception and behavioral interaction patterns, providing a robust foundation for future research in educational social robotics.

7. Conclusions

This study evaluated the effectiveness of a socially interactive robotic system designed to support English language practice and learner engagement. The results indicate high levels of user engagement, strong acceptance of the robot's design, and positive perceptions of its learning support mechanisms.

The integration of a question-driven interaction model appears to support active engagement and understanding, while repeated interaction leads to observable improvements in emotional comfort and task efficiency. Statistical analysis further suggests that changes in emotional engagement occur progressively over time.

The findings also highlight the importance of robot design and affective interaction in sustaining user engagement, particularly for young learners who may experience anxiety when practicing a second language. The use of a non-judgmental robotic companion appears to provide a supportive environment for language practice.

However, the findings are limited by the small sample size, the absence of raw observational data, and the lack of control conditions. Additionally, the current system relies on partially scripted interactions and limited conversational domains, which may restrict generalizability.

Future research should address these limitations through larger-scale and controlled experimental designs, while also improving system autonomy and adaptability for more natural and personalized interactions.

Overall, the study provides preliminary evidence that a socially interactive and pedagogically guided robotic system may be a promising tool for enhancing engagement and perceived support during early language-learning activities.

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**Correspondence: deepal@sjp.ac.lk*