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The Impact of Social Robot Interaction on Engagement and Narrative Complexity in Primary School Children

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Abstract

Social robots are increasingly being integrated into educational settings as they can enhance engagement and learning, particularly in young learners. This study explored the impact of a social robot (NAO) during a storytelling activity with primary school children, focusing on engagement, narrative skills, and introspective language, compared to the interaction with a standard technological device such as a tablet). It was hypothesized that, in comparison to the use of a tablet, interacting with a social robot would enhance engagement, narrative complexity, and the use of psychological lexicon (Hy 1) as well as the relationship between introspective language and narrative complexity (Hy2). A within-subjects design involved 40 children (aged 7–9) completing a storytelling task in two conditions: with a social robot (NAO) and with a tablet. Engagement was assessed via psychophysiological (heart rate) and behavioural (observational scales) measures. Narrative complexity and introspective skills were assessed via linguistic analysis and psychological lexicon use. Heart rate analysis showed physiological activation during storytelling, with no differences between conditions.Behavioural engagement and narrative complexity were significantly higher in the robot condition, and some engagement indicators were positively correlated with narrative complexity. Moderation analysis showed that the relationship between psychological lexicon use and narrative complexity holds only in the social robot condition. Findings suggest that providing children with a social robot coach during a storytelling task may enhance behavioural engage- ment and support narrative complexity development, indicating potential for cognitive-linguistic skill enhancement in educational contexts.

Keywords Social robotics · Engagement · Narrative complexity · Introspective skills · Storytelling · Children

1 Introduction

Social robotics focuses on the development of robots capable of interacting with humans in an empathetic and relational manner, rather than merely performing mechanical tasks [1]. Unlike conventional tools or technologies, social robots do not merely assist users but establish a relationship with them, making them particularly suitable for educational settings, where engagement and relational interaction play a crucial role [2]. Indeed, the use of social robotics is becoming increasingly widespread in educational and rehabilitative settings from early stages of development. Research suggests that social robots can positively impact both socio-emotional and cognitive aspects in diverse educational environments, including general and special education [3]. Social robots can enhance children's motivation through their interactive features, such as movement and verbal and non-verbal communication, as well as through the intrinsic

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enjoyment derived from interacting with them. [4]. Moreover, the ability to pre-programme and control the robot's actions allows expert adults to design specific activities and stimulus-response situations to facilitate the acquisition of particular knowledge and skills. From this perspective, social robotics has been integrated with learning-by-doing paradigms, as the robot's actions can concretely translate theoretical representations and knowledge, and learning-by-teaching, where the social robot's learning process can serve as the goal of the child's learning experience [5, 6]. Moreover, the programmable nature of social robots enables their configuration as interactive coaches capable of providing sustained, individualised support across educational tasks, potentially addressing scalability constraints inherent in human-delivered individualised instruction [7, 8]. Within this framework, the learning-by-teaching paradigm can be applied through various school or everyday tasks [9–11], such as storytelling, which is an ecological activity rich in information about the child's skills and psychological state [12].

In this context, this paper aims to evaluate the impact of a social robot on engagement and narrative complexity in primary school children during a storytelling task with a humanoid robot (i.e. NAO) in comparison with non-robotic devices (i.e. tablet).

1.1 Social Robotics and Engagement

Engagement is defined as the level of an individual's active participation in their environment, resulting from dynamic interaction with social and material elements [13, 14]. It is a multifaceted and multidimensional construct encompassing behavioural, emotional and cognitive components [15, 16]. At the behavioural level it refers to observable behaviours such as active participation, persistence, and initiative-taking [15]; in terms of emotions, engagement includes emotional reactions such as interest, enthusiasm, satisfaction, and a sense of belonging [17]; and when considering cognitive processes, mental investment, concentration, sustained attention, and the use of effective cognitive strategies are addressed [18].

Given the multidimensional nature of the engagement, it is measured through various methodologies, including psychophysiological and behavioural indicators, that need to be integrated [14, 19]. Psychophysiological measures of engagement include several types of measures such as heart rate, galvanic skin response, and eye movement [20]. Particularly, heart rate variability (HRV) reflects the balance between sympathetic and parasympathetic nervous system activation: a reduction in HRV is associated with increased and a stress response, whereas an increase indicates greater vagal regulation and an optimal state of engagement [21–24]. The relationship between engagement and changes in cardiac vagal tone has been demonstrated also in school-aged children [25]. The observational methodology systematically analyses behavioural manifestations associated with different levels of engagement, such as attention, active participation, and emotional responses to activities [26]. These assessments may include self-report measures as well as third-party evaluations (proxy reports) filled by expert adults [27]. behavioural observation of positive engagement include smiles, relaxed postures, and prolonged active participation, indicating an effective interaction with the task [26]. Conversely, frustration manifests itself through tense expressions, agitation, and negative verbalizations, often in response to comprehension difficulties [16]. Through observation of the behaviour may subtend cognitive difficulties, for example confused looks, distracted glances, irrelevant interactions, requests for help or approval, and failed attempts, suggest attentional difficulties and presence of anxiety whereas, stable eye contact and ready responses are an indicator of attention control [15, 28, 29]. These methodological approaches to engagement assessment provide the foundation for examining whether enhanced engagement in robot-mediated interactions translates into measurable learning outcomes

1.1.1 Social Robotics and Learning

It is commonly acknowledged that the presence of social robots in educational environments increases motivation and engagement of students across lifespan, since early ages. Young children tend to anthropomorphize social robots due to their ability to integrate movement and multi-modal interactions, which, in comparison to non social technologies, such as tablets and pc, can foster greater engagement and supports learning processes [7, 30, 31]. Since the attractiveness of robotics is so widespread that it is generally well received by both adults and children, it has recently been incorporated into national educational curricula across different grades (e.g EARLY: Education Advancements through Robotics Labs for Youth).

Social robots have emerged as effective tools in education, enhancing students' learning outcomes across various domains, including reading, writing, maths, and reasoning [7, 32]. Their integration into classrooms has enabled personalised and interactive learning experiences, particularly when functioning as tutors, learning companions, or coaching agents that provide contingent feedback and sustained interactive support [7, 33]. A review [7] highlighted how these robots contribute to both cognitive and socio-emotional learning by providing adaptive feedback, moderating discussions, and maintaining student engagement. Empirical studies demonstrate that social robots effectively support diverse educational objectives. For instance, social robots have been used in primary and secondary education to foster computational thinking, language learning, and socio-emotional development [33]. Robots have also been employed in subject-specific interventions, such as teaching mathematics [34], scientific concepts [35], and language acquisition [36, 37]. Beyond subject instruction, they encourage curiosity [38] and a growth mindset [39], also facilitating collaborative learning by guiding problem-solving discussions and answering students' questions [40].

In literacy development, social robots have proven particularly beneficial for younger learners. Studies show that robots functioning as interactive reading coaches improve phonetic skills, sentence construction, and reading comprehension more effectively than traditional book-based or tablet-based methods [37, 41]. Their capacity to provide embodied, responsive feedback during literacy tasks mirrors key elements of effective one-to-one instructional coaching while operating within classroom resource constraints [42]. Moreover, research indicates that students working alongside robotic peers exhibit higher self-efficacy and cognitive engagement, particularly in STEM and language learning [43]. The majority of social robotics research in education focuses on children aged 4 to 12, with an emphasis on primary school learners [7, 33]. These robots provide real-time adaptive feedback based on students' learning trajectories, fostering knowledge retention, motivation, and self-regulation [7, 44, 45]. Their embodied presence enables the use of non-verbal cues, such as gestures and facial expressions, which contribute to a heightened sense of social presence and empathy, positively impacting cognitive and emotional learning outcomes [46, 47].

Beyond general education, social robots support differentiated instruction, particularly for students with special educational needs. Their ability to recognise emotions [48] and provide affect-adaptive tutoring helps mitigate frustration and cognitive overload, fostering a more supportive learning environment [49]. This adaptability makes them valuable tools for learners with autism spectrum disorder or learning difficulties [50, 51]. As research continues to explore the role of social robots in education, their potential to enhance personalised learning and interactive pedagogy remains a promising avenue for future development [52, 53]. Among these educational applications, storytelling tasks represent a particularly suitable context for assessing both engagement and linguistic development, as narrative production requires sustained attention and the coordination of complex cognitive and linguistic processes.

1.2 Storytelling

Narrative competence is a fundamental construct in children's cognitive and linguistic development. It is defined as the ability to organize and communicate experiences through the construction of coherent, structured, and meaningful narratives [54]. This competence, which is crucial for symbolic thinking and social interaction, initially emerges in oral narratives and progressively evolves into written narratives as children transition from early childhood to school age [55, 56]. From a developmental perspective, narrative competence is shaped by a combination of cognitive and linguistic factors, including lexical and morphosyntactic knowledge, which enhance the ability to produce structured and content-rich narratives [54]. Empirical evidence suggests that narrative coherence and cohesion improve with age, alongside an increasing ability to coordinate complex elements such as psychological lexicon and mental state references [55, 57].

The narratives produced by schoolaged children exhibit structural advancements that reflect cognitive maturation. Specifically, they include more articulated representations of events, characters, and causal relationships, as well as an increasingly sophisticated use of mental state references [56, 58]. This mental language, which encompasses terms related to emotions, thoughts, and intentions, is strongly correlated with narrative competence. The storytelling task is widely used in developmental psychology and education, providing an in-depth assessment of children's linguistic and cognitive abilities, as well as their expressed emotional states [59–61]. Indeed, narrative complexity is closely linked to the integration of psychological lexicon within stories, enabling children to express an increasingly sophisticated understanding of social dynamics and characters' internal processes. In this context, the ability to coordinate narrative structure with mental state references improves significantly from preschool to primary school, suggesting a high informative potential of this task already in the early years of primary school [60]. The integration of psychological lexicon within narratives is theoretically grounded in theory of mind development, as children's capacity to attribute mental states to story characters reflects their broader sociocognitive maturation [57, 62]. Research has demonstrated that narrative competence, particularly the ability to incorporate mental state language within story structures, serves as an indicator of children's understanding of others' minds and their capacity to detect psychological causality, with developmental progression observed from kindergarten through primary school [63].

Educational interventions designed to support narrative development have been shown to improve children's narrative skills, particularly when they incorporate structured scaffolding, modelling, and contingent feedback [64]. Nevertheless, systematic implementation of intensive and individualized approaches may be constrained by practical considerations, including the instructional time and personnel resources required for sustained one-to-one support [65]. From this perspective, social robots may represent a technologically mediated coaching solution that preserves core interactive elements, particularly embodied presence and non-verbal responsive behaviours, while addressing practical limitations of human-delivered individualized instruction.

Extensive literature in educational psychology has documented narrative complexity development through established frameworks, notably story grammar analysis [66]. Story grammar frameworks systematically assess structural narrative elements including setting, initiating events, character goals, attempts, and resolutions [67]. These approaches have demonstrated developmental progression in narrative abilities and have informed intervention programmes in traditional educational contexts. Nevertheless, these studies have examined narrative production almost exclusively within dyadic childadult or child-peer contexts, leaving largely unexplored how different forms of technologically mediated interactions might influence narrative complexity. Crucially, no study has yet directly compared these deep narrative dimensions between robotic agents and standard technological devices (e.g., tablets).

Within human-robot interaction research, storytelling has emerged as a prevalent educational activity. Studies have examined children's engagement with robotic storytellers [68], vocabulary acquisition through robot-led narratives [69], and basic linguistic outcomes such as word count and lexical diversity [70]. However, existing HRI storytelling research has predominantly assessed engagement metrics or surface-level linguistic outcomes, without employing developmental frameworks for narrative complexity assessment or examining psychological lexicon integration within narrative structures. Research has shown that social robots can effectively stimulate language and storytelling skills through their capaity for social responsiveness and the creation of interactive contexts. For instance, studies indicate that robots functioning as coaches can introduce new vocabulary, model narrative structures, provide feedback, and engage children in collaborative storytelling activities, leading to improved language acquisition and retention [37, 71]. This coaching capacity, characterized by sustained responsive interaction and embodied social presence, distinguishes robot- mediated storytelling from interaction with passive technological devices.

Social robots, through their anthropomorphic features and interactive capabilities, may enhance children's engagement and support cognitive-linguistic development [8]. Nevertheless, the specific mechanisms distinguishing robot-mediated storytelling from interaction with standard technological devices remain underexplored. Furthermore, while engagement and narrative competence have been examined separately, their interrelation in human-robot interaction requires systematic investigation. Of particular interest is whether the social presence of an embodied agent influences not only engagement levels but also the integration of psychological lexicon within narrative structures.

2 Study Aims

This study aimed to explore the effects of using social robots in educational contexts, focusing on how they influence engagement, narrative abilities, and introspective skills in primary school children during a storytelling task. Specifically, the study compared engagement levels and narrative complexity when children interacted with the NAO robot, which provided sustained non-verbal feedback through physical presence and responsive listening behaviors, against a tablet condition in which the device served solely as a passive interface for recording control, without providing any interactive feedback to the child.

It was hypothesized (Hy 1) that performing a storytelling task with a social robot providing non-verbal coaching feedback would result in higher engagement and narrative performances compared to completing the same task using a tablet as a passive non-interactive interface. Engagement was measured in terms of psychophysiological activation (heart rate), behaviour (observational scale), and children's self-evaluation of the task, as well as narrative performance in terms of linguistic (narrative complexity) and introspective (psychological lexicon) competencies.

Additionally (Hy 2), it was hypothesized that the presence of a social robot would positively influence children's access to the psychological lexicon, strengthening the relationship between introspective competencies and narrative abilities in the social robot condition compared to the non-robotic device condition.

Furthermore, as an exploratory analysis, the study examined whether children's explicit perception of the robot's anthropomorphic qualities would correlate with narrative and engagement outcomes, thereby investigating potential mechanisms underlying robot effectiveness.

3 Materials and Methods

This section describes the instrumentation used as well as the experimental protocols, the participants and the evaluation tools.

3.1 Instrumentations

NAO is a programmable humanoid robot developed by United Robotics Group (formerly Aldebaran Robotics, France). It measures 574 mm in height, weighs 5.4 kg, and features 25 degrees of freedom (DOF), with 11 DOF in the lower body (legs and pelvis) and 14 DOF in the upper body (trunk, arms, and head). Communication and expression are enabled through two loudspeakers and 25 actuated joints that allow it to produce lifelike gestures. The robot is equipped with two cameras, four micro-phones, joint position sensors, and an inertial measurement unit with a fall detection system. Its processing capabilities are driven by an Intel ATOM 1.6 GHz CPU running a Linux kernel. In the context of this study, the robot's actions were programmed in Python 2.7 using NAOqi APIs and developed via Choregraphe 2.1.4.

In the robot condition, children interacted with Nao as it performed scenario-specific gestures and dialogues preprogrammed via the NAOqi framework [72]. A custom Python-based user interface running on a personal computer managed the robot's behaviour and coordinated the acquisition of multimodal data. Audio and video recordings of the interactions were captured using an Orbbec camera and an additional horizontal-view camera. To monitor participants' physiological responses, a Fit-bit Versa 2 bracelet recorded heart rate (HR) data in real time [73]. In the tablet condition, the task was programmed with the same interface as the robot to start audio and video recording.

3.2 Experimental Protocol

A within-subjects design was employed; all participants were assessed in both the robot condition and tablet condition, with half of the sample following the robot-tablet order and the remaining half the reverse. The inter-session interval ranged from approximately two weeks to one month, depending on school scheduling constraints. The experimental setting for both conditions is illustrated in Fig. 1 The study was conducted in a quiet school environment. In both conditions, an experimenter was present throughout the session. The session began with the child wearing the Fitbit device to record HR.

In the robot condition, the robot stood up, waved in greeting, introduced itself, and asked the child's name, then delivered the task instructions with accompanying hand movements and body animations, stating: "I really want to hear a story told by you. Would you like to tell me one?" Following the child's acceptance, the robot specified: "I would like a story invented by you; it doesn't matter if it's long or short, happy or sad, any type of story is fine." In case of initial refusal, the robot provided encouragement by reiterating the request with a supportive prompt (e.g., "I know you are brilliant at telling stories, could you tell me one?"). If the child refused a second time, the session was terminated. During the narration, the robot maintained an active listening posture, nodding its head at randomized intervals between 10 and 30 seconds. non-verbal feedback alone was provided during this phase, as preliminary feasibility testing indicated that verbal interjections disrupted children's narrative flow. At the conclusion of the story, the robot thanked the child, waved in farewell, and returned to a seated position.

In the tablet condition, the experimenter delivered verbally the identical instructions, including the encouragement phase in case of initial refusal, and the greeting at the end. During the narration the experimenter remained present but silent and positioned outside the child's field of view, providing no feedback.

In both conditions, children were asked to freely invent a story on any theme without constraints on time or length. The tablet served exclusively as a session control interface, providing buttons to confirm participation, start the narration, and signal its conclusion. Audio and video were recorded using identical equipment across both sessions (see Fig 1).

3.3 Participants

Contacts were established with partner primary schools in central Italy by approaching the school principals of local institutions to request authorization for their schools' participation in the study. Following approval from the school principals, the process continued with the collection of written informed consent from the parents of all participants. The study was approved by the University of Florence Research Ethics Committee (No. 342 of 12 July 2024) and was conducted according to ethical standards of the Declaration of Helsinki.

A total of 62 primary graders were initially recruited for the study; all subjects were native Italian speakers. Due to school absences during one of the administrations, it was not possible to assess both conditions for seven children. Six children were excluded from participation based on school documentation indicating certified atypical developmental profiles requiring individualised educational support services; for privacy reasons, school personnel could not disclose the specific nature of diagnoses but only confirm the presence of such certification. Of the remaining participants, four children were excluded in the robot condition (three refusals, one silence), one in the tablet condition (silence), and four in both conditions (two remained silent, two presented substantial intelligibility issues). Consequently, the data from 40 participants (aged 7–9 years,

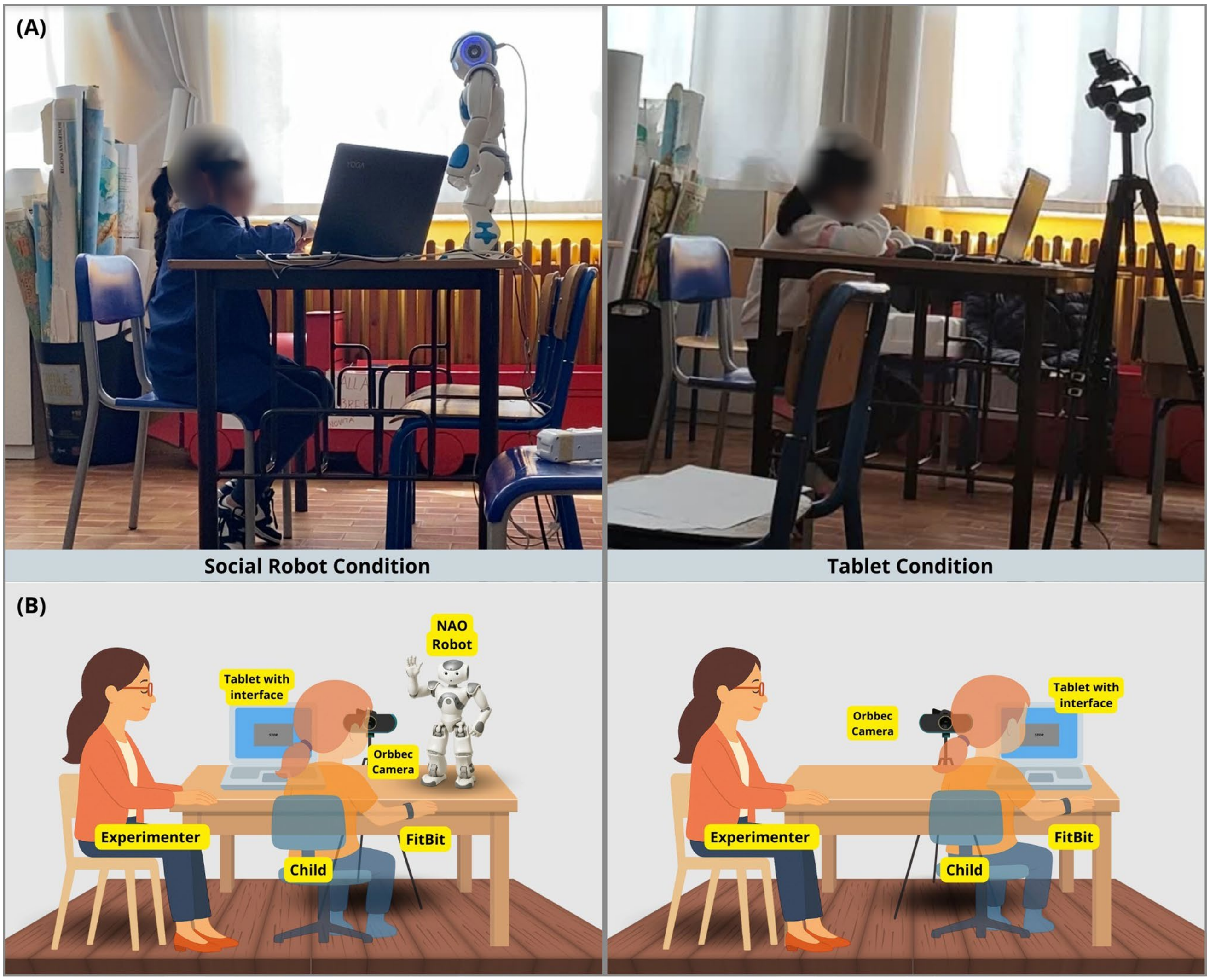

Fig. 1 Experimental conditions. (**A**) Photographs of robot condition (left) and tablet condition (right) showing identical recording equipment (Orbbec camera, Fitbit Versa 2) and interface. (**B**) Schematic diagrams illustrating the key procedural difference: NAO robot provided task instructions and active non-verbal listening cues during narration (left), while in the tablet condition no feedback was provided (right). In the tablet condition, the experimenter delivered verbally the identical instructions. In both conditions, the experimenter remained silent and positioned outside the child's visual field during the storytelling phase

$M = 8.30$, $SD = 0.79$; II gr.: 11, III gr.: 11, IV gr.: 18) were retained for analysis.

3.4 Measures

In order to pursuit the study aims, four type of measures were collected as described in the following paragraphs.

3.4.1 Psychophysiological Measures

Heart rate (HR) was assessed using the Fitbit Versa 2, a wearable device equipped with a photoplethysmography (PPG) optical sensor that enables continuous heart rate monitoring. Data were collected at three distinct time points: at baseline (T0), during a structured storytelling task (T1), and after task completion (T2). HR measurements were recorded in beats per minute (BPM).

3.4.2 Behavioural Engagement

To measure engagement at the behavioural level the Martinovic Engagement Observation Scale is used. It is a structured observational instrument designed to assess behavioural and cognitive engagement in children [26]. It consists of eight items, each rated on a five-point Likert scale (1 = strongly disagree; 5 = strongly agree). The scale evaluates multiple dimensions of behavioural engagement. It measures the extent to which the child demonstrates enjoyment, assessing whether they appear to be having fun. Frustration is also evaluated, considering the degree to which the child exhibits signs of distress or difficulty. The scale further examines task comprehension by determining whether the child understands and follows the task instructions. Attention is assessed based on the child's ability to maintain focus throughout the activity. Anxiety levels are measured by observing signs of nervousness or apprehension. Additionally, the scale considers distraction, identifying instances where the child becomes disengaged. The extent to which the child requires external motivation or encouragement is also taken into account. Finally, the scale evaluates the level of effort the child exerts to complete the task.

Scores from the Martinovic Engagement Scale and OES were assigned through offline analysis of video recordings captured with an Orbbec camera. Three raters (A.B., S.S., M.B.), all of whom are authors of the present study, reviewed all recordings and entered their evaluations into a standardised spreadsheet. Pre-consensus ICC(3,k) values indicated excellent reliability [74, 75] across all behavioural engagement measures. Specifically, reliability coefficients for the eight Martinovic scale items ranged from 0.85 (95% CI [0.81, 0.88]) for attention to 0.93 (95% CI [0.92, 0.95]) for anxiety, with the Overall Engagement Scale demonstrating ICC(3,k) = 0.95 (95% CI [0.94, 0.96]). Following initial coding, discrepancies were resolved through collaborative discussion among the three raters until full consensus was achieved. This two-phase procedure is consistent with established practices in developmental narrative research for managing complex interpretive judgments that require nuanced evaluation [76, 77].

3.4.3 Robot Perception

At the end of the social robot condition, participants were requested to compile the Godspeed Questionnaire Series [78], which evaluates five core dimensions in the perception of social robots: anthropomorphism, animacy, likability, perceived intelligence, and perceived safety. The questionnaire was administered with the active support of the experimenters: children provided their responses orally, which were then transcribed by the experimenters. In case of necessity, the experimenter could clarify terminology and ensure accurate comprehension of each adjective pair.

The questionnaire consists of 24 pairs of semantically opposed adjectives (e.g., *"machine-like" – "human-like"*), rated on a 5-point Likert scale, where higher scores indicate greater attribution of human-like qualities to the robot. Only the anthropomorphism sub-scale, composed of 5 adjective pairs, was employed for the present study. This sub-scale was selected due to its specific relevance to the research objectives and its established sensitivity in capturing children's perception of the robot's human-like characteristics supporting the results discussion and interpretation. The adjective pairs included: *"fake – natural", "machine-like appearance – human-like appearance", "artificial – life-like", "unconscious – conscious", "moving rigidly – moving elegantly"*. In addition, participants were asked to rate the overall pleasantness of the activity using a numerical scale ranging from 1 (not at all pleasant) to 10 (extremely pleasant), in order to assess their subjective enjoyment of the interaction with the robot.

3.4.4 Narrative and Introspective Skills

The storytelling task was analysed through video and audio recordings based on multiple narrative features, including latency (time taken before starting the narration), measured in seconds, total word count, number of minimal clause units, and narrative complexity.

Narrative complexity was assessed using a five-level hierarchical coding system developed by Pinto, Tarchi, and Bigozzi [54], which evaluates the structural organization of children's narratives based on the presence or absence of eight key narrative elements: (1) title, (2) conventionalized narrative opening (e.g., "once upon a time"), (3) identifiable characters serving as protagonists, (4) setting providing spatio-temporal context, (5) explicit problem representing a conflict or obstacle, (6) central event constituting the main action of the story, (7) resolution addressing the problem, and (8) conventionalized narrative closing (e.g., "and they lived happily ever after"). Temporal coherence was evaluated through the identification of causal and temporal connections, as well as inconsistencies or gaps in the narrative timeline, such as temporal incoherence or missing elements. This approach provided a comprehensive assessment of the narrative's structural and cognitive organization, emphasizing its overall complexity. Narrative complexity score assignment followed a hierarchical structure reflecting increasing narrative complexity. Narratives receiving a score of 1 (no narrative) consisted of simple descriptions or lists of events, objects, or facts without narrative structure. A score of 2 (sketch narrative) was assigned when narratives included either the combination of opening, setting, characters, and conclusion or the combination of opening, sketch of problem, and resolution. Narratives scored as 3 (incomplete narrative) contained opening, characters, problem, and resolution, whereas those receiving a score of 4 (essential narrative) demonstrated opening, characters, problem, central event, and resolution. Finally, a score of 5 (complete narrative) was assigned when all eight elements were present, reflecting a fully developed narrative structure with title, opening, characters, setting, problem, central event, resolution, and closing. Transcripts regarding were coded by three trained raters (A.B., M.B., S.M.) all of whom are authors of the present study. The assessment of inter-rater reliability demonstrated an excellent level of agreement, yielding an average mea-sure of ICC(3,k) = 0.97 (95% CI [0.8999]) [74, 75]. Following initial coding, discrepancies were resolved through collaborative discussion among the three raters until full consensus was achieved.

Concerning the psychological lexicon, the coding system used was proposed by Tarchi [60], which categorized the different psychological dimensions expressed in the narratives. Specifically, the analysis focused on terms describing world perception, emotional states, volitional expressions, cognitive processes, moral reasoning, and socio-relational dynamics.

Perceptual states included terms related to sensory experiences, such as watching, listening, or noticing. Emotional states were divided into positive and negative emotions, with terms such as *"happy", "caring",* and *"hugging"* representing positive emotions, while words such as *"sad", "scared",* and *"crying"* indicated negative affect. Volitional expressions reflected will or intentionality, including terms such as *"trying", "hoping"*, and *"seeking"*. Cognitive states included references to thought processes, such as *"knowing", "thinking",* and *"remembering"*. Moral states were identified through terms related to ethical reasoning and normative behavior, including *"obeying", "promising"*, and *"reprimanding"*. Socio-relational states encompassed terms describing interactions between characters, such as *helping, abandoning*, or *becoming friends*. The proportion of mental state terms relative to the total number of words spoken by each child was calculated to assess the extent to which psychological elements were integrated into the narrative. For example, if a child's story contained only the word *"thinking"* out of a total of 60 words, the resulting ratio would be 0.016. This measure provided a quantitative index of the prominence of mental state language in children's narratives, allowing for comparisons across different conditions. A total score of the psychological lexicon was computed by calculating the ratio of the total number of words associated with the psychological lexicon to the total number of words in the story.

Narrative complexity and psychological lexicon transcripts were coded by three raters (A.B, M.B, S.M), trained in the coding system. The inter-rater agreement was 100%, as any coding discrepancies were discussed until a complete resolution was reached among the raters.

4 Statistical Analysis

The data collected during the experiment were analysed offline. Statistical analyses were conducted using IBM SPSS Statistics Version 29.0 [79]. Descriptive statistics were computed for all variables. The alpha level for statistical significance was set at 0.05 for all inferential analyses and was subsequently adjusted for multiple comparisons using the Holm-Bonferroni sequential correction [80]. Normality of data distribution was assessed through skewness and kurtosis indices, with values falling within the ±2 range considered acceptable [81]. To examine the interaction between the variation in HR between the baseline (T0) and the beginning of the task (T1) in the two experimental conditions (social robot vs tablet), a multivariate analysis of variance (MANOVA) was conducted. Mauchly's sphericity test was calculated to verify the assumption of sphericity in the data. Paired-samples t-tests and Wilcoxon signed-rank tests were employed for normally and not-normally distribute variables. Effect sizes were interpreted according to Cohen's [82] conventions, with $|r| = 0.10$ indicating a small effect, $|r| = 0.30$ a medium effect, and $|r| = 0.50$ a large effect. The one-tailed Spearman correlation analysis was conducted separately for social robot and tablet conditions to examine the relationship between narrative complexity and engagement, measured using the Martinovic Engagement Scale and OES. To explore whether individual differences in perceived anthropomorphic characteristics of the robot were associated with cognitive-linguistic outcomes, additional correlations between the Godspeed Anthropomorphism subscale and narrative complexity, psychological lexicon ratio, and behavioural engagement indices were computed for the social robot condition. To determine whether the use of a social robot, in comparison to a tablet, could affect the relationship between the psychological lexicon and the narrative complexity, a moderation model was used. The analysis was conducted using Hayes' PROCESS procedure (Model 1).

5 Results

At the Martinovic scale, the mean scores in both the social robot and tablet conditions exceeded the midpoint value (3) of all the items representing positive engagement and were below it for the items describing difficulty in engaging with the task. Specifically a high percentage of participants scored equal or over the midpoint in happiness (social robot: 87,5%; tablet:65%), attention (social robot: 95%; tablet: 100%), commitment (social robot: 100%; tablet: 92.5%) and below the middle value in difficulties in task comprehension (social robot: 95%; tablet:100%), frustration (social robot: 100%; tablet: 95%), anxiety (social robot: 97.5%; tablet: 95%) distraction (social robot: 92.5%; tablet: 100%), and need of encouragement (social robot: 95%; tablet: 92.5%). The mean total score of engagement (OES) exceeds the midpoint (4) in the social robot condition but not in the tablet condition, with 87.5 and 25% of participants in the social robot and tablet conditions respectively.

Concerning the distribution of narrative complexity across the five-level hierarchical coding system, in the robot condition 10.0% of participants obtained the minimum score (Level 1), 37.5% scored at Level 2, 15.0% at Level 3, 10.0% at Level 4, and 27.5% achieved the maximum score (Level 5). In the tablet condition, the distribution was 12.5% at Level 1, 50.0% at Level 2, 20.0% at Level 3, 12.5% at Level 4, and 5.0% at Level 5. Accordingly, the combined proportion of participants scoring at the two lowest complexity levels was 47.5% in the robot condition and 62.5% in the tablet condition.

Descriptive statistics for the five items of the Godspeed anthropomorphism subscale revealed variability in participants' responses. The highest mean was observed for the item *"conscious"* ($M=4.68$; SD = 0.76), followed by *"natural"* ($M=4.45$; SD = 1.13). Conversely, the lowest mean was recorded for *"moving elegantly"* ($M=2.78$; SD = 1.64). Intermediate values were found for *"humanlike"* ($M=3.15$; SD = 1.55) and *"lifelike"* ($M=3.38$; SD = 1.53). Across the five items, the proportion of participants scoring above the neutral midpoint of the scale (i.e., 3) was as follows: 87.5% for *"natural"*, 40% for *"humanlike"*, 45% for *"lifelike"*, 97.5% for *"conscious"*, and 32.5% for *"moving elegantly"*.

Participants' global evaluation of the storytelling activity in the social robot condition, based on the 10-point scale, yielded a mean score of $M=8.98$ (SD = 1.05), indicating a generally high level of perceived enjoyment and appreciation.

The mean scores obtained at the storytelling task (see Table 1) resembled those obtained in previous studies on primary graders in terms of narrative complexity ([56]: $M=3.07$, sd = 1.35 [60]: $M=2.23$, SD = 1.06 [61]: $M=3.52$, SD = 0.8), total number of words ([61]: $M=98.33$, SD = 49), and total psychological lexicon ([60]: $M=0.06$, Sd = 0.04[61]:$M=1.10$,SD = 1.4). Nevertheless, visual inspection of the distributions revealed considerable inter-individual variability in narrative measures, particularly for latency, duration, and word count.

5.1 Differences Between Robot and Tablet Conditions

Psychophysiological measures. Multivariate analyses of variance (MANOVA) on the HR values revealed a significant effect of Time, confirming a significant variation between T0 and T1 ($F(1, 39)=43.31$, $p<0.001$, $\eta 2=0.53$) and between T1 and T2 ($F(1, 39)=6.01$, $p<0.01$, $\eta 2=0.13$) measurements. Conversely, the main effect of condition

Table 1 Mean, standard deviation, skewness and Kurtosis in the social robot and tablet conditions

Category	Measures	SR M(SD)	SR Sk	SR Ku	T M(SD)	T Sk	T Ku
Heart	Baseline (BPM)	85.43 (12.36)	0.66	0.41	85.85 (12.76)	0.79	0.72
Rate	T1 (BPM)	98.98 (17.00)	0.86	0.87	98.73 (18.29)	1.01	1.24
	T2 (BPM)	91.80 (13.29)	0.48	−0.21	96.35 (12.45)	0.29	−0.30
	Happiness	3.25 (0.74)	0.35	0.15	2.70 (0.65)	−0.21	0.18
	Frustration	1.97 (0.70)	0.03	−0.85	1.50 (0.82)	1.79	2.85
	Task Comprehension	1.83 (0.90)	0.80	−0.25	1.43 (0.55)	0.80	−0.43
Martinovic	Attention	3.67 (0.69)	−0.43	0.33	3.43 (0.50)	0.32	−2.00
Scale	Anxiety	2.32 (0.66)	0.12	0.03	1.90 (0.84)	0.74	0.15
	Distraction	2.33 (0.89)	0.68	0.99	1.55 (0.68)	0.85	−0.37
	Encouragement	1.63 (0.90)	1.29	0.70	1.38 (1.03)	2.87	7.41
	Commitment	4.32 (0.66)	−0.45	−0.65	3.52 (0.68)	−0.61	0.01
Total	OES	4.50 (1.18)	0.00	0.76	2.92 (0.80)	−0.18	−0.64
Engagement	Latency (s)	40.53 (53.62)	2.42	7.24	54.05 (103.22)	3.03	9.61
Narrative	Duration (s)	93.40 (81.81)	3.01	12.67	110.45 (142.61)	2.75	7.63
Measures	Number of Words	95.35 (63.48)	0.99	0.06	125.90 (174.27)	3.48	12.91
	Narrative Complexity	3.08 (1.42)	0.25	−1.42	1.47 (1.03)	0.79	0.20
	Perception Ratio	0.005 (0.007)	1.43	0.95	0.235 (1.422)	6.32	39.98
	Cognitive Ratio	0.002 (0.005)	1.96	2.64	0.002 (0.005)	2.73	7.12
	Positive Emotion Ratio	0.009 (0.016)	2.40	5.87	0.011 (0.024)	3.16	11.87
Psychological	Negative Emotion Ratio	0.004 (0.010)	3.06	10.30	0.005 (0.010)	2.85	9.84
Lexicon	Physiological Ratio	0.017 (0.022)	1.56	2.56	0.013 (0.020)	2.00	4.78
	Moral Ratio	0.004 (0.008)	2.13	4.29	0.004 (0.011)	4.56	23.59
	Volition Ratio	0.013 (0.020)	1.73	2.08	0.009 (0.028)	5.22	29.84
	Socio-relational Ratio	0.007 (0.012)	1.89	3.38	0.006 (0.018)	4.38	20.88
	Total Lexical Ratio	0.061 (0.035)	0.66	0.11	0.059 (0.052)	1.92	5.12

Note. SR = Social Robot; *T* = Tablet; Sk = Skewness; Ku = Kurtosis

(T0 - T1: F(1, 39) = 0.001, $p = 0.97$, η2 = 0.00; T1 - T2: F(1, 39) = 0.75, $p = 0.39$, η2 = 0.02) and the interaction between condition and time (T0 - T1: F(1, 39) = 0.028, $p = 0.87$, η2 = 0.00; T1 - T2: F(1, 39) = 2.41, $p = 0.13$, η2 = 0.06) were not significant (see Fig. 2).

Behavioural Engagement. Pairedsamples t-tests and Wilcoxon signed-rank tests on the scores obtained at each item of the Martinovic scale revealed that, following Holm-Bonferroni correction for multiple comparisons, the social robot exhibited significantly higher levels of happiness (t(39) = 4.64, $p < 0.001$, α_holm = 0.0056, d = 0.87) and commitment (t(39) = 6.99, $p = 0.001$, α_holm = 0.00625, d = 1.11) compared to the tablet condition. Accordingly, distraction (t(39) = −4.64, $p < 0.001$, α_holm = 0.0071, d = 0.73) and anxiety (t(39) = −2.54, $p = 0.01$, α_holm = 0.01, d = 0.40) were significantly lower in the social robot than in the tablet condition. The overall OES score was significantly higher (t(39) = 8.05, $p < 0.001$, α_holm = 0.0083, dz = 1.27) in the social robot than in the tablet condition. Nevertheless, attention, task comprehension, and frustration levels were statistically significant before correction but did not reach significance following adjustment for multiple comparisons, whereas no significant differences were found between the social robot and tablet in the need for encouragement. Complete statistics for all Martinovic scale items are reported in Supplementary Table S2.

Narrative Complexity and Psychological Lexicon. Wilcoxon signed-rank tests revealed that narrative complexity was significantly greater during the interaction with the robot than with the tablet, following Holm-Bonferroni correction for multiple comparisons (Z(39) = 2.34, $p = 0.01$, α_holm = 0.0125, $r = 0.37$). Nevertheless, no significant differences emerged between conditions for latency time, duration of narration, or number of words. Similarly, analyses of psychological state terms revealed no significant differences between the social robot and tablet conditions. Complete statistics for narrative variables and psychological lexicon categories are reported in Supplementary Tables S3 and S4, respectively.

5.2 Correlations and Moderation Analyses

Spearman correlation analysis between narrative complexity and the behavioural engagement at the Martinovic scale and the OES in social robot condition, revealed a significant correlation between narrative complexity and commitment (rho = 0.32, $p = 0.05$). No other correlations were found in the social robot condition (see Supplementary Table S5). In the tablet condition, narrative complexity was significantly positively correlated with frustration (rho = 0.47, $p = 0.002$) and with the OES score (rho = 0.39, $p = 0.01$). All other correlations in the tablet condition were non-significant (see Supplementary Table S6). Spearman correlations between Godspeed Anthropomorphism subscale scores and study variables revealed no statistically significant associations (all ps > 0.05; see Supplementary Table S7).

At the moderation analysis, the experimental condition moderated the relationship between the total score of the psychological lexicon and narrative complexity (B = −17.14, SE = 6.61, $t = -2.59$, $p = 0.01$), as the relationship was significant in the social robot condition (B = 11.83, SE = 5.47, $t = 2.16$, $p = 0.03$) but not in the Tablet condition (B = −5.31, SE = 3.72, $t = -1.43$, $p = 0.16$) (see Fig. 3).

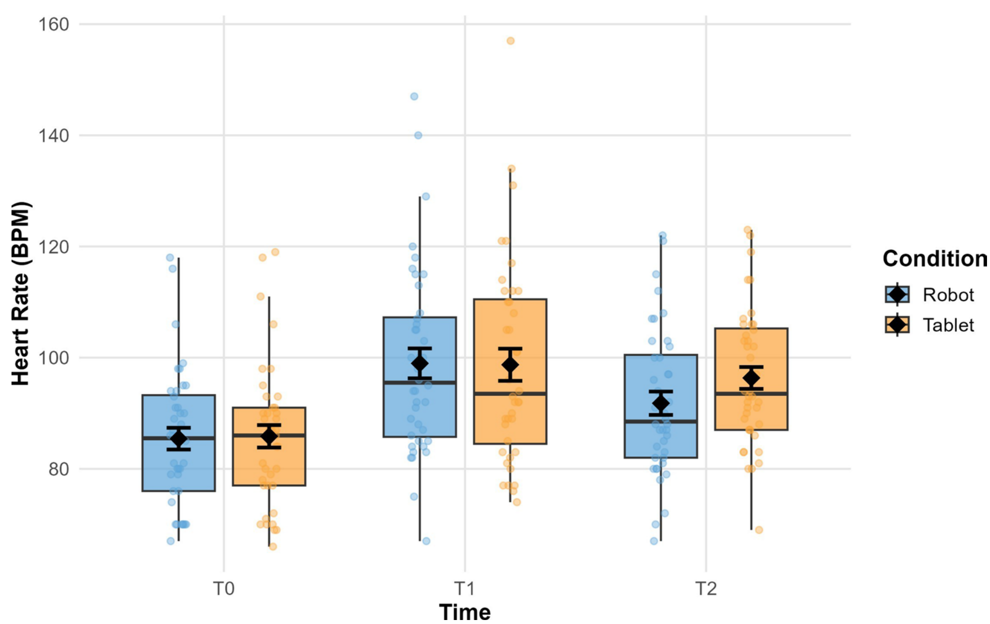

Fig. 2 Heart rate (HR) across time points (T0, T1, T2) and conditions (social robot vs. Tablet)

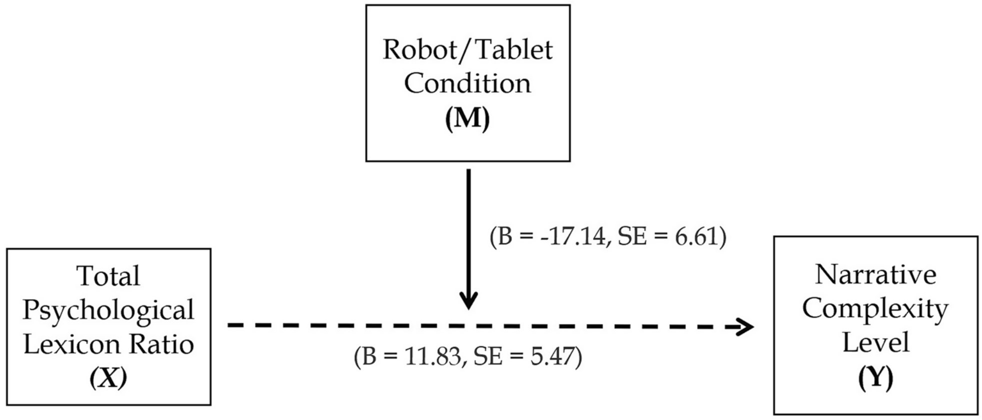

Fig. 3 Moderation role of robot vs tablet condition on the relationship between total psychological lexicon Ratio to narrative complexity level in the storytelling task

6 Discussion

The present study aimed to investigate the effects of social robot coach on engagement, narrative skills, and introspective competencies in primary school children engaged in a storytelling task. Specifically, we hypothesized that interacting with a social robot (NAO) during storytelling would result in greater engagement and improved narrative performances compared to completing the same task using a non-social technological device, such as a tablet (Hy 1). Additionally, we hypothesized that the presence of a social robot would enhance children's access to psychological lexicon, leading to a stronger relationship between introspective competencies and narrative skills in the social robot condition compared to the tablet condition (Hy 2). To this aim, the engagement was assessed through both psychophysiological activation (HR), behavioural measures (observational scales) and children's self-evaluation of the task, while narrative and introspective skills were assessed by the linguistic parameters and the presence of psychological lexicon in the invented story. A within-subjects experimental design was employed, in which 40 primary school children (aged 7–9 years) participated in two storytelling sessions-one with the NAO robot and one with a tablet. The robot was programmed to listen and respond with social cues, while the tablet simply recorded the story without interactive feedback. Data were collected through video and audio recordings, transcribed, and analysed to compare engagement and storytelling outcomes across conditions. Overall, the psychophysiological and behavioural measures suggested a positive engagement of children in the storytelling task, both in the social robot and tablet conditions. Similarly, the mean of the narrative and introspective skills for both conditions fell in the expected range for primary graders [56, 60, 61].

Psychophysiological Engagement. Concerning psychophysiological measures of engagement, the HR had a significant increase from the baseline to the beginning of the task (T1) and a subsequent adjustment of the heart rate per minute during the task performance (T1–T2) that was equivalent in the robot and tablet conditions. This pattern may suggests that the story-telling task itself elicited physiological activation, regardless of the interlocutor modality. These findings align with research suggesting that HR reflects physiological regulation related to stress or engagement in educational activities [25]. The absence of significant differences in heart rate patterns warrants careful interpretation. This finding may reflect comparable levels of physiological arousal, suggesting that the cognitive and emotional demands of storytelling elicit similar cardiovascular activation regardless of the interlocutor's social agency. In this context, the intrinsic engagement required by the narrative task appears to be the primary driver of arousal, outweighing the physical or social presence of the robot compared to the tablet. Nevertheless, heart rate measures alone could not be sufficiently representative of the child's emotional engagement. As demonstrated by Zhao & McEwen [83], stable mean heart rate patterns may coexist with substantial variations in heart rate variability and electrodermal activity. While mean heart rate captures baseline arousal, it may fail to reflect emotional valence or the dynamic regulatory processes unique to each modality. Consequently, while both conditions engaged children's attention to a comparable degree, more nuanced autonomic measures are required to isolate the specific impact of social agency on emotional quality and regulatory engagement.

Behavioural Engagement and Robot Perception. Analysis of behavioural engagement measured by the Martinovic scale revealed that, although global engagement was positive, as indicated by mean scores above the midpoint on all positively valenced items, children in the robot condition reported significantly higher levels of happiness and attention, and lower levels of frustration, task-related confusion, anxiety, and distraction compared to the tablet condition. These findings are consistent with the results of the Godspeed anthropomorphism subscale, which indicated a general tendency to attribute humanlike qualities to the robot, particularly in terms of consciousness and naturalness. This perceived anthropomorphism may have contributed to the enhanced affective and attentional engagement observed in the robot condition. Furthermore, the storytelling activity in the presence of the social robot was particularly appreciated by the children, who rated it highly on the liking scale [84]. Accordingly, the overall engagement score was significantly higher in the robot than in the tablet condition. These findings are consistent with previous studies suggesting the potential value of interacting with social robots during learning tasks [85, 86].

Narrative Complexity and Interactive Feedback. The comparison between experimental conditions revealed that narratives produced during interactions with the social robot were significantly more complex than those generated using the tablet. As no significant differences emerged in latency, narrative duration, word count, or number of propositions, the finding suggests that the increased complexity was not due to a mere expansion of speech but rather to enhanced structuring of narrative content. This finding provides empirical evidence distinguishing, the effect of an interactive social robot and that of a passive technological device on a learning task that, such as storytelling, involves communicative objectives and social interactions. One possible explanation is that the robot's perceived social agency, reflected in the high scores on the Godspeed anthropomorphism subscale, particularly for items such as "conscious" and "natural", may have encouraged children to adopt a more elaborate communicative stance [87]. This perception likely enhanced the robot's social presence, potentially prompting richer and more structured storytelling from the participants, in line with research showing that social robots can serve as effective scaffolding tools for language development [88]. Additionally, the non-verbal social presence provided by the robot might have implicitly guided children toward greater narrative cohesion and sophistication, an effect that was absent in the non-interactive tablet condition.

Regarding the observed differences between conditions, it must be acknowledged that research in child-robot interaction consistently demonstrates how physical embodiment fosters a heightened sense of social presence [89, 90]. Nevertheless, contingent interactivity, specifically including non-verbal cues such as nodding and attentive posture, plays a crucial role in sustaining engagement and promoting linguistic development [46]. It can be hypothesized, therefore, that the results of the present study reflect a synergistic interaction between embodied physical presence and responsive social behaviour, rather than the effects of embodiment in isolation ([91]. From this perspective, the social robot's combination of physical presence and contingent non-verbal feedback can be conceptualized as constituting a technologically mediated coaching system that supports narrative production through sustained, responsive interaction while addressing the resource constraints inherent in human-delivered individualized instruction.

The correlations found between the scores at the Martinovic scale and the narrative complexity of the invented story, support that the presence of a social robot may induce a more positive attitude towards the storytelling task in comparison to the use of a technical no-social device. Indeed in the robot condition narrative complexity was positively associated with commitment measured at the Martinovic scale, whereas in the tablet condition, narrative complexity correlated with frustration and need of encouragement. This suggests that the social nature of the robot can foster an immersive and enjoyable storytelling experience, leading to deeper cognitive engagement. Nevertheless, the tablet, as a less interactive tool, may have increased cognitive load, making the task feel more challenging and frustrating [7, 31]. These findings support theories of social presence and embodied interaction, which suggest that physical and responsive interlocutors enhance engagement and performances in learning tasks [88]. Furthermore, regarding the exploratory analysis on perceived anthropomorphism, the absence of significant correlations between Godspeed scores and either cognitive-linguistic outcomes or behavioural engagement measures offers a theoretical insight. Specifically, this observed dissociation suggests that the robot's effectiveness, both as a narrative scaffold and as an engaging social partner, may not strictly depend on the child's explicit attribution of high-level human-like qualities, such as consciousness or elegance. Instead, the results appear to support a'functional' view of social presence, wherein the robot's physical embodiment and contingent feedback (e.g. nodding or gaze orientation) may trigger automatic social processing and communicative alignment, regardless of the child's conscious evaluation of the agent's anthropomorphism [92].

It must be acknowledged that the narrative measures exhibited substantial inter-individual variability, as revealed by visual inspection of the distributions. This variability, while reflecting genuine individual differences in spontaneous storytelling abilities, contributes error variance that may attenuate effect sizes and reduce statistical power to detect smaller condition differences. Nevertheless, the significant differences observed between robot and tablet conditions in behavioural engagement and narrative complexity demonstrate robust effects that withstood this considerable individual variability. Future studies employing larger sample sizes would reduce the proportional impact of inter-individual differences on effect size estimates, thereby enabling more precise detection of subtle condition effects. Accordingly, the paper's findings suggested that the interaction context, robot versus tablet, modulated the relationship between psychological vocabulary use and narrative complexity (see Fig. 3). In other words, the physical presence of the robot and its interactive capabilities appeared to enhance children's engagement and attention to mental states during storytelling activities that in turn increased the narrative level of the invented story. Accordingly, research suggests that children are more likely to emulate the language and behaviours of a robot perceived as a peer, leading to improved linguistic skills [88]. The robot's ability to provide immediate, contingent responses may have created a dynamic interaction that mirrors human conversational patterns, thereby promoting more sophisticated psychological vocabulary use. Nevertheless, tablet-based interactions, although interactive in a different sense, lacked the embodied presence that characterises interactions with robots. The absence of a physical interlocutor may have resulted in lower social engagement, as children interacted with a static, non-responsive interface. While tablets provide valuable digital story-telling opportunities, they may not foster the same level of social-cognitive engage- ment as embodied agents.

7 Limitations and Future Directions

Despite these promising findings, several limitations of the present study must be acknowledged. First, the sample size, although adequate for a preliminary analysis, was relatively small and limited to a specific age group. Consequently, future studies should aim to include a larger and more diverse sample to enhance the generalisability of the results.

A further limitation concerns the lack of analysis of condition order effects. The relatively small sample size ($n=40$, yielding $n=20$ per order group) precluded adequate statistical power for examining whether the sequence of robot-tablet interactions influenced outcomes. Future studies with larger samples should investigate potential order effects on narrative performance and engagement.

A methodological limitation concerns the comparison between the two experimental conditions. Accordingly, the tablet served primarily as a low-interactivity control rather than a matched non-embodied interactive agent. Therefore, future studies should compare social robots with interactive digital applications (e.g., conversational agents) that provide matched feedback without physical embodiment to isolate the specific contribution of physical presence versus interactive responsiveness.

A further limitation concerns the reliance on mean heart rate as the sole psychophysiological measure. Although heart rate provided information regarding general arousal during task engagement, future research should incorporate continuous physiological signals, such as heart rate variability, electrodermal activity, and eye-tracking methodologies, which may reveal patterns of emotional and regulatory engagement not captured by aggregated measures.

In addition, engagement was assessed using observational scales filled by raters who were not blind to the study's aims, a factor that could have introduced potential bias. Moreover, although inter-rater agreement was high, the presence of experimenters and cameras may have influenced children's behavior, leading to potential observer bias. Accordingly, future research should consider employing more automated engagement-tracking methods, such as machine learning-based facial expression analysis.

Finally, a limitation of the present study is the lack of an analysis regarding individual differences. Factors such as prior exposure to technology, personality traits, or socio-emotional competencies might influence how children respond to different storytelling mediums. Thus, future research should explore these aspects to identify which children might benefit most from robot-assisted storytelling.

8 Conclusion

The present study explore the specific effect of social robots functioning as a non-verbal interactive storytelling coaches in respect to standard technological devices, such as tablets, on narrative tasks within the school setting. The results of this study suggest that social robots may foster greater engagement and narrative complexity in educational settings compared to tablets. Children displayed high engagement, reduced frustration, and more structured storytelling, both in terms of narrative structure and of psychological-narrative relationship, when interacting with a social robot, suggesting the potential benefits of a socially interactive storytelling partner.

These findings indicate that providing children with a social robot coach during a storytelling task may enhance behavioural engagement and support narrative complexity development, suggesting potential for cognitive-linguistic skill enhancement in educational contexts. Specifically, the capacity of social robots to provide embodied presence and contingent non-verbal feedback during narrative tasks positions them as potentially scalable coaching agents that may address the resource limitations constraining systematic implementation of individualized instructional approaches in standard classroom settings. Nevertheless, further investigation is required to determine the specific mechanisms through which robot-mediated coaching interactions influence narrative production and to evaluate the scalability and long-term effectiveness of such technological solutions across diverse educational contexts. Integrating social robotics into early education as interactive coaching systems could provide an innovative approach to supporting children's cognitive and linguistic development, although systematic evaluation of implementation feasibility and educational outcomes remains necessary.

Author Contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [S.S, LF, LP, EA, AB, MB, SM, CP]. The first draft of the manuscript was written by [SS, LF], and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics Approval and Consent to Participate Ethical approval was granted by the Ethics Committee of the University of Florence (No. 342 of July 12, 2024). All procedures performed in this study complied with the ethical standards set forth in the Declaration of Helsinki.

Consent for Publication Informed consent for participation and publication of data was obtained from the legal guardians of all participants.

Conflict of interest The authors declare that they have no financial or non-financial conflicts of interest to disclose.

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