"The Robot Made Us Hear Each Other": Fostering Inclusive Conversations among Mixed-Visual Ability Children

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Inclusion is key in group work and collaborative learning. We developed a mediator robot to support and promote inclusion in group conversations, particularly in groups composed of children with and without visual impairment. We investigate the effect of two mediation strategies on group dynamics, inclusion, and perception of the robot. We conducted a within-subjects study with 78 children, 26 experienced visual impairments, in a decision-making activity. Results indicate that the robot can foster inclusion in mixed-visual ability group conversations. The robot succeeds in balancing participation, particularly when using a highly intervening mediating strategy (directive strategy). However, children feel more heard by their peers when the robot is less intervening (organic strategy). We extend prior work on social robots to assist group work and contribute with a mediator robot that enables children with visual impairments to engage equally in group conversations. We finish by discussing design implications for inclusive social robots.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; **Laboratory experiments**.

Additional Key Words and Phrases: Robot, Mediator, Conversation, Visually Impaired, Inclusion

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1 INTRODUCTION

Around the world, students with disabilities are increasingly educated alongside their non-disabled peers in a practice known as inclusive education [30]. Inclusive education can have numerous benefits for students with and without disabilities, including enhanced academic achievements [6, 37], increased likelihood of employment [50, 75], and development of ethical principles [16, 26, 68, 72].

Nevertheless, recent research shows that children with visual impairment (VI) still face issues related to classroom participation and collaborative learning opportunities [45, 49]. Particularly, they face a lack of participation in a fundamental and common classroom activity: small group conversations [41, 49]. These conversations often consist up to five children engaging in a discussion about a given topic. They improve communication skills and vocabulary, promote critical thinking and perspective taking, boost interest in study topics, and help build relationships and

Fig. 1. The robot asks the least participative child to speak.

community [15, 38, 46, 71]. However, children with VI are disadvantaged when participating. It can be challenging to read nonverbal communication cues, initiate and maintain conversations, and use eye gaze to regulate interactions, resulting in lower participation and isolation [41].

Recent work in Human-Robot Interaction (HRI) has shown that robots can foster inclusion in small groups [28, 61]. For instance, Sebo et al. [61] have shown that supportive robot utterances in group conversations can encourage contributions from individuals who feel excluded. Gillet et al. [28] used a mediator robot in a music-based puzzle to facilitate the inclusion of migrant children in classrooms. Others have explored how social robots can influence group dynamics, such as group cohesion [66] or balanced participation [79]. However, little attention has been paid to groups of children in mixed-ability settings and previous mediation behaviours are not accessible by design for children with VI, for instance.

In this work, we aim to foster inclusion in a meaningful classroom activity (i.e., small group conversations) in which children with and without visual impairment share the same technology. We developed a mediator robot that encourages group members to contribute equally to the conversation while acknowledging individual participation. Designed using Shore's model of inclusion [65], it aims to meet group members' needs of *belongingness* and *uniqueness* by performing accessible mediating actions. It encourages the least active members and values their contributions through multisensory feedback (verbal, visual, motion and proximity)

Our paper addresses three main research questions: (1) What are the behavioural differences and similarities between VI and sighted children in a conversational task? (2) Can a mediator robot foster inclusion in mixed-visual ability group conversations? (3) How does a robot influence group dynamics in small-group conversations? To answer these questions, we designed two robot mediation strategies that autonomously adapt to children's speech and mediate the conversation by balancing participation. Both strategies were created and refined through an iterative design process. We evaluated the effectiveness of the mediator robot in a user study (N=78, 26 children with VI), Fig. 1, in which groups of three children between ages 6 and 14 were exposed to decision-making activities in which they needed to express individual opinions and negotiate a consensus . We used a within-subjects design with three conditions: (1) baseline - children engaged in a group discussion without the robot, (2) directive - the robot was constantly encouraging the least participative child to speak, (3) organic - the robot followed the group's natural conversational flow and occasionally prompted the least participative child to speak. We assess the influence of the robot in shaping group conversational dynamics, task performance, perceived inclusion, and perceived fairness towards the robot's behaviours. Results show that constantly encouraging the least participative child can positively balance the children's speaking time; however, children felt more heard when the robot followed their conversation flow and only occasionally intervened. The mediator robot did not influence the ratio of ideas accepted and valued by the group. Additionally, results highlight some of the risks of using mediator robots, particularly in reducing children's engagement with each other. Furthermore, children's obedience to the robot's orders can create awkward silent moments and a sense of unfairness.

The key contributions of this paper are: (1) **Inclusibo**, an accessible robotic kit designed to foster inclusion in mixed-visual ability group conversations; (2) empirical evidence and analysis of the effectiveness of the mediator robot, acting with two mediating strategies, collected from a user study with 78 participants; (3) implications for the design of mediator robots within mixed-visual ability groups. These contributions are relevant to HRI researchers that aim to facilitate inclusion and designers working towards technologies to support inclusive education. They provide the bases for designing social robots for mixed-ability classrooms.

2 RELATED WORK

We first discuss related work on inclusive education, its challenges and benefits. Then, we discuss research on child-robot interaction in educational settings. Finally, we present previous attempts in HRI to support and enhance group conversations.

Inclusive Education. Although there is an effort to have a fully inclusive education in which all children feel included and have access to the same opportunities, many children with disabilities still struggle to access effective inclusive education programs. Inclusion is not just placing children side by side in the same place, *inclusion is each child's perceived value of their unique voice, belongingness and participation in the school dynamics* [24, 25, 42, 53, 65]. Inclusive education has numerous short and long-term benefits for students with and without disabilities. For instance, students with disabilities develop stronger academic skills [6, 37], demonstrate higher levels of engagement and social skills [37, 60], and are more likely to be employed or live independently [50, 75]. Students without disabilities develop an awareness of people who look or behave differently, an increased social cognition, increased conflict resolution skills, and warm and caring friendships [16, 21, 26, 30, 68, 72].

There is a need to adapt the classroom activities and the technology so that every child feels included [53] while having in mind the associated ethical concerns [63, 82, 83]. For instance, current classroom accommodations for children with VI include a dedicated teaching assistant who sits with them through classes supporting their learning activities. Although current practices and tools (e.g. screen reader) can provide access, they are designed to be used by children with VI alone, leading to learning in isolation [8, 43]. Indeed, recent studies show that children face issues related to classroom participation and lack of collaborative learning opportunities [45, 49]. Particularly, children with VI lack engagement and participation in a fundamental and commonly used classroom activity: group conversations [41, 49]; it can be challenging to read nonverbal communication cues, initiate and maintain conversations, and use eye gaze to regulate interactions. Our work explores **technology's potential to overcome those educational and social barriers in group conversations**. It uses a robot as an accessible device to create inclusive conversational experiences.

Robots for Inclusive Education. Robots can use their physicality to assist children with VI train spatial cognition [12], learn handwriting [5, 48], and navigate [56]. Robots are especially used when there is a need for physical interaction [7, 34, 54], like tutoring physical exercises [39]. They can play different roles in schools, such as tools, teachers, tutors, or peers [13, 33, 85]. Alternatively, they have been also used to support the integration of children with Autism Spectrum Disorder, Down syndrome, intellectual disabilities and motor impairments [76]. In mixed-visual ability groups, robots can support learning activities and social interactions. For example, they can provide a shared workspace and enhance joint attention [11, 44]. Prior research leveraged robotic devices to support mixed-ability computational thinking learning [12, 45, 55, 57, 58, 78, 80], and playful classroom activities [3, 44, 49].

However, most research primarily focus on dyadic interactions outside the classroom. Schools are demanding new technologies to allow full participation in the class, regardless of children's abilities. Namely, small group conversations are often used in classroom activities [15]. The most extrovert and knowledgeable learners often dominate the conversation, while children with VI or shyness may be reluctant to speak at all [29, 81]. The lack of participation can

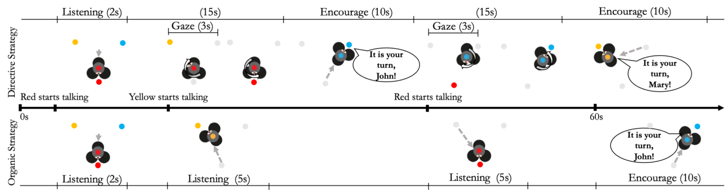

Fig. 2. Illustration of the directive and organic strategies. A new speaker is suggested every 15s and 60s for directive and organic, respectively. The directive one stays close to the suggested speaker while the organic one is closer to the actual speaker.

compromise group performance and reduce the commitment of team members [14, 59, 65]. The potential of robotic devices to foster balanced conversations in mixed-visual ability classrooms remains, so far, unexplored. In this paper, we investigate how **social robots as engaging agents** can **mediate mixed-visual ability group conversations, allowing children to express their ideas**.

Robots in Group Conversation. Robots can influence the conversation flow by directing attention to a specific group member, signalling turn-exchange using sounds [18], gaze and head pose [1, 27, 70], and proxemics [9, 10]. They can drive participation [28, 69, 79], distribute resources [19, 22, 23, 35], or influence group behaviour [74]. For example, robots can balance participation by encouraging the least participative group members [79], asking directed questions [69, 70], gazing the least expert-matter participant [27] or praising [62].

Robots' social behaviours can also negatively and positively impact human interpersonal relationships. When social robots adopt an unfair resource distribution strategy, they can negatively influence group members' interactions [35]. On the other hand, robots reduce human conflict in verbal discussions by emotionally reacting to the tone of the conversation [31]. More recently, research has shown that one can trigger prosocial behaviours in humans previously ostracised by robots [22, 23]. Additionally, social robots can also improve team's problem-solving performance [35, 36, 79] and group cohesion [17, 51, 67].

Prior research also investigated the influence of robots on groups of children. Social robots were able to manage children's conflict [64], improve collaboration, perceived belongingness [73, 74], engagement [2], and caring [77] in group activities. Gillet et al. [28] used a mediator robot alongside an audio-puzzle task to help the inclusion of outgroup children in schools.

Research has demonstrated that autonomous robots can influence social dynamics and interpersonal relationships. However, little attention has been paid to groups of children in mixed-ability settings. By proposing **new inclusive mediation behaviours for a social robot**, this work aims to open new avenues toward more balanced participation in children's conversations.

3 INCLUSIBO, AN INCLUSIVE ROBOTIC KIT

We designed **Inclusibo**, an accessible robotic kit that mediates small-group conversations between children with mixed-visual abilities. Inclusibo consists of a mainstream robot, speech sensors to estimate participation among children, and two mediating strategies. The prototype aims to foster group inclusion by engaging the least participative speakers in the conversation, either with a directive or organic strategy.

Hardware and Software. Inclusibo uses a Dash robot [40] that can move on the floor. Dash was chosen due to its size, feedback capabilities, cost-effectivenes, and robustness; we wanted children to be able to manipulate the robot and hear its movement. Each child wears an Agptek lavalier microphone to capture their speech. We rely on a computer to connect to the microphones and the robot. The communication is achieved using a Bluetooth library - Bleak - while the auditory output is controlled via a python library - SimpleAudio. To sense the children's conversations, we use the python voice detection module by Gillet et al. [27] with adaptations to handle children's voices and their idle speech. Each microphone is calibrated in the speech detection module to avoid detecting breathing, other child's speech or general noise. The detection module measures children speaking time in real-time and informs the behaviour module about the current least participative child.

Robot's Mediation Strategies. Inspired by [79], we designed four actions for the robot. Those actions were inclusive and used lights (frequently perceived by people with VI), sound (speech and dash motor noise) and movement. 1) the **encourage** action prompts the least participative child to speak by moving closer to them (it takes around 10 seconds, if it is near another child), calling by their name, and changing the lights according to the child's predefined colour (red, yellow, or blue); 2) the **gaze** action in which it looks to the speaker, for three seconds, to show interest using head movements (and associated motor noise); 3) the **listening** action is a more explicit version of engagement, in which the robot moves closer to the current speaker and changes its lights to the child's colour to signal interest; and 4) the **praise** action in which it aims to praise the speaker through head nods and audio backchanneling ("mmm") for one second. Then, we defined two mediation strategies: the directive and organic strategies, combining the previously described actions. In Fig. 2, we illustrate the different strategies.

In the **directive mediation strategy**, the robot uses a more intervening strategy and tries to balance children's speaking time frequently; i.e., after 15 seconds of being near a child, the robot performs an **encourage** action to the child who had spoken the least overall. Based on this strategy, we conducted several pilot tests with seven adults, one with VI, to tune all actions and their duration times. Although the directive strategy showed promising results in balancing conversations, it also could create discomfort when the robot encouraged the same speaker frequently or only once. Thus, we devised and refined an organic strategy to reduce these potential negative effects.

The **organic mediation** uses a less intervening strategy by allowing the robot to follow the children's natural speech flow and occasionally encouraging participation. Whenever a new child starts to speak, a **listening** action is triggered (after 3s), and the robot moves closer to the speaker. Every 60 seconds of organic speech, Inclusibo evaluates who is the least participative speaker and performs an **encourage** action for 20 seconds to prompt them to talk; after, the system starts counting another 60 seconds of organic speech. In both mediation strategies, whenever someone starts to speak, the robot will wait for 0.5 seconds and then **gaze** to the speaker; the robot will also **praise** every speaker after a 4-second speech once per turn. In an idle speech situation (silence for more than ten seconds), the robot will **encourage** the least participative speaker; if they do not start to speak, the robot will encourage another child. Finally, we conducted a pilot study with 42 sighted children, in groups of three, to tune the voice activation module, and validate the user study procedure.

4 USER STUDY

We investigate how **Inclusibo** can support inclusive small-group conversations in mixed-visual ability groups. Specifically, the user study assesses how different mediation strategies affect group inclusion. Briefly, in the directive strategy, the robot constantly mediates the conversation by encouraging the least participative child to speak every 15s; in organic, the robot follows the natural conversational flow and occasionally (every 60s) encourages them. We expect both strategies to positively affect the participation unevenness compared to a baseline without the robot. Nevertheless, the organic strategy is expected to be perceived as more inclusive than the directive strategy, as children control when to speak, which makes them feel their voices are more valued.

Study Design. The study had three independent variables in a mixed design. The **mediation strategy** was manipulated as a within-subjects factor with three conditions: *Baseline*, children played an activity without any robot; *Directive*, the activity included a mediator robot with the directive strategy; and *Organic*, the activity had a robot that follows children's flow and only occasionally mediates. The second and third conditions were counterbalanced, while the baseline characterises children's initial group dynamics.

The second independent variable was children's **visual acuity**. All groups were composed of two sighted children and one child with VI. As a result, we used this independent variable with two between-subjects levels, sighted and visually impaired. This independent variable was not used for the analysis of group measures.

The last independent variable was the **group's baseline participation balance**, which was split into two between-subjects levels: balanced and unbalanced groups. We classified a group as unbalanced if one of the children talked more than 50% of the time and classified the group as balanced otherwise. Based on these criteria, we had 12 unbalanced and 14 balanced groups.

Participants. We recruited 78 children, 40 girls and 38 boys (ages 6 to 14), in 26 groups of 2 sighted children and one child with VI (M=9.35 SD=2.06) from the same class in 9 mainstream schools. The teachers formed the groups, sometimes they choose a specific student or ruffle, depending on the class and children's dynamic. Children self-reported their familiarity with their peers in a 7-point scale ($M = 4.77, SD = 0.65$) [4]. Our institution's ethics committee approved the research protocol, and the legal guardians signed consent forms. Children's teachers informed us of their visual acuity based on professional diagnosis categorised into 4 levels [52]: low (G3, G11, G17, G20, G22, G24), medium (G12, G18, G19), high (G1, G2, G4, G6, G7, G15, G23), and blind (G5, G8, G9, G10, G13, G14, G16, G21, G25, G26). Only G9 and G21 did not perceive lights. All children agreed to participate and could quit at any time.

Group Activities. During the session, the groups completed four activities. The goal was for each group to engage in a debate activity through verbal discussion and reach a consensus. We chose activities considering children's age range and adequacy to the classroom. Activities required children to analyse possible options and make a joint decision. Before the session, we asked children to individually engage with these activities and provide an answer via the questionnaire. The first, third and fourth activities were counterbalanced and focused on similar decision-making subjects: deserted island, spaceship, and air balloon, inspired by pedagogical activities [15]. On the deserted island activity, children had to decide one object they would take to a deserted island between the three objects they had chosen while answering their questionnaire. In the spaceship activity, children had to choose five people to live on another planet from the eight options: a 30-year-old female musician, a 60-year-old male politician, a 40-year-old policewoman, a 23-year-old student, a 32-year-old female teacher, a 35-year-old male doctor, a 6-year-old girl, and a 10-year-old boy. We presented them with dolls representing each person as a visual and tactile aid. In the air balloon activity, they had to choose which person or character would go on a trip with them. The second activity used only for training was always about which cartoon/tv series they would choose to see together.

Procedure. We conducted the sessions in the schools' library, which took 45 minutes. Two researchers were present and were responsible for setting up the equipment and guiding the children throughout the study. There were three separate tables with the questionnaire, a Hanoi tower, and three dolls in red, yellow, and blue . A separate area with three pillows (red, yellow, and blue) for the children to sit facing each other, a microphone for each, a computer, and four cameras (one per child and for the robot).

Children arrived, were guided to separate tables (where their peers did not hear or see their answers) and assigned a colour. The researchers asked the questions and gave them dolls to aid them in answering. The first part of the individual questionnaire asked children how they related to each other, adjusting the seven-scale inclusion scale to a tactile questionnaire [4]. They placed the dolls on the scale representing how they related to the other children in their group. Then, we collected their individual answers about the four activities described.

Afterwards, the group gathered for the activities sitting on their colour pillow and facing each other. Before the activities, the researchers calibrated the microphones. The first activity was the baseline condition. Then, researchers introduced the robot and the training activity (in which the robot randomly applied its different actions) to familiarise children with the device and its four actions. In the third and fourth activities, while children debated, the robot followed either a directive or organic mediation strategy in a counterbalanced order between groups. The researchers scaffolded their interventions to promote discussion in idle times or reminded them of their pre-activity choices.

After each robot condition, children answered individual questions about how they felt using the robot and within the group. Children used a tangible version of a five-point Likert scale (zero circles for never, and four for always), and a doll to represent themselves in the inclusion-exclusion continuum [25].

Measures. Our measures focus on team inclusion in a conversation and map into three categories: 1) Objective individual measures, 2) Objective group measures, and 3) Children's subjective perceptions.

Objective individual measures. These measures were coded based on the video and audio recording and, when needed, normalised by the activity duration, i.e. the time the children took to reach a decision. The **generated ideas** is the normalised count of each child's creative moments [84]. The **accepted ideas** is the number of each child's ideas included in the group's final decision [47]. The **speaking time and turn** are the normalised duration and counts when a child speaks [47]. The **praising and being praised** are the normalised counts when a child gave or received verbal positive reinforcement [29, 79]. Our **engagement** measure is the normalised time that each child spent in an engagement behaviour speaking and listening to the conversation (not distracted with something else) [29]. The **gaze to the robot** and **gaze to the group** are the normalised time each child was looking at the robot or the group, respectively. Additionally, **individual deviation** of a measure is the difference between each child's value (of speaking time or accepted ideas) and their group's average [79].

Objective group measures. These measures were obtained based on the previously described individual deviation measures. **Group unevenness of speaking time and accepted ideas** are the sum of the absolute value of individual deviations of each group for speaking time and accepted ideas measures, respectively. The group unevenness is the computed value of the group's deviation from the mean and expresses the group's balance of speaking time and ideas accepted. Groups are more balanced as their group unevenness measures are closer to zero. The **performance time** is the activity duration, i.e. the time taken by the group to reach a decision. The **obedience measure** is the normalised number of times that each group acknowledges and obeys the robot's encourage actions.

Children's subjective perceptions. These measures are individual measures based on the questionnaires. The **proximity** measures the closeness of each child's friendship with the other group members [4] in a seven-point scale (from "I do not know them", "I know them from school", "I know them from the classroom", "We occasionally play", "We play every week", "We are always together", and "We even play outside of the school"). The perception of inclusion is built upon self-reported measures **give their opinions** and **being heard measure** answered with a five-point Likert scale to the following questions in each robot's activity. "Were you able to give your opinion" and "How much did you feel heard?". The **Inclusion-exclusion continuum** metric [25] was assessed after each robot activity. For the thematic analysis, the following counts were based on open questions and video coding, **robot's recalled behaviours**, **robot's perceived utility**, and **fairness**.

Data Analysis. We recorded circa 5 hours of activity per group; each video frame has four synchronised views of each webcam, with the children's face and the robot. The data from the video recordings was analysed in three stages. First, two coders annotated the behaviours based on uniqueness [47, 79, 84], robot impact in speaking turns [20], engagement [29], and conversational roles [47]. Coders then iterated until converging on an inter-rater reliability (Cohen's Kappa) score of 0.78. Three researchers conducted peer validation throughout the coding process.

The statistical analysis was first performed for individual measures. Whenever a main effect of visual acuity was found, we additionally computed the individual deviation from the group mean to check for group unevenness based on visual acuity. Consequently, the significant differences in the individual deviations led us to analyse unevenness of group measures. We used Mixed ANOVA Tests with the robot condition as the within-subjects factor. The between-subjects factors varied according to the dependent variable being individual-based or group-based. Individual-based analyses used visual acuity and the initial speaking balance factors, while group-based analyses only used the initial speaking balance factor. The ANOVA assumptions were checked and, whenever the sphericity was not met, we report values with the Huynh-Feldt correction. Additionally, we used a Chi-Square Goodness of Fit Test to compare children's preferences between the two robots.

Finally, we analysed the Likert scales questions (give their opinions, being heard and proximity). Those questions did not meet the normality assumption; thus, we used non-parametric tests. We used Mann-Whitney U tests to compare levels of visual acuity, and Wilcoxon signed-rank tests to compare between conditions. One researcher conducted a thematic analysis of the children's answers to open questions following a iterative inductive coding approach.

5 RESULTS

In this section, we start by analysing objective individual measures; then, we report on group measures and finish with results on children's perception of the Inclusibo. We only report the main findings; the exhaustive list of results is in the supplementary files and the code, procedure and questionnaires in a GitHub [32].

5.1 Objective Individual Measures

Generating and accepting ideas - *Although sighted and VI contributed with a similar number of ideas, children with VI had fewer ideas accepted in the group's final decision.* We first analysed the normalised number of ideas that each child contributed to their group discussion, and we did not find a significant main effect of children's visual acuity ($F(1,68) = 2.243, p = .139, \eta^2 = .032$). However, the percentage of accepted ideas for the group's final decision revealed a main effect of the independent variable visual acuity ($F(1,68) = 4.966, p = .029, \eta^2 = .068$)). The ideas proposed by sighted children were more often integrated into the group's final decision ($M = 48.3\%, SE = 4.2\%$) than those of children with VI ($M = 32.0\%, SE = 6.0\%$). Having found this effect, we additionally analysed the individual deviation of accepted ideas from the group mean, which also showed a significant main effect of visual acuity ($F(1,71) = 5.790, p = .019, \eta^2 = .075$). The individual deviation of accepted ideas by children with VI was below the group mean ($M = -.097, SE = .050$), while for sighted children, it was above the group mean ($M = .050, SE = .035$). This last result suggests that the number of accepted ideas is uneven at the group level.

Speaking time and turns - *Sighted children spoke longer in total.* We found a significant difference of children's visual acuity on the percentage of time they spoke during the task ($F(1,71) = 4.835, p = .031, \eta^2 = .064$), but no significant difference on speaking turns ($F(1,70) = 3.743, p = .057, \eta^2 = .051$). Sighted children spoke more ($M = 38.2\%, SE = 2.0\%$)) and had more speaking turns ($M = 2.40$ (per minute), $SE = .12$), compared to children with VI ($M = 30.7\%, SE = 2.8\%$ and $M = 1.98$ (per minute), $SE = .18$) respectively). Furthermore, we found an effect of children's visual acuity on the individual deviations of speaking time from the group means ($F(1,71) = 6.175, p = .015, \eta^2 = .08$), which additionally suggests that this measure is uneven in group level.

Praising and being praised - *Children were praised less in the conditions with the robot.* We analysed the number of times children praised their peers and found no significant difference of their visual acuity ($F(1,71) = .309, p = .580, \eta^2 = .004$). We found, however, a significant difference between conditions ($F(1.242, 88.183) = 7.815, p = .004, \eta^2 = .099$). Specifically, it was higher in the *baseline* condition ($M = .36$ (per minute), $SE = .12$) compared to both the *directive* condition ($M = .12$ (per minute), $SE = 0$; $p = 0.026$) and the *organic* condition ($M = .06$ (per minute), $SE = 0$; $p = 0.008$). We found similar results for the number of times children were praised by their peers, a significant main effect of the condition ($F(1.310, 92.976) = 5.061, p = .018, \eta^2 = .067$) but no main effect of visual acuity ($F(1,71) = 1.276, p = .262, \eta^2 = .018$). The only significant pairwise comparison revealed that children were less praised in the *organic* condition ($M = .06$ (per minute), $SE = 0$) compared to the *baseline* condition ($M = .24$ (per minute), $SE = 0.06$; $p = 0.033$).

Engagement - *Children showed less engagement in the directive condition.* When analysing children's engagement in the task, no significant difference was found between children with and without VI ($F(1,71) = 2.550, p = .115, \eta^2 = .035$). There was, however, a significant main effect of the group's initial balance on children's engagement ($F(1,71) = 4.902, p = .030, \eta^2 = .065$), revealing the percentage of time that balanced groups were engaged was higher ($M = 70.0\%, SE = 2.6\%$) compared to unbalanced groups ($M = 61.4\%, SE = 2.9\%$). We also found a significant main effect of our within-subjects factor on children's engagement ($F(1.625, 115.403) = 3.814, p = .033, \eta^2 = .051$). The pairwise comparisons further showed that children were less engaged in the *directive* condition ($M = 61.2\%, SE = 2.7\%$), compared to both the *baseline* condition ($M = 69.0\%, SE = 2.5\%$; $p = 0.043$) and the *organic* condition ($M = 66.9\%, SE = 2.5\%$; $p = 0.017$).

Children's visual ability also had an effect on their gaze behaviours toward the robot ($F(1,74) = 21.564, p < .011, \eta^2 = .226$) and towards the group ($F(1,74) = 5.983, p = .017, \eta^2 = .075$). Children with VI gazed on average more towards the robot and less towards the group ($M_{gaze-robot} = 30.1\%, SE = 3.0\%$; $M_{gaze-group} = 39.5\%, SE = 5.4\%$), compared to sighted children ($M_{gaze-robot} = 13.1\%, SE = 2.1\%$; $M_{gaze-group} = 55.5\%, SE = 3.8\%$).

5.2 Objective Group Measures

Unevenness of accepted ideas - *The robot was not effective in reducing the unevenness of accepted ideas.* The unevenness of the accepted ideas by the group was not significantly different between conditions ($F(2,44) = .510, p = .604, \eta^2 = .023$), nor between balanced and unbalanced groups ($F(1,22) = .330, p = .572, \eta^2 = .015$). We also did not find a significant interaction between these two independent variables ($F(2,44) = .800, p = .456, \eta^2 = .035$).

Unevenness of speaking time - *Unbalanced groups improved their speaking time unevenness in the directive condition.* There was a significant interaction effect between the condition and the group's initial balance on the unevenness of the speaking duration ($F(2,46) = 5.025, p = 0.011, \eta^2 = .179$; see Fig. 3). To understand this interaction, we ran pairwise comparisons between the condition levels on balanced and unbalanced groups separately. None of the pairwise comparisons for balanced groups were statistically significant ($p > .050$). However, for initially unbalanced groups, children showed a lower unevenness of speaking duration in the *directive* condition ($M = .319, SE = .058$) compared

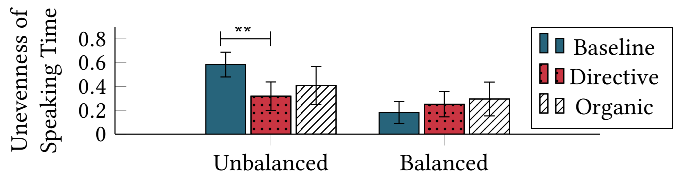

Fig. 3. Interaction effect between the robot condition and the group's initial balancing level. The plot uses the estimated marginal means with 95% confidence intervals. $^{**}p < 0.01$

to the *baseline* condition ($M = .584, SE = .051$; $p = 0.004$). The comparisons between the *baseline-organic*, and *directive-organic* were not significant.

Performance - *Both children's performance and the robot's performance were similar between conditions.* We assessed children's performance with the time they took to reach a group decision, which was not statistically significant between conditions ($F(2, 46) = 1.878, p = .164, \eta^2 = .075$). We also assessed the robot's performance by looking at the children's obedience to the suggested turn exchanges by the robot. The percentage of turn exchanges that the groups respected was also not significantly different between the two experimental conditions ($F(1, 16) = .710, p = .412, \eta^2 = .043$).

5.3 Subjective Perceptions of Children

Perception of inclusion - *Children perceive being more heard with organic mediating behaviours.* In the questionnaire, when children were asked if they could give their opinions during the group conversation, they reported similar levels in the *directive* ($M = 3.623, SE = .795$) and *organic* conditions ($M = 3.680, SE = .712$; $Z = -.515, p = .607$). However, children reported being more heard in the *organic* condition ($M = 3.564, SE = .783$) compared to the *directive* condition ($M = 3.299, SE = .947$; $Z = -2.163, p = .031$). Similarly, the inclusion-exclusion continuum was partially significant ($Z = -1.948, p = .051$), and the trend supports the same finding of the feeling heard, i.e. higher perceived inclusion in the *organic* condition ($M = 6.701, SE = .586$) compared to the *directive* ($M = 6.467, SE = .954$). Lastly, we also compared the differences on all these measures between the levels of visual acuity and no significant differences were found ($p > .050$).

Perception of the robot's utility - *Children perceive the robot as a conversation mediator.* The most frequent reported role for the robot was **a mediator** ($N = 41$), aligned with our design goal. The robot was seen as a timekeeper, turn-taking manager or enabler for expressing their ideas clearly and without overlapping. For example, *"The robot was controlling the time, so we were able to talk for some time" - Group5, yellow child, VI (G5Y-VI)* (children are denoted as *G<x><c>-<va>* x-group number, c-colour and va-visual ability); *"Robot says that it is my turn, and I will speak, and the others will not speak at the same time" (G6B-VI)*; or *"It (robot) asks us to speak, and we say what we want; otherwise it would be messy" (G9Y-S).* Children perceived the robot as acting with an **encouraging role** ($N = 3$) (e.g. *"The robot was always looking at us, it was listening to us, it wanted us to solve the activity" (G6Y-S)*; or as **problem-solver** ($N = 8$) (e.g *"The robot made us hear each other; otherwise I would just choose my ideas" (G22Y-S)*, *"The robot helped us decide because otherwise we would have a big discussion and we would not decide" (G4R-VI).* However, the robot was also perceived as useless ($N = 7$), because some children thought that they were able to do the activity without help (e.g. *"We got to the solution without help") (G12Y-S)*, *"Without the robot it would be the same" (G9R-VI, G8R-VI).* The perceived utility of the robot was similar between conditions and children's visual acuity, supporting children's equal preference towards each robot from the questionnaire ($\chi^2(1) = .229, p = .633$).

Perception of the robot's fairness - *Our mediator robot was fair; however, sometimes, children perceived it as unfair.* The mediator robot was a resource distributor- It suggested time and attention for each child. E.g. *"let everyone talk and* *say what they wanted" (G9Y-S)*; *"with the robot we were more aligned, we heard each other, and talked more about ourselves and our preferences" (G14Y-S)*. Although the robot's algorithm was computed to be fair and allocated the speaking time and attention evenly, sometimes, children did not perceive the robot as fair. Our coders annotated all children's comments about the unfairness of the robot. For each comment, researchers identified the reason behind the comment and the group reaction. Children mentioned the unfairness of the robot seven times ($N = 7$), six of them in the *directive* condition and one in the *organic* condition. Children's perceptions could be related to themselves to someone in the group (e.g. *"The robot never goes near <G13Y-VI>", (G13B-S)*, *"I pulled the robot to my side, It does not like me" (G13B-S)*, *"<G17Y-S> only talked once... " (G13R-S)*. On all these occasions, the "excluded" child talked a lot about a topic outside the activity; thus, the robot did not encourage them to talk. All children in the group felt exclusion, verbalising their discomfort and trying to get the robot's attention towards their perceived excluded peer. They overcame it by ignoring the robot and asking them to talk.

Accessibility - *The mediating behaviour of the robot was accessible to all children.* Children's accessibility challenges and robots' behaviours were coded in each session. As expected, children with VI ($N = 27$) relied on the robot's wheel sound to perceive the robot's position. Additionally, children with VI (blind $N = 9$, low vision $N = 17$) frequently had gaze behaviours toward the robot, tracking its movements. Only two out of 11 children with blindness did not perceive the robot's lights near them ($N = 2$) and used their hands instead (G9R-VI, G21R-VI). Aligned with the robot's perceived utility, children recalled that the robot asked them to speak ($N = 43$), explicitly referring to their names ($N = 10$), control the time ($N = 8$), move closer to each child ($N = 21$), looking to the speaker ($N = 17$), and changing lights' colours ($N = 8$). Regarding visual acuity, children with VI recalled the name reference more (half of the references), and sighted children referred to visual cues more often, lights' colours and looking at the speaker (80% of the references). This result corroborates the importance of verbal behaviours in children-robot interactions, especially calling by their name. The robot's gaze with an intense light was crucial as most children with VI perceive lights and shadows. It also shows the potential of proxemics as a driving behaviour for mixed-ability.

6 DISCUSSION

This study aimed to evaluate whether a mediator robot could influence inclusion in the group conversation of mixed-visual ability children, prompting them to participate equally. In this section, we answer our overarching research questions and reflect on the broader implications of using social robots for inclusive education.

6.1 Answering the Research Questions

What are the behavioural differences and similarities between VI and sighted children in a conversational task? Children with VI do not have the same opportunities to express themselves and be valued for their ideas. Even though our participants were together daily in the same classroom, analysing the results from the baseline condition (i.e., without Inclusibo), children with VI spoke less time and less often than their sighted peers. Additionally, although they generate a similar number of ideas, those are less heard or accepted. This result is in line with previous disability studies reporting that children with VI have lower levels of participation in group conversations and fewer opportunities to express their ideas [41, 53]. We build on this body of work by considering that, in our sample, children were familiar with each other ($M = 3.77, SD = 0.65$) and used to working side-by-side in their classrooms. Our findings quantify an inclusion issue in mixed-visual ability group conversations.

Can a mediator robot foster inclusion in mixed-visual ability group conversations? As expected, in unbalanced groups, the speaking duration was significantly more even in the *directive condition* than in the *baseline condition* (without the robot) (see Fig. 3). Additionally, 7 out of 12 unbalanced groups became balanced in directive condition. If the group was initially balanced, we did not find evidence that the directive robot had a (positive or negative) impact. This result suggests that the directive strategy, in which the robot was always encouraging the least participative children, effectively balanced participation in the conversation.

We did not find any significant differences between the baseline condition (without the robot) and the *organic condition*. We expected that the *organic condition*, which was more natural for children, and less stressful, still had a balancing effect on the group speech, but that was not confirmed. A possible explanation is that children did not had enough explicit encouraging actions (calls by their names) to impact this condition. Indeed, in all the groups, the decision time was short ($M = 147s, SD = 51s$). Moreover, the robot performed few encourage actions ($M = 0.81, SD = 0.64$). In eight groups out of 26, the robot did not explicitly reference any of their children's names during the organic condition.

Additionally, the robot's directive or organic strategies did not affect the participants' contributions. The differences in ideas accepted were non-significant across conditions. The flow of ideas was similar across conditions and sighted children had their voices more heard and valued. Although we did not find any impact of robot strategy on children's acceptance of each other's ideas, they felt more heard in the *organic condition*. Possibly because most of the time, the robot followed children's speech and stayed more time near the speaker in listening action.

Overall, our findings support that a more directive strategy should be used for a robot to effectively balance speaking time in mixed-visual ability settings. However, considering children felt more heard when the robot used a more organic strategy, future studies should explore less intrusive actions to improve children's perceived value and engagement. These results extend prior literature that explored social robots to balance participation in adult discussions using gaze and peripheral behaviours [27, 79]. We shed light on robotic mediating strategies that are more intervening and affect children's conversations and inclusion in group interactions. Our robot uses proximity, gaze, and referencing children's names to explore how directive or organic robot strategies drive children's conversations for a more balanced and accessible group interaction, in which children feel heard nudging their sense of inclusion.

How does a robot influence group dynamics in small-group conversations? The gaze dynamics support that children with VI relied on the robot mediation to guide the conversation and that the robot's behaviours were accessible. For instance, children with VI gazed more towards the robot because its behaviours (using lights and proximity) were easier to follow than their peers gaze behaviours. However, the robot's presence also downsized the group dynamics. First, children were less engaged in the conversation in the *directive condition* than in *organic or baseline* conditions, as the robot might have been a distraction. Second, some children waited for the robot's suggestion to start discussing and only started talking after the robot moved closer. This dependency created awkward silent moments. Third, children tended to obey the robot ($M = 60.5\%, SD = 34.9\%$), even when they thought it was unfair. In these cases, they tried to get the robot's attention towards their perceived excluded peer, and only after several attempts they started to ignore it and ask the excluded peer to talk.

6.2 Broader Implications

Our work yielded a set of reflections and recommendations that can guide the design of future robots for inclusion in small group activities. First, the **robot's mediation actions using proximity and lights and naming** each child were crucial to enable an inclusive conversation. Proximity is a non-intrusive cue that can also be easily ignored if needed. Naming children was an effective and accessible way to refer to the suggested speaker explicitly. Also, as argued in the literature [25], its positive influence on the child's perceived value (e.g. *"It is your turn <name>", "The robot knows my name, he wants to hear me" (G26Y-S))*. Second, **depending on their visual ability, children used**

different strategies to track the robot. Sighted children usually kept the focus on the speaker and used peripheral sight to follow the robot, while children with VI focused more on the lights and movement and less on the speaker. Nevertheless, children touched, played and spoke to the robot independently of their visual ability. Third, children's obedience to the robot was high. Robots can be a powerful tool to drive children's actions, but it comes with high responsibility. As we observed, **mediation strategies can lead to unintended ostracism and exclusion** [23]. Third, the **mediation algorithm based on speaking time** can create awkward situations and may not be the best option during the entire conversation. For example, in *organic condition*, sometimes children wait for the robot's instructions to speak; on the other hand, in *directive condition*, children could feel excluded if the robot does not give them the floor. An option could be to have an adaptive algorithm according to conversation duration, idle moments and unevenness of the group speaking time. The system could use balancing turns or speaking time according to the conversation phase. For instance, the robot could balance speech turns in the beginning, to prompt all children to share their opinions upfront. Then, in the middle of the conversation, the robot could use a directive strategy when the group speaking duration was uneven (otherwise, use a more organic strategy). Additionally, the time to react to idle moments, and encourage a new speaker, could be shorter to reduce the awkward silences. Overall, striking a balance between directive feedback and perceived inclusion shows to be a challenging task that goes beyond balancing participation.

6.3 Limitations and Future Work

This study included 26 mixed-visual ability groups from 9 schools in a specific country. Although results can differ in other countries, the derived insights of this study may still apply. They represent a crucial user group when designing inclusive education technologies in mixed-ability settings. Further research should conduct longitudinal studies to assess the impact of mediating strategies in the long term and explore adaptive mediation algorithms using turns and speaking time according to speech phase and group evenness. Additionally, an exciting research avenue would support children and adults with other exclusion factors to foster inclusion as a combined perception of participation, belongingness and uniqueness.

7 CONCLUSION

This paper uses a robotic device to mediate small-group conversations in mixed-visual ability settings. Our approach elicits children with and without visual impairment to participate equally in conversations, using a robot as an accessible agent that mediates the speech flow. Results show that a more intervening/directive robot can balance the group's speaking time. Additionally, all children recalled robot behaviour and perceived its utility, making our prototype inclusive and accessible to mixed-visual ability children. Although the robot's mediation strategies did not influence children's perceived inclusion, they felt more heard when the robot's mediating strategy intervened less. Overall, our user study (1) reinforced the reinforced the existence of the participation gap in conversations between mixed-ability children, (2) found support for the positive impact of our robot's mediating strategies at different levels, and (3) revealed an impact on children's group dynamics.

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