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Enhancing wayfinding in pre-school children through robot and socio-cognitive conflict

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Abstract

Wayfinding is one of the most important skills that children have to learn in order to safely move in the environment. One problem that 5-year-old children encounter with wayfinding is changing their point of view to that of another person in different position in the same environment, such as that of a person opposite them whose perspective is turned 180° with respect to their own. Robots could help children in learning this skill, since children can instruct them to move in the environment, in predetermined paths, by starting from a rotated perspective. This study compares classic socio- cognitive conflict with a human partner, but in this case with a robot partner, in order to evaluate how a specific activity (instructing a robot to perform a given route) enhances the wayfinding skills of 156 5-year-old children. Using two different robots (humanoid and non-humanoid) and two different conditions (a child and the robot and two children and the robot), the study shows that children who performed the task with the humanoid robot improved their performance significantly better compared with those who used the non-humanoid robot. Furthermore, children engaged in the Socio-Cognitive Conflict situation with another child-outperformed children in the Socio-Cognitive Conflict with robots. Finally, children with low-level performance in the pretest made the greatest improvement both in terms of moves made and time taken to complete the task in comparison with children in the High-Level Group and of the Control Group.

Practitioner Notes

What is already known about this topic

- Five-year-old children show difficulties in wayfinding, particularly as it pertains to taking the point of view of a person opposite them (rotation of 180°).
- Robots are effective tools for enhancing knowledge (eg, foreign language; wayfinding; etc.) in children.
- Socio-cognitive conflict is an effective process to enhance children's cognitive development.

What this paper adds

- Evidence to integrate robots and socio-cognitive conflict to enhance wayfinding skills in children.
- Evidence to use a humanoid or non-humanoid robot as a child's partner to solve a given task.

Implications for practice and/or policy

- Teachers may benefit from the use of humanoid and non-humanoid robots as effective tools in educational and learning activities.
- Problem-ng tasks, designed by considering socio-cognitive conflict dynamics, may be effective methods for enhancing children's skills in wayfinding.

Learning with robots

Human–Robot Interaction (HRI) is an area that involves analysis of human behavior in natural and artificial contexts (Dautenhahn, 2007). One of the hallmarks of HRI is treating the robot as an active means of supporting children as they perform tasks (Belpaeme *et al.*, 2012; Belpaeme, Kennedy, Ramachandran, Scassellati, & Tanaka, 2018; Dautenhahn, 2007; Liu, 2010). Studies with pre-school and school children have focused on child–robot interactions during computational thinking tasks (Bers, Flannery, Kazakoff, & Sullivan, 2014), creative dance (Ros *et al.*, 2014; Ros & Demiris, 2013) storytelling (Fridin, 2014), learning English (Mazzoni & Benvenuti, 2015; You, Shen, Chang, Liu, & Chen, 2006) and scientific skills such as computer programming, engineering, physics and mathematics (Benitti, 2012). As suggested by Woods, Walters, Koay, and Dautenhahn (2006a, 2006b), this specific field needs to be extended to other areas of application so that input can be derived from the use of different research methods. Starting from the paradigm of the "Robot Partner" (Dautenhahn, 2007; Jones & Castellano, 2018; Serholt & Barendregt, 2016), this paper reports a research project which uses a humanoid robot and a non-humanoid robot to support pre-school children in improving their wayfinding skills.

The main theories regarding learning with robots are related to constructivism (knowledge is active and derived from individual experiences) (Mubin, Stevens, Shahid, Al Mahmud, & Dong, 2013), constructionism (learners construct mental models to understand the world around them) (Papert, 1980), and social constructivism (human development is socially situated and knowledge is constructed through interaction with others) (Kim, 2001). Social constructivism, in particular, is central to this research as regards the concept of the Zone of Proximal Development (Vygotsky, 1978). According to this concept, children can reach their full potential by interacting with a more experienced partner, placing emphasis on the active process of social interaction. However, as posited by Inhelder and Piaget (1969) and Vygotsky (1980), learning can be initiated through cognitive conflicts that originate during social interaction. In a series of studies using socio-cognitive conflict, Doise and Colleagues (Doise & Mugny, 2013; Doise, Mugny, & Perret-Clermont, 1975; Mugny & Doise, 1978) highlighted that the conflicts induced by the cognitive centrations of partners during a problem-solving activity led children to coordinate their points of view to solve the task, and this is fundamental to produce progress in all partners. In this situation, children were asked to reconstruct the experimenter's village, which was placed on a table to their left with a rotation of 90°. The two children in the experiment were placed facing each other, so their different positions in the setting, and consequently the different information they had to solve the problem, determined the conflict because they had different points of view to find a common solution (Mugny & Doise, 1978). Mugny and Doise (1978) showed that not only children with little or no experience benefit from their partner's point of view (in accordance with the theories of Vygotsky), but also more expert children benefit from working in pairs, increasing their performance capabilities. Starting from these premises, the present study makes the assumption that a robot-partner will be able to engage a child in an authentic situation of socio-cognitive conflict and thus enhance the child's wayfinding abilities.

Wayfinding and spatial orientation in children

The present study analyzes enhancement in wayfinding competence, which consists in defining and following the path between an origin and a destination (Golledge, 1999). According to Piaget and Inhelder's studies (1967), children gradually create a flexible geometric system that helps them to represent their spatial knowledge. These mental schemas are constructed through active interaction with the environment and are related to the different phases of growth. However, other authors (Heft & Wohlwill, 1987; Hermer-Vazquez, Spelke, & Katsnelson, 1999; Spencer & Darvizeh, 1981) suggested that such schemas do not appear in specific stages of development but are always available to the child. More recently, Liben and colleagues (2013), examining the orientation abilities of children between 9 and 10 years old in a real space, showed that children who achieved the best results in a spatial orientation test were also able, in the same way, to orient themselves more effectively in real spaces.

The use of robots in child education

In a review of the applicability of robotics in education, Mubin and colleagues (2013) assume that child-cooperative learning achieves better results than individual knowledge acquisition. Thus, by assuming that a robot can take on the role of a tutor (the robot helps the child), peer (the robot supports the child), or tool (the child plays with the robot) in learning activities, this study aims to evaluate whether a robot might be a suitable partner in the learning process by comparing it with the effectiveness of cooperative learning between children.

Mubin and colleagues (2013) refer specifically to the use of robotics in education and one category they explore regards non-technical education: the robot is used as an intermediate tool in order to develop specific abilities (Highfield, Mulligan, & Hedberg, 2008). However, certain aspects, such as the most appropriate type of robot or its role, depend on the setting and the person who will interact with it. If the goal is merely to instruct the robot to perform a task, basic and low-cost robots such as Bee/Blue-Bot (https://www.youtube.com/watch?time_continue=5&v=T6SyP7Imygs) or Ozobot (https://www.youtube.com/watch?v=YbnyFCXdoxI) are recommended. By contrast, robots like Nao (https://www.youtube.com/watch?time_continue=123&v=EonsuxKyYNE) (Tanaka & Matsuzoe, 2012), Pepper (https://www.youtube.com/watch?v=oDeQCIkrLvc) (Tanaka *et al.*, 2015) and MecWilly (https://www.youtube.com/watch?v=ruf0J1QRXHE) (Mazzoni & Benvenuti, 2015) are particularly useful in enhancing abilities or acquiring non-technical knowledge such as music, spatial orientation and language (Mubin *et al.*, 2013). Some studies with children have shown that the use of a human-like robot behaving as a peer in the learning process can be highly effective (Mazzoni & Benvenuti, 2015; Moreno, Mayer, Spires, & Lester, 2001; Okita, Ng-Thow-Hing, & Sarvadevabhatla, 2009).

MecWilly and Blue-Bot: Two learning-partner robots

The present study used two robots: the humanoid robot MecWilly (Figure 1), and the non-humanoid robot Blue-Bot (Figure 2).

Two principal features characterize MecWilly: the simulation of human emotions, and the ability to interact with children in non-fixed contexts. MecWilly integrates software and sensors in order to be able to recognize human language, objects and environmental changes determined by human behavior. It is also possible to predefine its behavior and answers in order to create a structured setting like that described in this study.

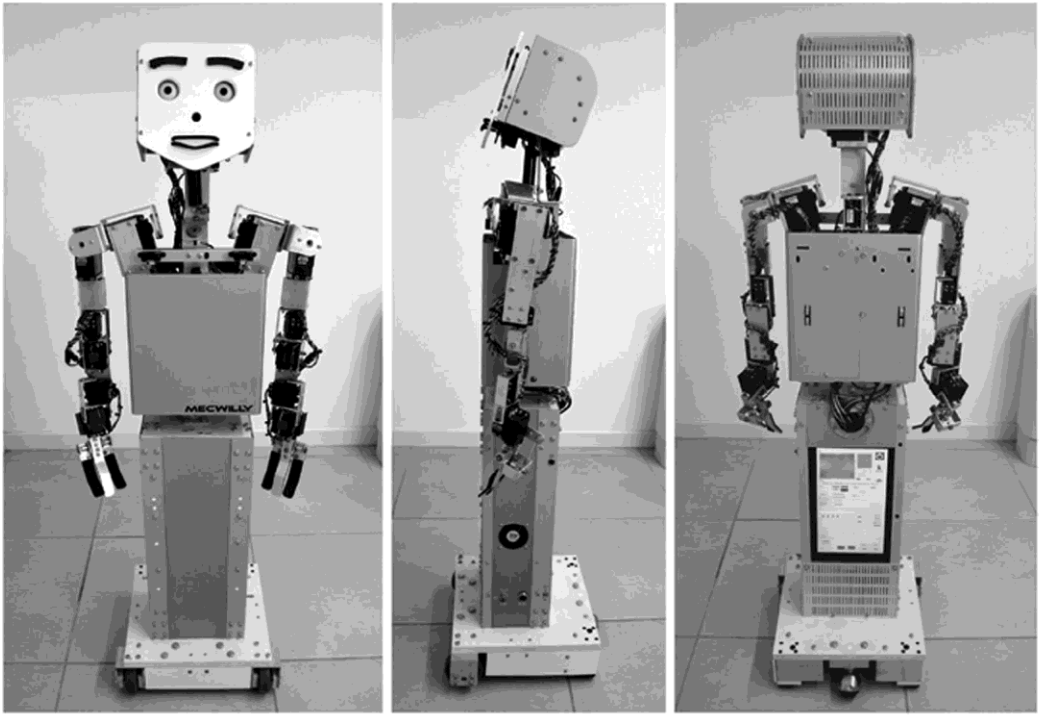

Figure 1: MecWilly the humanoid robot in original size

Figure 2: Blue-Bot, the non-humanoid robot

Blue-Bot (Figure 2) is a little robot more similar to a toy designed to teach coding, develop problem-solving abilities and analyze action sequences.

Blue-Bot has different directional buttons on its back (forwards, backwards, right and left), which allow the user to plan a route (each of Blue-Bot's movement covers 15 cm).

The external and interactive features of the two robots define the research contexts in which the two robots can be used. MecWilly is constructed to create interactive situations between child and robot for knowledge development (Mazzoni & Benvenuti, 2015), while Blue-Bot is more suited to problem-solving situations connected to a sequence of actions to facilitate knowledge development (Elkin, Sullivan, & Bers, 2016; Komis & Misirli, 2016; Komis, Romero, & Misirli, 2016).

Research hypotheses

This study aims to verify the effectiveness of robots as learning-partners for 156 5-year-old preschool children acting within their Zone of Proximal Development. Moreover, the study aims to evaluate how a specific activity enhances their wayfinding skills.

It considers the presence of two robots (the humanoid robot MecWilly and the non-humanoid robot Blue-Bot), two types of Cognitive Conflict (two children, and one child and a robot), four experimental conditions, and foresees a Control Group (Table 1):

The following research hypotheses were formulated:

H1: In all four experimental conditions, though not in the Control Group, a statistically significant improvement in the time and number of moves required to perform the task is expected from the pretest to the posttest phase.

H2a: According to Doise and Mugny (2013), socio-cognitive conflict supports learning when children are discussing the resolution of a task. If a child performs the task without taking into account the information or opinion of their partner, there will be no negotiation, and the enhancement will be less notable. Thus, as negotiation between two children should be more interactive and feature a greater number of conflicts than negotiation between a child and a robot, the two-children experimental groups (MecWilly two Children and Blue-Bot two Children) are expected to show greater posttest improvement compared to the one-child groups (MecWilly one Child and Blue-Bot one Child). This is expected both in terms of the time and number of moves needed to complete the task. Negotiation has been guaranteed in the MecWilly condition by the preset answers of the robot after the moves suggested by the children: it pushed the children to reflect on their instructions coming from different points of view and to find a common solution. On the other hand, in the Blue-Bot condition with one child, the researcher used the same answers to stimulate a decision by the child, but only in case of a standoff. Although the same procedure was provided with the two-children scenarios, it was never necessary to intervene because in the event of a deadlock on of the children took the initiative and pushed the other to make a common decision. Indeed, the robots used in this experimentation do not have artificial intelligence software that allows us to simulate child-to-child interaction. Rather, the robots interact according to preset sequences. More specifically, Blue-Bot moves on the basis of received instructions and gives final feedback (sound) upon completion of the movement, while MecWilly interacts verbally, but following a predefined and standardized protocol. These robots' characteristics make it possible to standardize their behavior to the maximum in the various conditions. This is to the detriment of the communicative unpredictability of the children that can lead to greater conflicts and, consequently, greater disputes in the coordination phase of the points of view. Based on the description of the socio-cognitive conflict, this should lead to a more evident cognitive improvement.

Table 1: Description of the experiMental conditions

ExperiMental conditions	*MecWilly robot*	*Blue-Bot robot*
One child SCC	**MecWilly + 1 child** A child individually performs a task with MecWilly. A researcher is always present, but without inter- vening, because MecWilly interacts by talking directly to the child by means of pre-configured sentences; see Appendix A. The child and MecWilly are facing each other, separated by a grid drawn on the floor, and the robot moves based on instructions received.	**Blue-Bot + 1 child** A child individually performs the task with Blue-Bot. The child and Blue-Bot are fac- Ying each other, separated by a chessboard, and the robot moves based on instructions received. Since Blue-bot does not interact by talking to the child, a researcher is always present and he/she intervenes only in case of a stand-off, using the same pre- configured dialog of the MecWilly condi- tion (see Appendix A—standoff situation).
Two children SCC	**MecWilly + 2 children** Two children collaborate to perform a task with MecWilly. A researcher is always present, but without intervening, because MecWilly interacts by talking directly to the children by means of pre-config- ured sentences; see Appendix B. The children are facing each other, on opposite sides of the grid drawn on the floor within which MecWilly moves based on the shared instruc- tions received.	**Blue-Bot + 2 children** Two children collaborate to perform a task with Blue-Bot. The children are facing each other, on opposite sides of a chess- board placed on a desk, within which Blue-Bot moves based on the shared instructions received. Since Blue-Bot doesn't interact by talking to the children, a researcher is always present and he/she intervenes only in case of a stand-off by using the same preconfigured dialog of the MecWilly condition (see Appendix B—standoff situation).
Control group	Children do not perform any tasks between the pretest and posttest. They simply participate in the pretest and, after the same time needed for the tasks with robots, they participate in the posttest. After the posttest, they have the possibility to play with the robots in the same way as the other conditions.	

H2b: Although conflictual situations arise with both types of robots (due to the disposition of children and robots), the interactive features of the humanoid robot MecWilly permit the cre- ation of a child–robot negotiation phase which would be impossible to create with the non-humanoid robot Blue-Bot. As described, the experimental groups working with MecWilly (MecWilly two Children and MecWilly one Child) are therefore expected to make greater posttest improve- ment compared to that made by the experimental groups working with Blue-Bot (Blue-Bot two Children and Blue-Bot one Child), both in terms of the number of moves necessary and the time required to complete the task.

H3: According to Doise and Mugny (2013), a learning situation that creates genuine socio-cognitive conflict leads to significant improvements in the performance of both the students par- ticipating in the situation and, in particular, of those showing less ability in the initial phase. Furthermore, following the functional organ theory of Leont'ev (1978, 1981), a technological artifact can improve human performance in the same way as other humans by acting within their zone of proximal development. Therefore, based on the median of the number of moves required to complete the task during the pretest, this study compares the improvement of the children who have achieved the highest results in the pretest

(High-Level Group) with that of the children who obtained the lowest scores in the pretest (Low-Level Group), irrespective of the robot involved in the experimental phase. The Low-Level Group is expected to make greater improvement than the High-Level Group in the number of moves necessary, and consequently in the time required to complete the task in the posttest phase.

Method

Participant

The research test involved 156 5-year-old pre-school children (80 females and 76 males), randomly assigned to the different experimental groups (Table 2). Data were collected over three months (10 sessions).

The study and related data processing was agreed with the schools and with the children's parents. The classes participated voluntarily in accordance with the teacher's joining up; in order to avoid differences in treatment within the same classes, it was decided to associate all the children from a given class with the same experimental condition. This meant that it was not possible to define a priori a homogeneous sample quantity for the various experimental conditions, although each experimental condition was then randomly associated with the various classes.

Preparation and experimental procedures

The research was carried out in the kindergartens which participated in the project. All the children were individually evaluated in a pretest phase (before the experimental activity) and in a posttest phase (after the experimental activity), and the entire procedure took half a day per each class. The setting was different in schools, according to whether MecWilly or Blue-Bot was used. Indeed, the interactive features of MecWilly allow the robot to be preconfigured for supporting children in specific and standard ways during the task, particularly as regards pushing them to reflect before giving an instruction to move the robot. For example, if the child instructs the robot to go on the left, MecWilly audibly repeats the instruction to confirm it has understood correctly. Furthermore, in case two children give different instructions, MecWilly ask them to reach a solution together and give a single command.

However, the behavioral features of Blue-Bot allow it to give standard sound and visual feedback when the robot completes the received moving instruction. Thus, the MecWilly robot can be seen as a true partner that interacts with the child (even though according to preconfigured patterns), while Blue-Bot proposes a more typical stimulus-response situation without interactive communication between the robot and the child.

Table 2: A sample of the study split by gender and experimental conditions

Robot	*Conditions*	*N (%) Female*	*N (%) Male*	*Total*
MecWilly	2 Children	22 (50.0)	22 (50.0)	44 (28.2)
	1 Child	13 (44.8)	16 (55.2)	29 (18.6)
Blue-Bot	2 Children	8 (44.4)	10 (55.6)	18 (11.5)
	1 Child	9 (60.0)	6 (40.0)	15 (09.6)
Control Group		28 (56.0)	22 (44.0)	50 (32.1)
Total	2 Children	30 (48.4)	32 (51.6)	62 (39.7)
	1 Child	22 (50.0)	22 (50.0)	44 (28.2)
		80 (51.3)	76 (48.7)	156 (100.0)

Child socio-cognitive conflict versus robot socio-cognitive conflict

The activity makes use of two general conditions for HRI. In the first, called two Children Socio-Cognitive Conflict (Two Children SCC), two children discuss a joint solution, ie, giving the correct instructions to the robot to perform the task. As previously described in the H2a hypothesis, in the MecWilly condition, the robot answers are preset and, in the Blue-Bot condition, the same answers from the experimenter guarantee negotiations by the two children. As the preset, answers stimulate the children twofold before taking a final decision and finding a joint solution from their different points of view. In the second, called one Child Socio-Cognitive Conflict (One Child SCC), a single child interacts with a robot to perform the same task. Furthermore, a Control Group was also selected, and it underwent both the pretest phase and the posttest phase, having the opportunity to play with the robot only after the posttest phase. In the one Child situation, conflict is principally determined by the need for a mental rotation of 180° of the child's point of view to give the correct instructions. In this situation, in the MecWilly condition, the robot's preset answers push the child to reflect twofold on the suggested instruction and, in case of a move in a wrong direction, the robot prompts reflection on what was wrong in the given instructions. The same is true in the Blue-Bot conditions, but by means of the same preset answers of the researcher.

The experimental phase with MecWilly and Blue-Bot

Using MecWilly required a grid to be drawn on the floor with adhesive tape (Figure 3).

The grid comprised 6 × 6 squares and measured 3 × 3 m. Recycling bins were placed in specific squares of the grid: yellow for plastic, blue for paper, gray for non-recyclable waste, brown for

Figure 3: The MecWilly experimental phase

organic waste and green for glass. All the recycling bins were similar in color and shape to those used by the children at home; in this activity they represented obstacles, as MecWilly was only able to move in the empty squares of the board.

Using Blue-Bot required a chessboard, ie, a smaller version (90 × 90 cm) of the same grid used with MecWilly (Figure 4).

In all conditions, the children had to give the robot instructions (move forward, move backwards, turn right and turn left) to place a plastic bottle into the correct recycling bin. If the child directed the robot to a space occupied by a recycle bin, the experimenter said that the robot cannot pass through the object, thus the robot stopped in front of it.

The task could be accomplished in a minimum of nine moves over a maximum time of five minutes. Five minutes was chosen after a pre-experimental phase involving children not involved in the field testing; this preliminary phase also permitted testing of the measuring instruments. During the experiment, 92.31% of the sample (156 children out of 169) completed the pretest and posttest within the maximum time allowed.

One Child socio-cognitive conflict

In the one Child SCC, the children performed the task alone with the robot (Figure 5).

The difficulty of this condition lies in the difference between the view of the child and that of the robot. The child stood next to the plastic bin, outside the chessboard, on the opposite side of the robot. Therefore, in order to properly guide the robot inside the chessboard and avoid the recycling bin obstacles, the child had to mentally turn his/her point of view 180°.

Two Children socio-cognitive conflict

In the two Children SCC, the children performed the task in pairs with the robot. The children stood opposite each other (Figure 6), perpendicular to the robot, which was located to the left of one child and to the right of the other.

In order to reach the plastic bin and avoid all obstacles, the robot had to turn toward one child and turn away from the other. Herein lay the difficulty as, in this specific situation, for one of the two children the robot had to turn right, while for the other it had to turn left. They therefore had to negotiate their solutions but, above all, turn their point of view 180°in order to understand the other child's point of view and realize that they were both saying the same thing.

Pretest and posttest

All the children were subjected to an individual pretest before the experimental tasks and an individual posttest after the experimental tasks. Those in the Control Group completed both the pretest and the posttest before carrying out the same tasks as the children belonging to the one Child SCC group or the two Children SCC group. In this way, the activity carried out would not influence the results of the posttest.

In the pretest and posttest tasks, the children sat alone opposite the experimenter, separated by a smaller version of the same chessboard, which replicated the experimental conditions (Figure 7).

The children had to give the experimenter instructions to move a robot puppet around the chessboard and achieve the same goal as that of the experiment. If the child gave instructions to move the puppet to an occupied space, the experimenter said that the puppet could not pass through the object, thus the puppet would stop in front of it. Data collected during the pretest and posttest phases were time on task (in seconds) and number of moves required to complete the task.

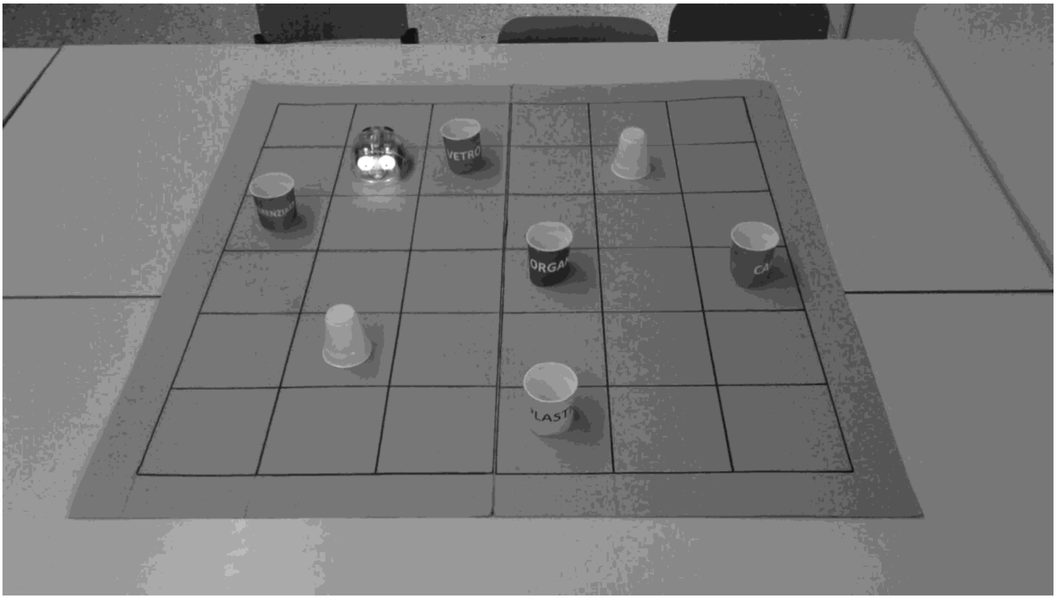

Figure 4: The Blue-Bot experiMental phase

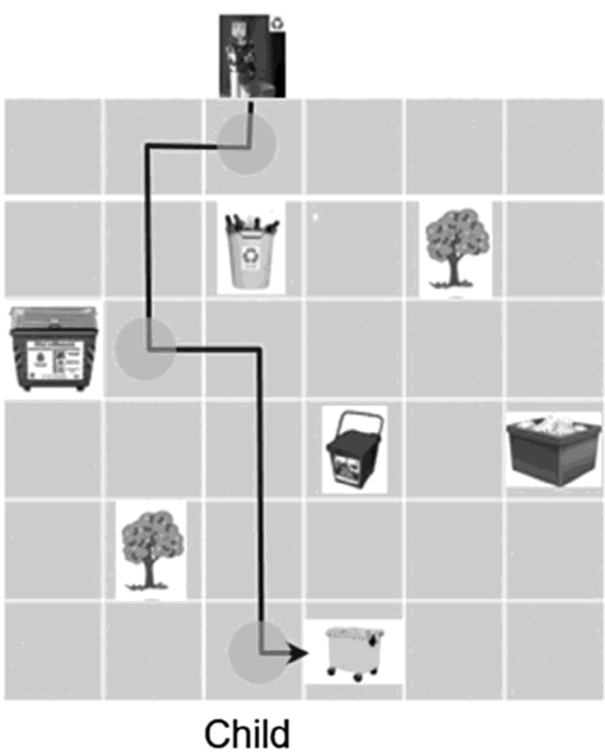

Figure 5: The MecWilly robot socio-cognitive conflict

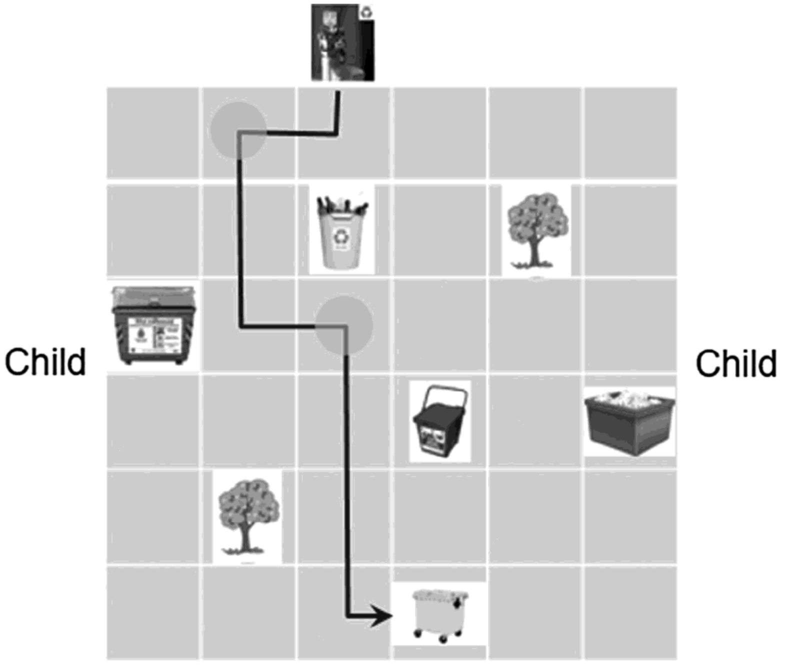

Figure 6: The MecWilly child socio-cognitive conflict

Figure 7: Pretest and posttest phases

Results

This research was designed to analyze what improvements, if any, the children achieved in way-finding when undergoing the different experimental conditions: two different robots, two different types of socio-cognitive conflict, and taking into account the skill level of the pretest.

Effect of conflict type on perforMance

Regarding hypothesis H1 (a statistically significant improvement in the time and number of moves required to perform the task is expected from the pretest to the posttest phase), Table 3 shows the differences between the pretest and the posttest, in all four experimental conditions and also in the Control Group.

The results showed a significant improvement in both the number of moves and the time required to perform the task in three of four experimental conditions (MecWilly two Children, MecWilly one Child and Blue-Bot two Children), while the experimental condition Blue-Bot one Child showed a significant improvement only in the time taken and not in the moves necessary to complete the task, just as in the Control Group.

To test hypothesis H2a (the two children SCC experimental groups: MecWilly two Children and Blue-Bot two Children, both expected to show greater posttest improvement compared to the one child SCC groups: MecWilly one Child and Blue-Bot one Child), an ANOVA with a post hoc test (Table 4) was performed by comparing:

- the two Children SCC group and the one Child SCC group,
- the MecWilly two Children group and the MecWilly one Child group,
- the Blue-Bot two Children group and the Blue-Bot one Child group,

while the Control Group was also taken into consideration.

Firstly, the results showed that there were no differences in the pretest between the experimental conditions. Secondly, regarding the SCC model, the post hoc test showed that there were no significant differences between the two Children SCC and one Child SCC conditions. However, in the two Children SCC condition, the children's performance significantly improved compared to that of the Control Group in terms of the number of posttest moves ($M_{\text{children}} = 12.27$; $M_{\text{control}} = 14.40$), the time taken to complete the task ($M_{\text{children}} = 124.24$; $M_{\text{control}} = 150.18$), and the difference in time required between the post and pretest ($M_{\text{children}} = 84.52$; $M_{\text{control}} = 46.06$). In the one Child SCC condition, the children's performance significantly improved compared to the Control Group as regards the difference in time taken to complete the task ($M_{\text{child}} = 123.36$; $M_{\text{control}} = 150.18$). Regarding the use of MecWilly, no significant difference was highlighted between the two Children SCC condition and the one Child SCC condition. Nevertheless, in the MecWilly two Children condition the children's performance significantly improved compared to that of the Control Group in terms of the number of moves ($M_{\text{MecWChildren}} = 12.30$; $M_{\text{control}} = 14.40$), in the time needed to complete the task ($M_{\text{MecWChildren}} = 126.05$; $M_{\text{control}} = 150.18$), and the difference in time required between the pre and the posttest ($M_{\text{MecWChildren}} = 88.59$; $M_{\text{control}} = 46.06$). Furthermore, the MecWilly one Child condition showed a significant difference with the Control Group, but only regarding the difference in the time taken to complete the task ($M_{\text{MecWChild}} = 117.14$; $M_{\text{control}} = 150.18$). Finally, concerning the use of Blue-Bot, no significant differences were found between the Blue-Bot two Children condition, the Blue-Bot one Child condition and the Control Group.

Effect of robot type on perforMance

In order to verify hypothesis H2b (the experimental groups working with MecWilly expected to make greater posttest improvement compared to those working with Blue-Bot), an ANOVA with a post hoc test (Table 5) was carried out by comparing the improvements made in the pretest and posttest of MecWilly and Blue-Bot in general; between the MecWilly two Children condition and the Blue-Bot two Children condition; between the MecWilly one Child condition and the Blue-Bot one Child condition; the Control Group was also taken into consideration.

Table 3: T tests and descriptive statistics of the number of moves and time taken to perform the task between MecWilly two Children, MecWilly one Child, Blue-Bot two Children, Blue-Bot one Child and the control group

	Group								
	Pretest			*Posttest*			*95% CI for Mean difference*	T	*Df*
	M	SD	N	M	SD	N			
MecWilly two Children									
Number of moves	14.95	4.377	44	12.30	2.707	44	1.223, 4.096	3.733**	43
Time (in seconds)	214.64	57.612	44	126.05	45.797	44	72.275, 104.909	10.949**	43
MecWilly one Child									
Number of moves	15.28	5.119	29	12.59	3.531	29	0.848, 4.531	2.992**	28
Time	204.93	60.771	29	117.14	55.595	29	65.694, 109.892	8.138**	28
Blue-Bot two Children									
Number of moves	14.72	4.184	18	12.22	2.415	18	0.889, 4.111	3.273**	17
Time	194.39	63.658	18	119.83	51.448	18	48.727, 100.384	6.090**	17
Blue-Bot one Child									
Number of moves	15.27	3.955	15	15.20	5.759	15	−2.845, 2.978	0.049	14
Time	180.47	65.406	15	135.40	72.817	15	19.687, 70.446	3.809**	14
Control									
Number of moves	14.94	4.838	50	14.40	3.790	50	−0.858, 1.938	0.776	49
Time	196.24	60.019	50	150.18	66.186	50	33.053, 59.067	7.116**	49

$^{**}p < .01$, $^{*}p < .05$.

Table 4: ANOVA and descriptive analysis to coмpare the different conditions of socio-cognitive conflict (SCC)

	Control group		*Two Children SCC*		*One Child SCC*			*MecWilly two Children*		*MecWilly one Child*			*Blue-Bot two Children*		*Blue-Bot one Child*		
Measures	*Mean*	SD	*Mean*	SD	*Mean*	SD	F	*Mean*	SD	*Mean*	SD	F	*Mean*	SD	*Mean*	SD	F
Pretest moves	14.94	4.838	14.89	4.289	15.27	4.707	.100	14.95	4.377	15.28	5.119	.053	14.72	4.184	15.27	3.955	.059
Posttest moves	14.40	3.790	12.27	2.606	13.48	4.526	4.864**	12.30	2.707	12.59	3.531	5.213**	12.22	2.415	15.20	5.759	2.716
Moves diff.	.54	4.921	2.61	4.321	1.80	5.083	2.656	2.66	4.725	2.69	4.841	2.886	2.50	3.24	.07	5.257	1.437
Pretest time	196.24	60.019	208.76	59.623	196.59	62.731	.776	214.64	57.612	204.93	60.771	1.124	194.39	63.658	180.47	65.406	.382
Posttest time	150.18	66.186	124.24	47.162	123.36	61.770	3.498*	126.05	45.797	117.14	55.595	3.696*	119.83	51.448	135.40	72.817	1.527
Time diff.	46.06	45.768	84.52	53.139	73.23	57.459	7.712**	88.59	53.673	87.793	58.098	9.886**	74.56	51.939	45.07	45.829	2.618

$^{**}p < .01$, $^{*}p < .05$.

Table 5: ANOVA and descriptive analysis to compare the two robots

	Control group		*MecWilly*		*Blue-Bot*			*MecWilly two Children*		*Blue-Bot two Children*			*MecWilly one Child*		*Blue-Bot one Child*		
Measures	*Mean*	SD	*Mean*	SD	*Mean*	SD	F	*Mean*	SD	*Mean*	SD	F	*Mean*	SD	*Mean*	SD	F
Pretest moves	14.94	4.838	15.08	4.654	14.97	4.027	.016	14.95	4.377	14.72	4.184	.018	15.28	5.119	15.27	3.955	.056
Posttest moves	14.40	3.790	12.41	3.041	13.58	4.458	4.604*	12.30	2.707	12.22	2.415	6.099**	12.59	3.531	15.20	5.759	2.623
Moves diff.	.54	4.921	2.67	4.738	1.40	4.380	3.117*	2.66	4.725	2.50	3.24	2.796	2.69	4.841	.07	5.257	2.141
Pretest time	196.24	60.019	210.78	58.663	188.06	63.828	1.879	214.64	57.612	194.39	63.658	1.344	204.93	60.771	180.47	65.406	.793
Posttest time	150.18	66.186	122.51	49.738	126.91	61.545	3.564*	126.05	45.797	119.83	51.448	2.978	117.14	55.595	135.40	72.817	2.439
Time diff.	46.06	45.768	88.27	55.075	61.15	50.739	10.518**	88.59	53.673	74.56	51.939	8.694**	87.793	58.098	45.07	45.829	7.094**

***p* < .01, **p* < .05.

Considering MecWilly and Blue-Bot in general, the results showed significant differences in the posttest in the number of moves made and in the time taken. Specifically, the MecWilly condition seemed to produce better performances than the Control Group in the posttest in both moves made and posttest time taken, while the MecWilly group seemed to perform significantly better than both the Blue-Bot group and the Control Group in terms of the time difference between the pre and posttest. As regards the two Children SCC condition, the MecWilly group performed significantly better than the Control Group in terms of the number of posttest moves and the difference in time, while the MecWilly group performed significantly better than both the Blue-Bot group and the Control Group in the one Child SCC condition regarding the difference in time required.

The effect on the High-Level and Low-Level Groups

Finally, H3 (children in the Low-Level Group expected to make greater improvement than those in the High-Level Group) was tested using the ANOVA shown in Table 6.

The results showed significant differences in all the variables considered in the study. Regarding pretest moves, the High-Level Group needed fewer moves to complete the task than both the Low-Level and Control Groups, but the Control Group also required fewer moves than the Low-Level Group. The High-Level Group performed significantly better than both the other groups as regards the number of moves required in the posttest, while no differences were found between the Low-Level and Control Groups.

Analysis of the time required to complete the task revealed results which were similar to those previously described for the number of moves needed: The High-Level Group took significantly less time than the other two groups in both the pretest and the posttest, while the Control Group took significantly less time than the Low-Level Group in the pretest.

Finally, the most interesting result from the research study as a whole was this: The Low-Level Group showed a significantly greater improvement than the High-Level and Control Group in the differences both in the number of moves required and in the amount of time taken to complete the task.

Discussion and conclusion

The proposed research presents a wayfinding task in five different conditions based on (1) the use of a humanoid robot and a non-humanoid robot, (2) the use of the socio-cognitive conflict with the robot as partner or with a child (in pairs) and the robot. From this point of view, the research is attributable to the second category (robot as a peer) described by Mubin and colleagues

Table 6: ANOVA and descriptive analysis to coMpare the high-level group with the low-level group

	High-level		*Low-level*		*Control group*			
Measure	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Df*	*F*
Pretest moves	11.50	1.603	18.46	3.538	14.94	4.838	2	50.628**
Posttest moves	11.46	2.762	14.04	3.806	14.40	3.790	2	10.918**
Moves difference	.039	2.758	4.42	5.083	0.54	4.921	2	15.906**
Pretest time	166.62	50.805	239.43	47.144	196.24	60.019	2	25.563**
Posttest time	105.37	45.977	141.70	54.423	150.18	66.186	2	9.332**
Time difference	61.25	43.024	97.722	59.534	46.06	45.768	2	14.705**

**$p < .01$, *$p < .05$.

(2013), ie, the use of robots as intermediate tools in order to develop specific abilities. In line with the social constructivism perspective, one of the main and general results is the effectiveness of interactions with a robot partner to develop and enhance knowledge in children.

Hypothesis H1 was partially confirmed: all groups made significant improvements in the amount of time and the number of moves required to perform the task, with the exception of the Blue-Bot one Child Group and the Control Group. These exceptions have two important implications. Firstly, from the pretest to the posttest, there is an improvement which is not determined by the experimental activities, in that it only concerns the amount of time needed to solve the task and not the quality of the solution found (ie, completing the task in fewer moves). Secondly, the Blue-Bot one Child scenario did not seem to improve the children's performance as effectively as the other three conditions using robots did. In this light, we can affirm that Blue-Bot's features do not allow the sort of child–robot interaction capable of triggering the negotiation on which effective socio-cognitive conflict is based.

The H2a hypothesis was only partially confirmed. Based on the findings of Mubin and colleagues (2013) on child cooperative learning, this hypothesis postulated that the two Children Group would achieve better results than the one Child SCC Group. The hypothesis was confirmed in general, but considering specifically the two different robots it was only corroborated for the MecWilly conditions and not for those of the Blue-Bot. A possible explanation could be found in the differences of the designed conditions and on the robots' characteristics. In the MecWilly conditions, children are separated by a large distance (more than 3 m), while in the Blue-Bot conditions they are only a meter away (either side of the table). The shorter distance in the latter conditions could have affected the different centrations of the two children who, leaning forward a little, could have a similar overhead view of the situation. The greater distance of the situations with MecWilly did not make this adjustment possible. Because, as described in the theoretical section, the difference in cognitive centrations is the third important prerequisite for interaction to produce progress in all partners, the two conditions could have differently affected the knowledge construction process.

As to the robot characteristics, the previous conclusion was further elaborated by testing hypothesis H2b, which directly compared the humanoid robot MecWilly with the non-humanoid robot Blue-Bot. The hypothesis could only be partially confirmed as there were significant differences between the two robots in general, and in particular between the MecWilly two Children condition in comparison with the Blue-Bot two Children condition. Nonetheless, the results showed that MecWilly performed very well in association with classic socio-cognitive conflict, in terms of improvement made in both the number of moves and in the amount of time required, while as far as robot socio-cognitive conflict is concerned, the two robots seemed to have similar effectiveness.

These results substantiated what had been previously highlighted concerning the interactive features of the two robots. In previous research (Mazzoni & Benvenuti, 2015), MecWilly proved to be as effective a learning partner as a human. However, considering the non-humanoid robot Blue-Bot, the results showed that the experimental condition with the robot did not provide real socio-cognitive conflict, particularly in the one Child SCC situation. As Doise and Mugny (2013) highlighted, socio-cognitive conflict should benefit learning when there is a negotiation of points of view. Therefore, interaction is a necessary but not a sufficient first step: verbal communication seems to play an essential and necessary role in achieving progress. One can deduce that the conditions using the MecWilly humanoid robot are more effective than those of the Blue-Bot, and the features of the MecWilly humanoid robot strongly influence the effectiveness of the two children condition.

Finally, hypothesis H3 was confirmed: the Low-Level Group made the greatest improvement both in terms of moves and time to complete the task compared to the High-Level Group and the Control Group. This result is relevant since it confirms the significance of the Zone of Proximal Development (and the relevance of the functional organ concept) in children's learning and in knowledge/competence construction. Since the neural/cognitive development of children of the same age and belonging to similar cultural contexts is likely to be similar, they may be expected to perform similarly in tasks such as those proposed in this study. Although environmental influences (education, schooling, parenting, etc.) can play an important role in determining the difference in the starting levels of children, their potential for improvement remains unchanged and this could explain why those with a lower initial level show the greatest improvement by the end of the experiment. From this point of view, both the socio-cognitive conflict and the robots used seem to be important in acting within the children's Zone of Proximal Development, though further studies, with broader samples of children from different cultural contexts, are needed in order to reach a deeper understanding of these dynamics.

LiMitations

Even though interesting results were obtained, some limitations were present, calling for further research. First of all, as explained in the methodological section, it was difficult to obtain quantitatively homogeneous samples. This limitation does not diminish the scope of the results obtained, however, particularly for the Blue-Bot group, further research with a quantitatively larger sample are needed to confirm the obtained results. A second limitation pertains to the contexts in which the experimentations took place. The experiments were carried out directly in the classrooms (specially pre-arranged) within the children's kindergartens. Although the contexts were very similar, since the kindergartens belong to the same organization, this may have led to a greater deficiency in the control of all the variables due to the different situations. Nevertheless, this approach ensured greater ecological validity in the study and, above all, more natural behavior in the children, which would have been difficult to obtain in a laboratory situation.

Future research will need to investigate which interactive features of robots (particularly humanoid robots) are most effective in fostering children's knowledge building. This aspect will be increasingly important from here onwards, given the rapid evolution in robotics, associated with artificial intelligence, and the construction of robots that not only react to inputs, but also learn and adapt to the interlocutor.

Practical iMplications

The three main results of the study are these. Firstly, robots seem to be effective partners for enhancing some specific skills in children, in this case wayfinding. Secondly, humanoid robots seem to perform better than non-humanoid robot in enhancing those skills. Thirdly, socio-cognitive conflict between two children and a robot seems to be more effective than socio-cognitive conflict between a single children and a robot. However, the problem-solving activities designed for the study show how teachers and researchers may benefit from the use of robots, both hu- manoid and non-humanoid, in their class activities as effective tools for enhancing skills or knowledge building. This is particularly true if the adopt activities that position socio-cognitive conflict as a method to create conflictual situations that need to be solved by integrating differ- ent and dissimilar point of views.

Statements on open data, ethics and conflict of interest

The data are available through a University of Bologna repository.

This research was approved by the University of Bologna bioethics committee.

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Appendix A: MecWilly Dialogs (experiMental condition MecWilly one Child)

If the child says	*MecWilly's answer*	*If the child says*	*After the correct Move-Ment MecWilly says*
MecWilly, go right	So, I turn right… Is that correct?	**Correct answer** MecWilly, turn right **Wrong answer** MecWilly says: "Try to think about it, where should I go?" After this, the child tries to reflect and answer differently	Well done!! Now, what is my next move?
MecWilly, go left	So, I turn left… Is that correct?	**Correct answer** MecWilly, turn left **Wrong answer** MecWilly says: "Try to think about it, where should I go?" After this, the child tries to reflect and answers differently until he/she says the correct answer	Well done!! Now, what is my next move?
MecWilly, go straight on	So, I go straight on… Is that correct?	**Correct answer** MecWilly, go straight on **Wrong answer** MecWilly says: "Try to think about it, where should I go?" After this, the child tries to reflect and answer differently until he/she says the correct answer	Well done!! Now, what is my next move?
MecWilly, go back	So, I go back… Is that correct?	**Correct answer** MecWilly, go back **Wrong answer** MecWilly says: "Try to think about it, where should I go?" After this, the child tries to reflect and answer differently until he/she say the correct answer	Well done!! Now, what is my next move?

Appendix A: Continued

If the child says	*MecWilly's answer*	*If the child says*	*After the correct Movement MecWilly says*
Stand off	If you do not say anything, I do not know where to go… Please tell me if I have to go left, right, forward or backward	**Correct answer** MecWilly, follow the right direction **Wrong answer** MecWilly says: "Try to think about it, where should I go?" After this, the child tries to reflect and answer differently until he/she say the correct answer	Well done!! Now, what is my next move?
			When MecWilly arrives at the correct recycle bin: We made it… mission accomplished! Well done!

Appendix B : MecWilly Dialogs (experiMental condition MecWilly two Children)

If children say	*MecWilly's answer*	*If children say*	*After the correct Movement MecWilly says*
MecWilly, go right	So, I turn right… Is that correct?	**Correct answer** MecWilly turn right **Wrong answer** MecWilly says (respectively): "Try to think about it, where I should go?" "Try to work in out, otherwise I do not know where to go" After this, the children talk to each other and answer differently	Well done!! Now, what is my next move?
MecWilly, go left	So, I turn left… Is that correct?	**Correct answer** MecWilly turn left **Wrong answer** MecWilly says (respectively): "Try to think about it, where I should go?" "Try to work it out, otherwise I do not know where to go" After this, the children talk to each other and answer differently	Well done!! Now, what is my next move?

Appendix B: Continued

If children say	*MecWilly's answer*	*If children say*	*After the correct Movement MecWilly says*
MecWilly, go straight on	So, I go straight on… Is that correct?	**Correct answer** MecWilly go straight on **Wrong answer** MecWilly says (respectively): "Try to think about it, where I should go?" "Try to work it out, otherwise I do not know where to go" After this, the children talk to each other and answer differently	Well done!! Now, what's my next move?
MecWilly, go back	So, I go back… Is that correct?	**Correct answer** MecWilly go back **Wrong answer** MecWilly says (respectively): "Try to think about it, where I should go?" "Try to work it out, otherwise I do not know where to go" After this, the children talk to each other and answer differently	Well done!! Now, what's my next move?
Stand off	If you do not say anything, I do not know where to go… Please tell me if I have to go left, right, forward or backward	**Correct answer** MecWilly follow the right direction **Wrong answer** MecWilly says (respectively): "Try to think about it, where I should go?" "Try to work it out, otherwise I do not know where to go" After this, the children talk to each other and answer differently	Well done!! Now, what is my next move?
			When MecWilly arrives at the correct recycle bin, s/he says: We made it… mission accomplished! Well done!