Investigating mental representations in children interacting with small mobile robots

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Abstract:

This research aimed at investigating the acquisition of comprehension of a robotic system in school age children by using two different methods: concept maps and interviews. We demonstrated that concept maps are an important instrument of verification of knowledge, offering the possibility to graphically re-examine the expressed knowledge, and training children to decompose a problem (analysis) and re-compose it in a more structured way (synthesis). The interviews confirmed the subjects' ability to apply the acquired technological concepts to different contexts, showing not only a deep comprehension of the functioning of the Lego MindStorms kit, but also the reorganisation of knowledge, a critical reflection on the contents, and therefore the restructuring of mental models.

1 Introduction

In cognitive psychology the theory of mental models provides a general explanation of human thought; at its core is the assertion that humans represent the world they are interacting with through mental models, which play a central and unifying role in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life [14]. Seel [24] defines mental models as cognitive artefacts, constructions of the mind which represent, organise and restructure domain knowledge. They have a predictive and exploratory power that permits the comprehension of the methods through which we are all able to interact with the instruments of the world [21], allowing us to make inferences [4]. According to Craik [7] each subject reproduces some "*small scale models*" of reality in his/her mind, which are used to build expectations about events in the world. Moreover, the mental representation which the subject makes depends on the type of task to be accomplished and on experience, since the individual's ability to refer to his/her own experience-knowledge, to interpret events or states, so as to make sense of the surrounding world and understand how things work, comes into play. Basically, in interacting with the environment, other people and technological artefacts, individuals create their own mental models of the objects with which they interact.
Gentner and Stevens [13] identify a series of techniques for studying mental models: protocol analysis, psychological experiments, and developmental studies. Moreover, use is made of think-aloud and verbal protocols, online protocols (audit trails), problem solving and troubleshooting performance, information retention over time, observations of system use, users' explanations of systems and users' predictions about system performance, to which Card, Moran and Newell [5] added drawing. The latter is a source of clues about a person's mental representations [10] and has been used to acquire knowledge of different behavioural areas, like language [11], writing [19]; [18], identity [23], motricity [16]; [17], space

structuring [25], visual perception [2], creativity [15]; [12] and sociality [3]. According to Arielli [1] graphical representation is a cognitive instrument that allows the development of thinking modalities which are rich in content and diversified in relation to both the acquisition of new knowledge and the evaluation of what has been learned previously. Through drawings children can explore the relationships existing between the concepts represented and the properties peculiar to each object. It is because of these aspects that graphical representations become an important instrument of verification, as they reveal the type and degree of knowledge possessed with regard to a specific topic. Moreover, drawings stimulate students to practise metacognitive reflection, offering the possibility to re-examine the graphically expressed knowledge; they stimulate the generation of new ideas and the comprehension of new knowledge; they train students to decompose a problem (analysis), while the relations permit the re-composition, in a more structured way, of the different represented parts (synthesis). All these factors, together with other properties, aim at aiding the comprehension of concepts, because they are "externalized forms of thought", thanks to which knowledge, instead of being stored in the memory, is also represented and codified into external artefacts.
In the research here presented, graphical representations such as concept mapping [22] have been used as a tool to allow primary school children to reproduce the functioning mechanism of a Lego MindStorms robotic agent. At the beginning, the children participated in a series of lessons aimed at exploring robotic concepts and, in particular, the functional characteristics of the Lego MindStorms system. The first task was to represent the functioning system of a Lego robot in graphical form and, after manipulation activities, the children were asked to produce a schematic representation of the functioning of the robotic agent, indicating graphically the relationships among concepts and links [8]; [9]. These representations were used as a stimulus for interviewing them and for verifying their true comprehension of the system.
The aim of the research was to analyse the acquisition of knowledge and competences regarding the functioning of a robotic agent built using a Lego MindStorms kit in two phases, the first of which took place in a group learning context. In section 2 we describe the first phase of the research, analyzing the graphical representations realized by the subjects; in section 3, we deal with the second phase of the research, analyzing the interviews with the children after the manipulation activity. Finally, in section 4 we have discussion and conclusions.

2 First phase of the research

2.1 Subjects

The sample, made up of 39 children, 18 boys and 21 girls, between 9 and 10 years of age, attending the 4th year at the "V Circolo Didattico" primary school in Rende (Cosenza), was divided into 8 working groups. 7 groups of 5 children and 1 group of 4, were identified by letters of the alphabet (Group A, Group B, Group C, Group D, Group E, Group F, Group G, Group H).
The research was carried out in the structured context of the educative environment to which the children belonged, delimiting the research field to a specific area.

2.2 Materials

Each group was supplied with a 66cm X 96cm sheet of drawing paper and a Lego MindStorms kit. The use of a rubber and coloured pencils was permitted.
The materials also included the Lego MindStorms kit, consisting of more than 700 pieces, a micro-computer called RCX (Robotics Command System), infrared transmitters, light and touch sensors, motors, gears, the RIS (Robotics Invention System) software to program the RCX, and the building guide "Constructopedia".

2.3 Procedure

The subjects attended 8 hours of theoretical lessons about Robotics and, in particular, about the functional characteristics of the Lego MindStorms system.
Then each group was supplied with a Lego MindStorms kit to build an autonomous mobile robot; after this activity of manipulation, each group was asked to realize a concept map (a graphical method to visually represent information) about the functioning mechanisms of the Lego Robotics System, following these steps:

- deciding on the elements essential to the robot's functioning;
- drawing the chosen elements (at least one for each component of the group), indicating the name and describing how it functions;
- linking the elements according to their relationship in the functioning process.

A time limit of one hour was established: no additional information was given during the realization of the in-group concept maps.

2.4 Analysis of the concept maps

Two types of analysis of the concept maps were carried out: "structural", concerning the external characteristics of the graphical representation, and "functional", concerning the represented functional characteristics of the Lego MindStorms system. For the first analysis, a category index was selected for each level considered by Castellazzi and Nannini [6] in relation to the Machover Test [20], attributing 0 points for the absence of one characteristic and 1 for its presence. The indices examined, as indicated in Table 1 are: accuracy of the lines for the graphic level, enhancement of some elements through emphasizing procedures for the formal level, global appearance of order for the content level.

Graphic Level	Accuracy of the lines.
Formal Level	Enhancement of some elements through emphasizing procedures (position, dimension, use of colour).
Content Level	Global appearance of order (disposition of the elements in space so that the links between them are simple and visually well organized).

Table 1. Methodology of structural analysis for graphical representations.

With regards to the functional analysis, in the graphical representations the identified categories were:

- iconic representations of the identified elements or fragments of elements;
- words to indicate the type of object and sentences to describe the properties of the elements represented and of the schematised links;
- arrows to make links between the various elements of the map so as to relate the functional aspects of the represented elements.

For the attribution of a score, these elements were included in two macro-categories called "Represented elements" and "Description of the represented elements", defining for each its respective micro-categories as specified in Table 2 and taking into consideration both the congruity of the graphical representations with the topic, and the consistency of the relations.

Represented elements	One point for the correct elements represented.
	One point for the correct links represented.
Description of the represented elements	One point for the identification of the represented objects.
	Three points for each explanation of the functioning of the represented objects.
	One point for each valid link described.

Table 2. Functional analysis methodology of graphical representation.

To analyse the results obtained in the first task, the following reference ranges were established, taking into consideration the distance between the figure with minimum value and that with maximum value:

- With a score below 40 – poor acquisition of concepts.
- With a score between 41 and 50 – sufficient acquisition of concepts.
- With a score above 51 – optimum acquisition of concepts.

2.5 Results

From the structural analysis of concept maps (shown in Appendix 1), it emerged that three groups (group C, E and G) had the best results with 3 points and that only two groups (A and H) obtained 1 point in the task; group B, D and F achieved an average score. To visualize clearly these results, whose methodology was specified in the previous section, we elaborated Figure 1:

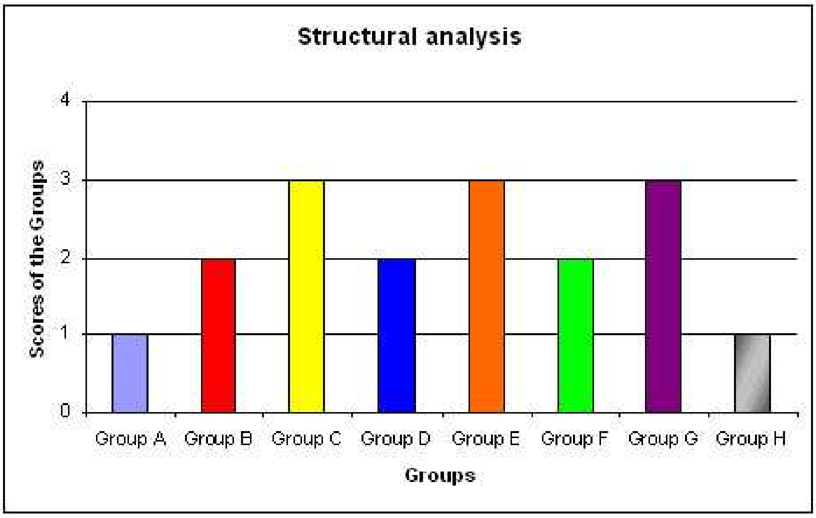

Figure 1. Scores of the groups in the structural analysis.

Regarding functional analysis, results shows that group G obtained the maximum score with 60 points, and group A, B and D achieved an optimum acquisition of concepts respectively with 53, 58 and 59 points. Group E demonstrated a sufficient learning with 43 points, while group C and H gained a border position (40 points) between an insufficient and a sufficient acquisition of the concepts. Only group F showed a poor knowledge of the topic with 32 points. With regards to the functional analysis, the score recorded by each group is highlighted in Figure 2.

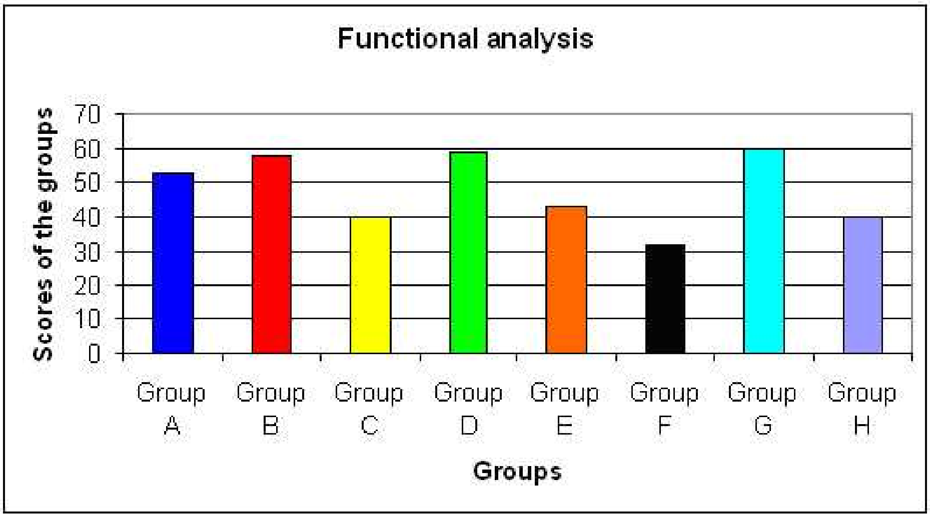

Figure 2. Scores of the groups in the functional analysis.

From the analysis of the scores (see Figure 3) recorded by the groups, it has emerged that 38% had a poor, 13% a sufficient and 49% an optimum acquisition of the concepts related to the functioning of the robotic agent.

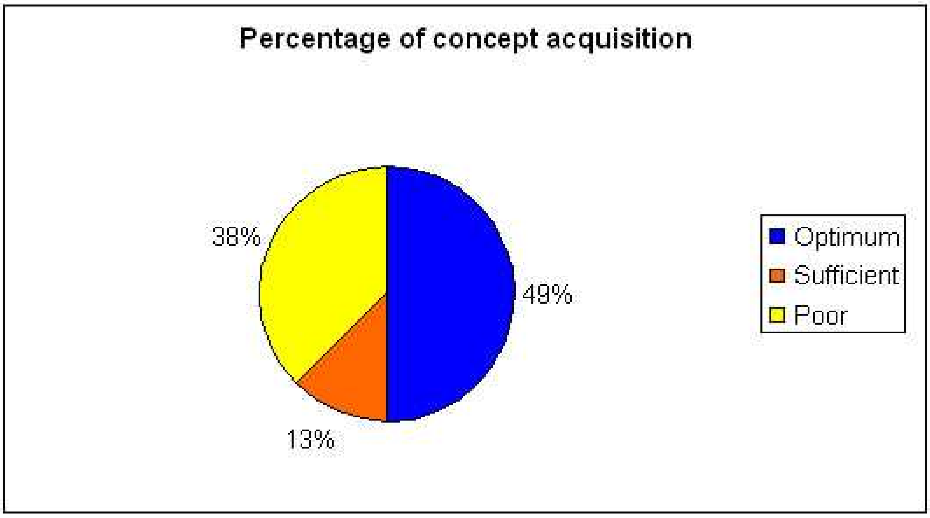

Figure 3. Percentage of concept acquisition in groups' score ranges.

From a comparison of the results obtained in the structural and functional analysis, we observed that Group G has an optimum knowledge of the functioning mechanism of the robotic agent, because it obtained the best result both in the structural and functional analysis. All other groups achieved good results only in one kind of analysis: Groups C and E had the best result in the structural analysis, but respectively a border and sufficient position in the functional analysis. Group B and D achieved an average score in the structural analysis and an optimum acquisition of the concepts in the functional one. The two groups A and H obtained only 1 point in the structural analysis, but group A achieved an optimum acquisition of concepts in the functional one, while group H gained a border position between an insufficient and a sufficient acquisition of the concepts. Group F showed an average score in the structural analysis results, but demonstrated a poor acquisition of the concepts in the functional one. These results show that, after theoretical lessons, some groups of subjects learned more accurately the concepts regarding the functioning of a Lego MindStorms robot, while others still show difficulties in representing graphically the correct elements and links of the system. Only the members of the group G show a structured mental model, because their graphical representation reflects a well-organized conceptual understanding of how the robotic agent works.

3 Second phase of the research

3.1 Subjects

The sample, made up of 39 children, 18 boys and 21 girls, between 9 and 10 years of age, and the educative area were the same as in the first phase of the study.

3.2 Materials

Each subject was supplied with a 21cm x 29,7cm sheet of paper, a pencil and a rubber.

3.3 Procedure

The subjects were asked individually to reproduce the functioning of the Lego MindStorms System in the form of a diagram, a schematic representation which defined the relationships between the Lego functional unities. These representations were used as a stimulus for individual interviews, with the aim of verifying the acquisition of participants' knowledge of the system.

3.4 Analysis of the interviews

The following criteria were selected to analyse the individual interviews: identification of those elements that allow the construction and programming of a Lego robot, identification of the modalities of connection of the elements, functional analysis of the elements, and identification of comparisons between the robot elements and everyday life phenomena or objects (Table 3). For each identified criteria, the subject recorded a point.

1) Identification of elements that allow the building and programming of a Lego robot Example: RCX, motor, gears, wires, etc.	1 point
2) How the elements that allow the building and programming of a Lego robot are connected Example: I connected the motor to the RCX by wires	1 point
3) Functional analysis of the elements that allow the building and programming of a Lego robot Example: the motor makes the wheels turn around.	1 point
4) Identification of the phrases in which one robot element is compared with a phenomenon or element in real life. Example: RCX can be considered to be the robot's brain.	1 point

Table 3. The criteria for the analysis of the interviews.

In order to analyse the results obtained by the groups in the second task, the following reference ranges were established for the first three criterions, taking into consideration the distance between the figure with minimum value and that with maximum value:

- With a score below 4 – poor acquisition of the concepts,
- With a score between 5 and 8 – sufficient acquisition of the concepts;
- With a score above 9 – optimum acquisition of the concepts.

The "Identification of the phrases in which one robot element is compared with a phenomenon or element of real life" criterion represents and additional analysis to evidence the capacity of abstraction regarding the acquired knowledge related to the functioning of the

Lego robots. Starting from the fact that it gives supplementary information, it was not included in score ranges.

3.5 Results

Regarding the individual interviews with the subjects, for the "identification of the elements which allow the building and programming of a Lego robot" criterion, 30% of the subjects scored 8 points. The lowest score, obtained by 3% of the subjects, was 2, while the maximum score, obtained by 3% of the subjects, was 12 (Figure 4).

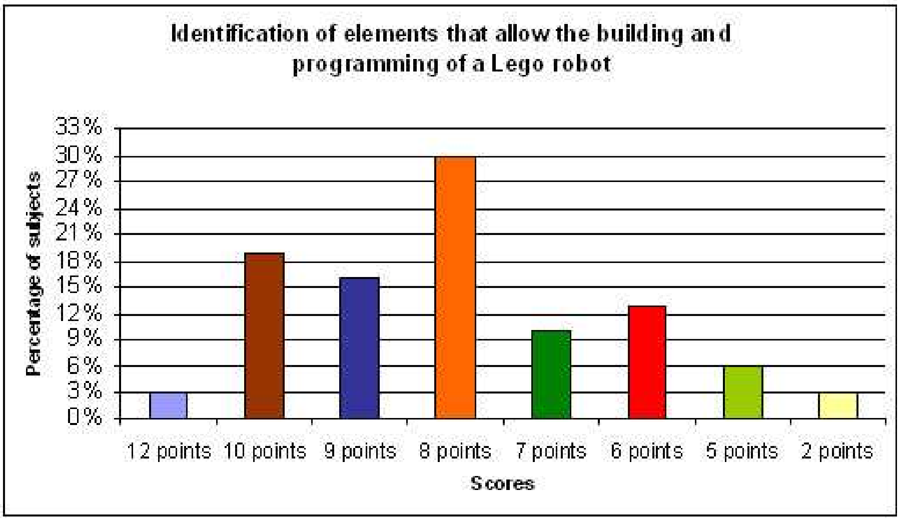

Figure 4. Identification of Lego elements.

On the other hand, for the "Connection modalities of the elements that allow the building and programming of a Lego robot" criterion, 30% of the subjects recorded 5 points. The lowest score, recorded by 6% of the subjects, was 1 point. The maximum score, recorded by 3% of the subjects, was 13 points (Figure 5).

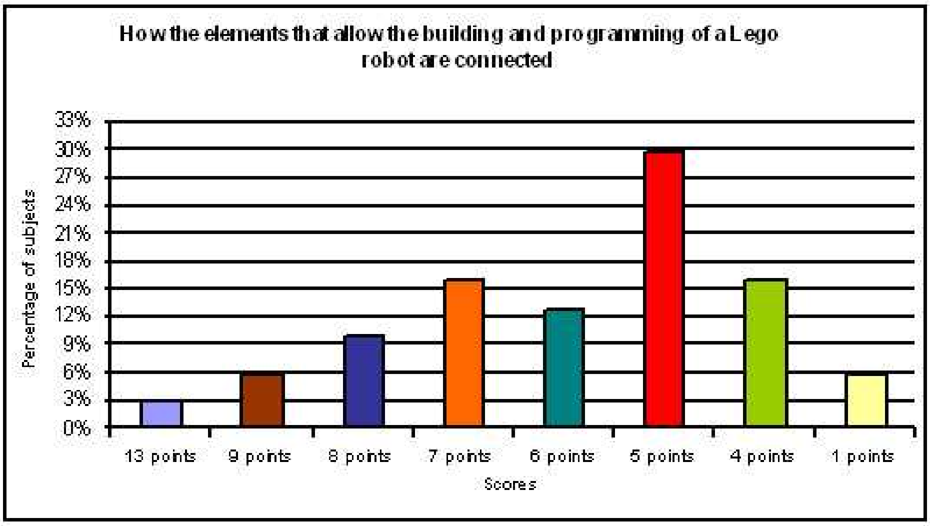

Figure 5. Connection modalities of Lego elements.

Regarding the "functional analysis of the elements that allow the building and programming of a Lego robot", 33% of the subjects obtained a score of 7, whilst the lowest score of 1 was obtained by 6%. Following this modality, the highest score, obtained by 6% of the subjects, was 10 (Figure 6).

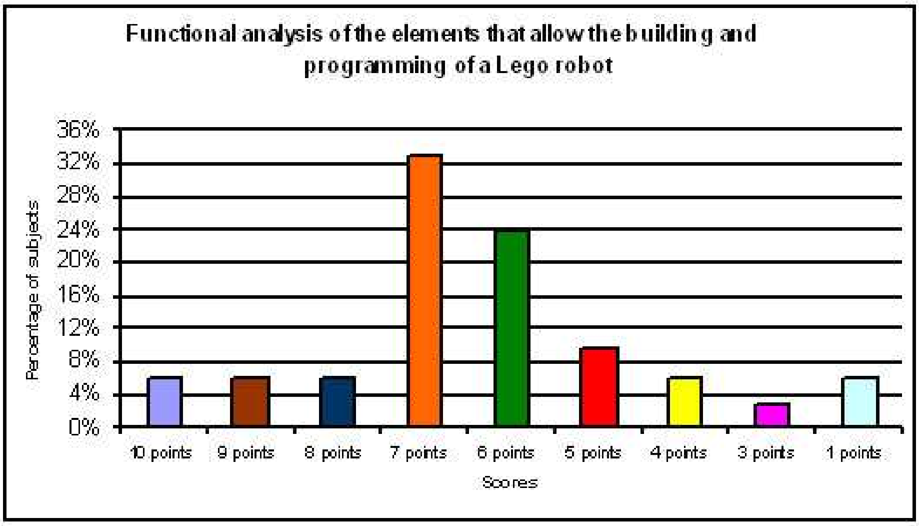

Figure 6. Functional analysis of the Lego elements.

In describing the way the Lego system works, some of the children interviewed referred both to phenomena and aspects of reality (see Figure 7). In particular, 23% of the subjects described the functionalities of some pieces using a comparison such as: "the RCX is like the brain", "the light sensors are for seeing as if they were the eyes". 3% of the subjects individuated two elements of comparison. This shows that the subjects had deeply understood the properties of specific Lego elements, trying to render their comprehension even more explicit by using references and putting together various forms of comparison.

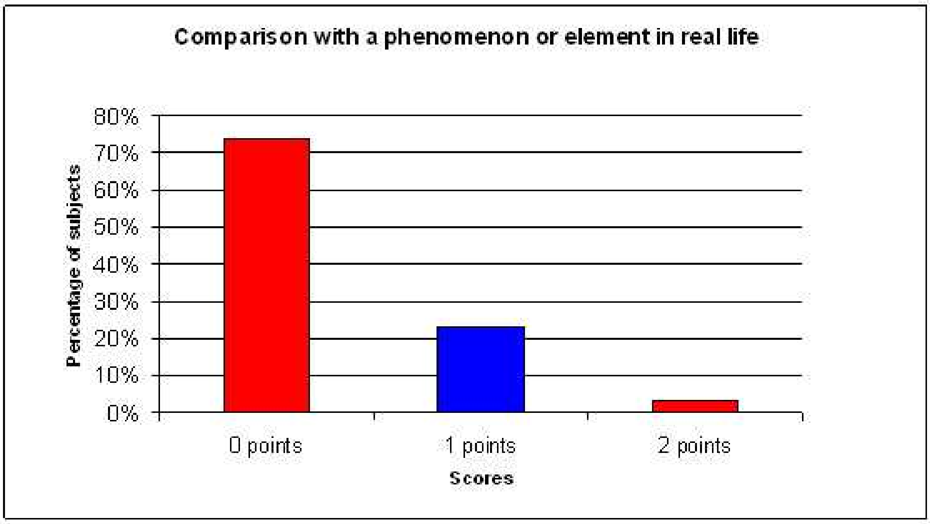

Figure 7. Identification of the phrases in which one of the robot's elements is compared with a phenomenon or an element from real life

In conclusion, regarding the "Identification of elements that allow the building and programming of a Lego robot" criterion, results demonstrated that only 3% of subjects had a poor acquisition of concepts regarding Lego system (with a score below 4), 59% a sufficient level of acquisition (with a score between 5 and 8 points) and 38% an optimal one (with a score above 9). From this analysis, the majority of subjects demonstrated the ability to identify Lego RCX, motors, light sensors and gears.
Regarding the "How the elements that allow the building and programming of a Lego robot are connected" criterion, 22% of subjects showed a poor acquisition of concepts, 69% a sufficient acquisition and only 9% an optimal one. From this analysis the majority of subjects

demonstrated the ability to specify the connections between Lego elements; for example, children connected the motor to the RCX in the robotic agent programming.
Regarding the "Functional analysis of the elements that allow the building and programming of a Lego robot" criterion, 15% of subjects showed a poor acquisition of concepts, 73% a sufficient acquisition and12% an optimal one. In particular, from the analysis of the interview, the majority of subjects correctly detected the functional parts of the agent. For example, children showed their comprehension of the robot movements management (motors linked to the RCX) and described how to realize a program in the RCX and how to download it to control the robot behaviour.
Regarding the "Identification of the phrases in which one robot element is compared with a phenomenon or element of real life" criterion, 26% of subjects showed a deep comprehension of the properties of the elements in Lego MindStorms, comparing the parts of the robotic system to some elements in real life.

4 Conclusions

This work analyses the evolution of comprehension of a robotic system in subjects of school age through two different methods, using the separate instruments of graphical representation and interview. In particular, in the first phase of the research, groups' graphical representations (concept mapping drawings) were analysed to assess subjects' familiarity with Robotics. The results shows that 38% of subjects had a poor, 13% a sufficient and 49% an optimal acquisition of the concepts related to the functioning of the Lego MindStorms robot. In the second phase of the research, we used individual interviews based on diagrams as stimulus in order to analyse not only the children's level of comprehension of the Lego mechanism, but also to acquire additional elements (explanations, comments, opinions, and so on) that it was not possible to obtain by concept mapping analysis. The main result that the data shows is that 59% of subjects identified elements that allow the building and programming of a Lego robot" criterion with a sufficient score, 69% of subjects showed a sufficient acquisition in the identification of the connections among the elements that allow the building and programming of a Lego robot. Moreover, regarding the functional analysis of the elements that allow the building and programming of a Lego robot, 73% had a sufficient acquisition of the concepts. Therefore, in general, the results show that some subjects do not show the optimal comprehension demonstrated in the first phase (49% of groups). This could be due to the fact that some children had difficulties in the use of a technical vocabulary for describing robots' characteristics (RCX, motors, sensors, and so on). In this view, the different results could be due to the use of different methodologies in the two phases (graphical representations in the first, and interview in the second): drawings stimulate students to practise metacognitive reflection, offering the possibility to re-examine the graphically expressed knowledge, stimulating the generation of new ideas and the comprehension of new knowledge, training children to decompose a problem (analysis), but also permitting the re-composition in a more structured way (synthesis). Moreover, the obtained results could also be due to the manipulation and workgroup of the first phase (collaborative learning).
Finally, 26% of subjects associated some aspects of the knowledge acquired in the field of Robotics with elements and phenomena in daily life: these results indicate that, after the manipulation and programming session, 26% of children were able to reorganize the acquired knowledge. This ability to apply the acquired technological concepts to different contexts not only showed a deep comprehension of the functioning of the Lego MindStorms kit, but also the reorganisation of knowledge, a critical reflection on the contents and therefore the restructuring of mental models.
Finally, thanks to the interview, we showed as 26% of subjects were able to associate some aspects of the knowledge acquired in the field of Robotics with elements and phenomena in

daily life: this ability to apply the acquired technological concepts to different contexts not only showed a deep comprehension of the functioning of the Lego MindStorms kit, but also the reorganisation of knowledge, a critical reflection on the contents and therefore the restructuring of mental models.

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Appendix 1: Concept Maps

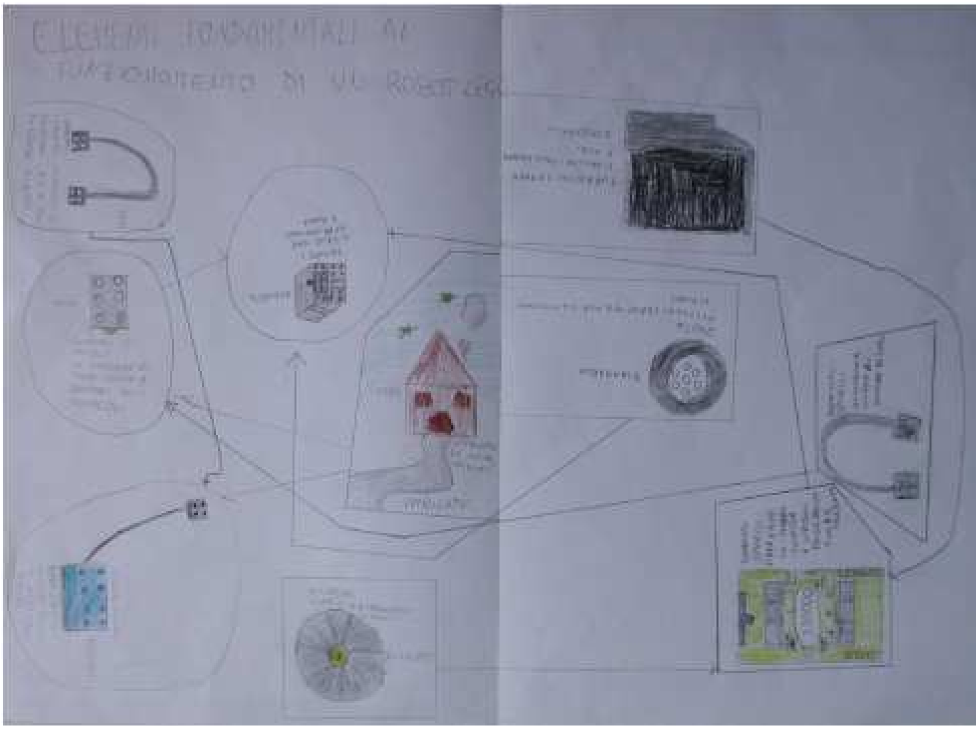

Figure 1. Group A.

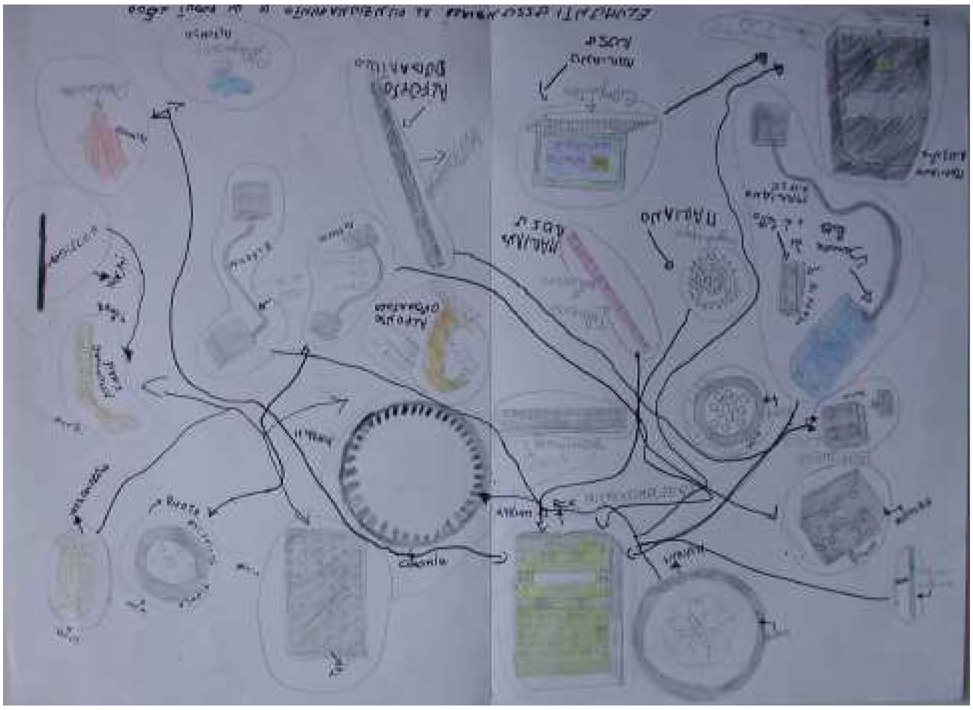

Figure 2. Group B.

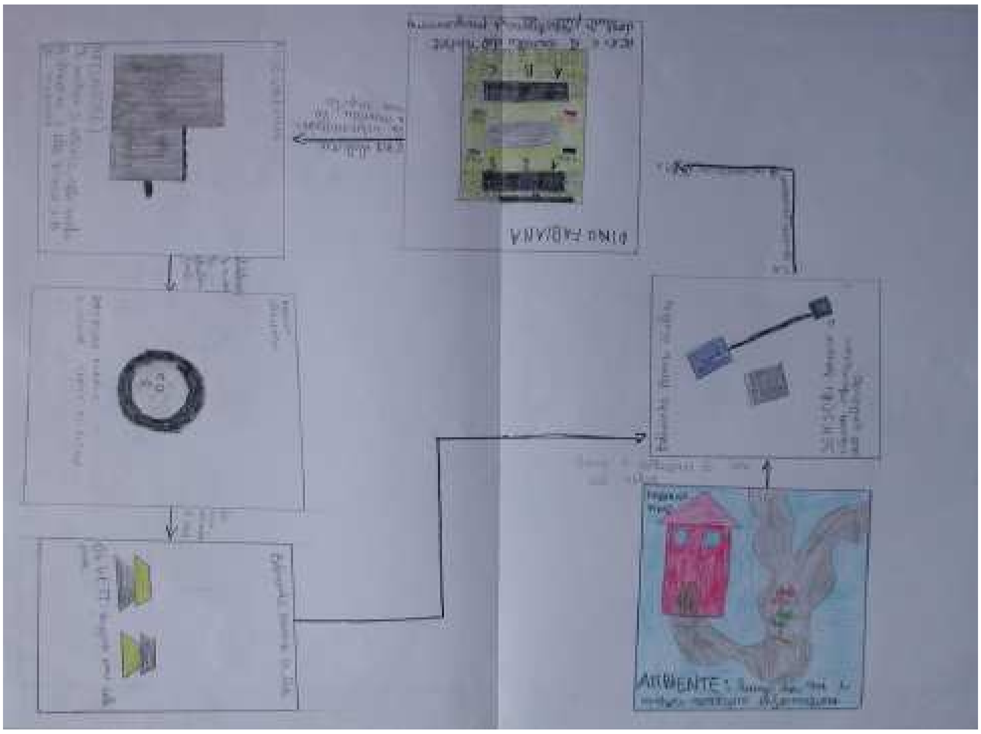

Figure 3. Group C.

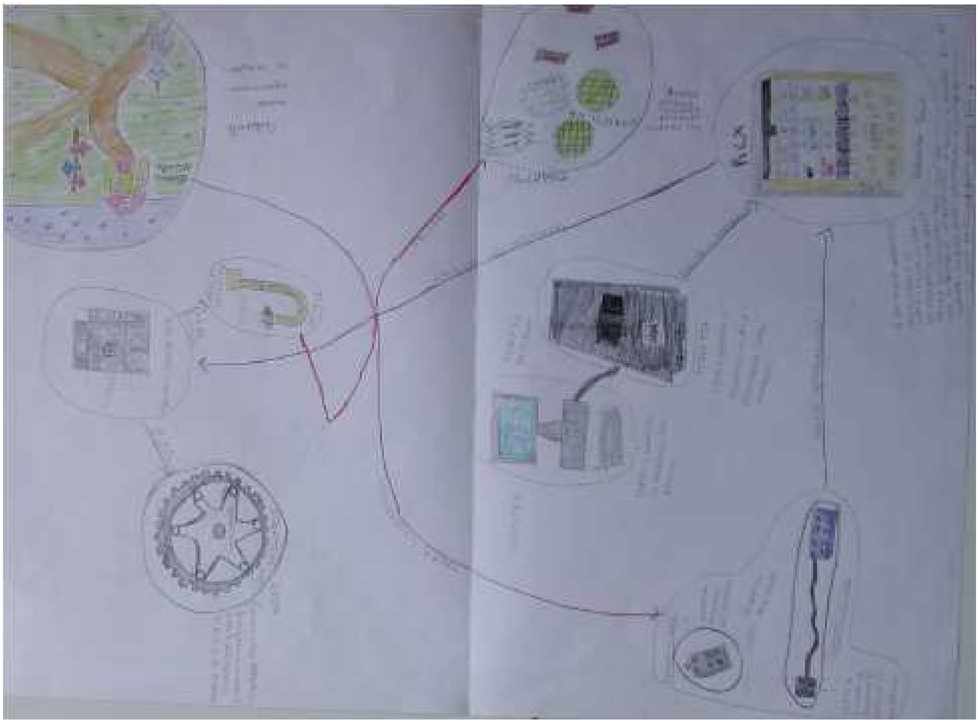

Figure 4. Group D.

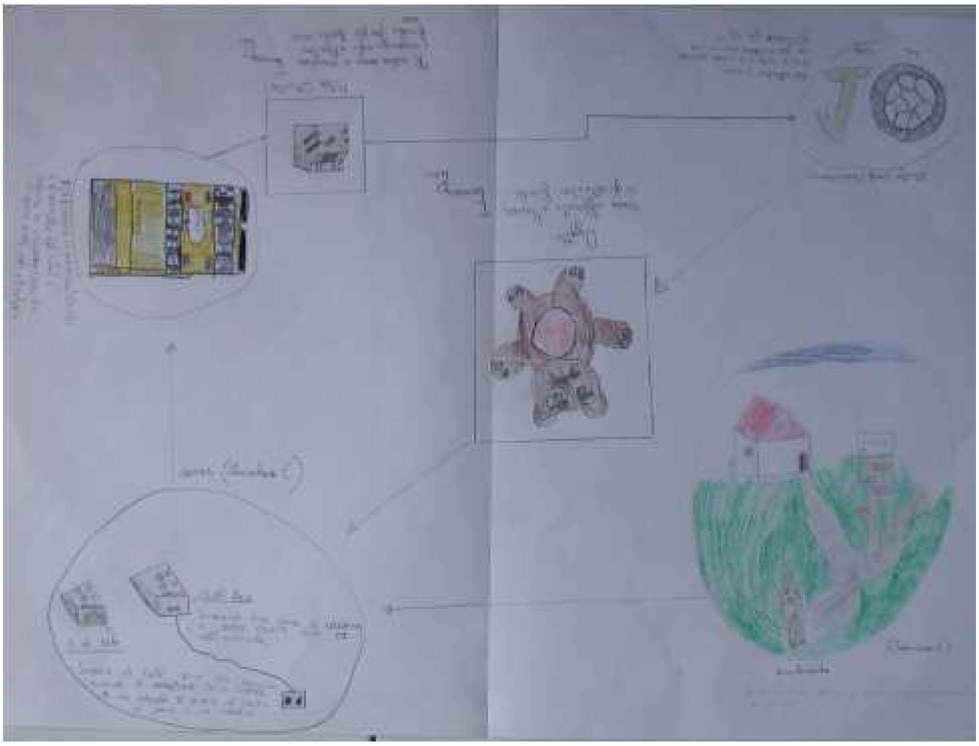

Figure 5. Group E.

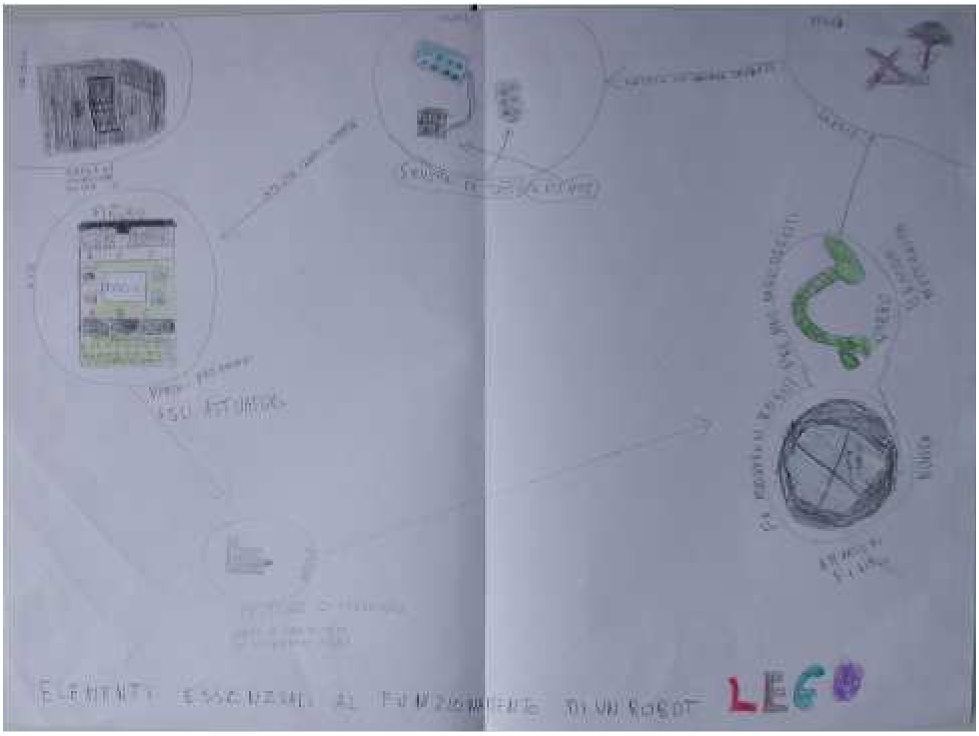

Figure 6. Group F.

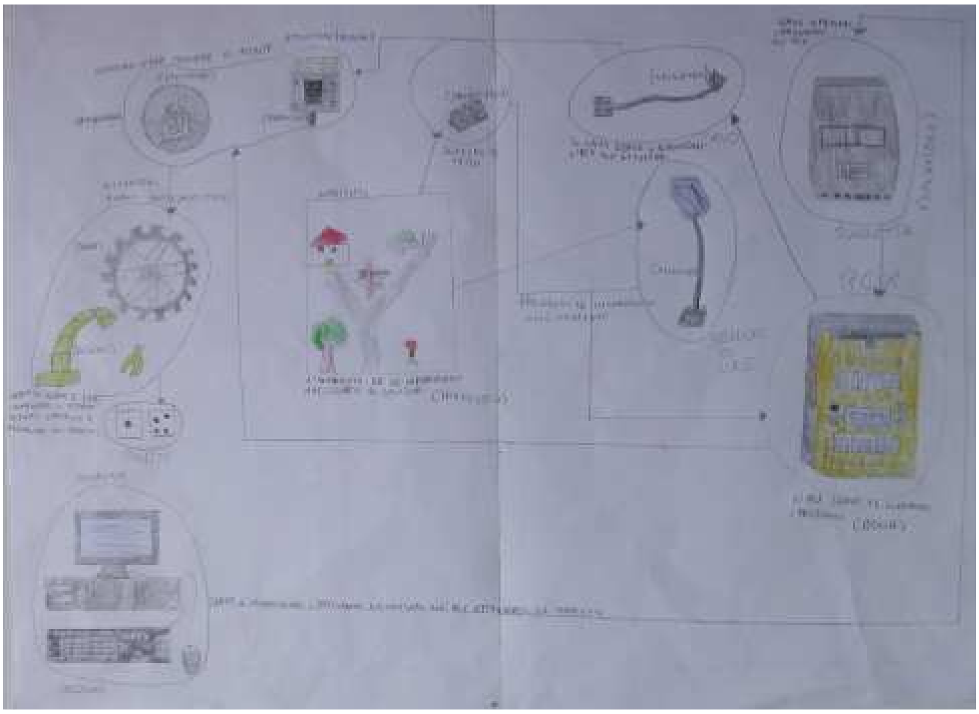

Figure 7. Group G.

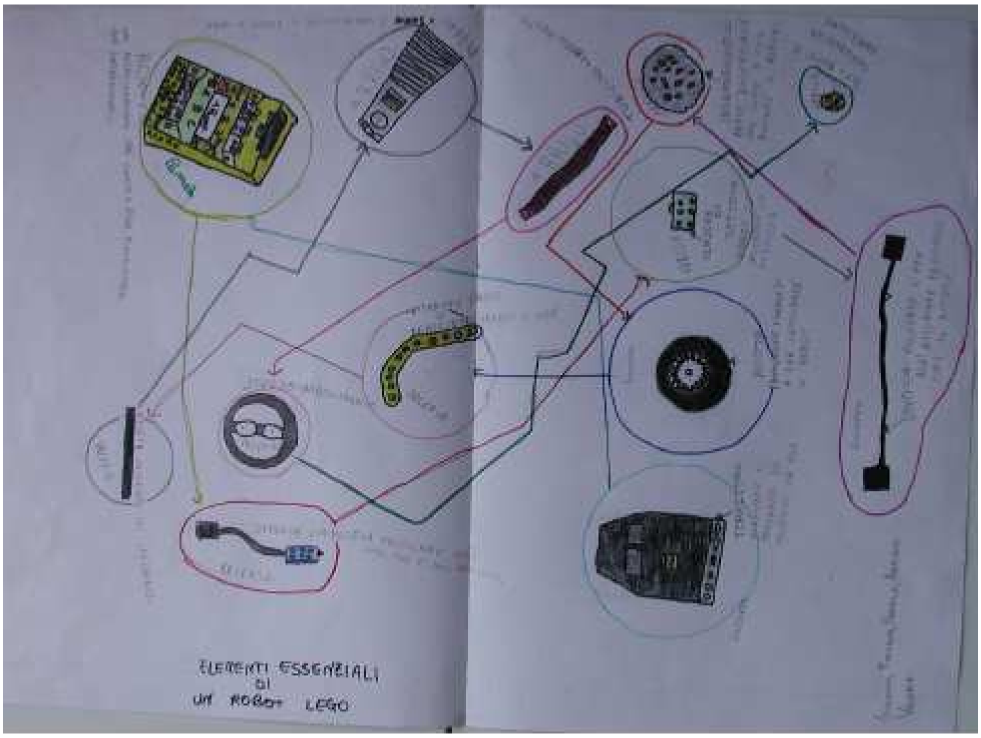

Figure 8. Group H.