DOCUMENT RESUME

ED 392 643 SE 057 '77

AUTHOR	Mason, Lucia
TITLE	Collaborative Reasoning on Self-Generated Analogies: Conceptual Growth in Understanding Scientific Phenomena.
PUB DATE	Apr 95
NOTE	35p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, April 18-22, 1995).
PUB TYPE	Reports - Research/Technical (143) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Concept Formation; *Cooperative Learning; Foreign Countries; Grade 4; *Group Discussion; *Group Dynamics; Intermediate Grades; *Knowledge Representation; *Scientific Concepts; *Thinking Skills
IDENTIFIERS	Alternative Conceptions; *Analogies; Italy

ABSTRACT

This study investigated fourth graders' (N=18) self-generated analogies and the effects of their collaborative reasoning and arguing over these analogies on individual understanding of three scientific phenomena concerning air pressure. The data were subjected to both a qualitative and quantitative analysis. The first showed that the children, on the basis of their alternative representations of what air could do, produced and used their own analogies as self-explanations both to help them learn the new material and communicate their understanding to others. Moreover, the analysis of the collaborative reasoning and arguing developed in small group discussions revealed that through steps of critical opposition and co-construction, the learners negotiated and renegotiated meanings and ideas to share a new common knowledge. The quantitative analysis showed that socio-cognitive interaction in small groups was fruitful as the children significantly progressed on an individual plane in giving their own explanations of each phenomenon as well as in recognizing the similarities between the three phenomena. In addition the qualitative data showed evidence that the children were able to exhibit metacognitive awareness of their conceptual growth. Educational implications are discussed. Contains 63 references. (Author/JRH)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED 392 643

Collaborative Reasoning on Self-Generated Analogies: Conceptual Growth in understanding Scientific Phenomena

Lucia Mason

Lucia Mason

Department of Educational Sciences
University of Padova
Piazza Capitaniato 3
35139 Padova, Italy
E-mail: edusc01@ipdunivx.unipd.it

BEST COPY AVAILABLE

Manuscript prepared for the
American Educational Research Association annual meeting,
San Francisco, CA, April 18-22, 1995

ERIC

Collaborative Reasoning on Self-Generated Analogies:
Conceptual Growth in Understanding Scientific Phenomena

Abstract

This study investigated fourth graders' self-generated analogies, that is, *own* analogies giving self-explanations - opposed to analogies provided by a teacher- and the effects of their collaborative reasoning and arguing over these analogies on individual understanding of three scientific phenomena concerning air pressure. At the beginning the children were individually asked to give their own explanations, explicitly encouraged to think of something similar which could help them to understand better what they had experienced. Then, divided in small groups they were asked to compare their accounts to collaboratively reach a shared explanation of each phenomenon. At the end, the children were again individually asked to give their explanations. The data underwent both a qualitative and quantitative analysis. The first showed that the children, on the basis of their alternative representations of what air could do, produced and used their own analogies as self-explanations both to help them learn the new material and communicate their understanding to others. Moreover, the analysis of the collaborative reasoning and arguing developed in small group discussions revealed that through steps of critical opposition and co-construction, the learners negotiated and renegotiated meanings and ideas to share a new common knowledge based on the explicitations of more appropriate analogies supporting more advanced explanations. The quantitative analysis showed that socio-cognitive interaction in small groups was fruitful as the children significantly progressed on an individual plane in giving their own explanations of each phenomenon as well as in recognizing the similarities between the three phenomena. In addition, the qualitative data showed evidence that the children were able to explicit metacognitive awareness of their conceptual growth. Finally, educational implications have been drawn.

Collaborative Reasoning on Self-Generated Analogies: Conceptual Growth in Understanding Scientific Phenomena

Theoretical framework

This study investigates the production and use of elementary school children's *own* analogies, as opposed to analogies provided by a teacher, and their collaborative reasoning and arguing on them within a socio-constructivist learning environment characterized as a community of discourse (Brown, 1995; Brown et al., 1993; Brown & Campione, 1994).

Analogy is the transfer of a relational structure from a known domain (the source) to another fundamentally similar but less known domain (the target). All the systematic approaches which explain how this mapping occurs attribute crucial importance to the mapping stage of the source characteristics into the target and to the elaboration of higher-order relations connecting the two domains (i.e. Gentner, 1983; 1989; Gick & Holyoak, 1980, 1983; Holyoak, 1985; Sternberg, 1977, 1982). Analogy is thought to be one of the fundamental methods to enhance knowledge in the processes of scientific discovery. Historical accounts of scientific insights, based on scientists' retrospective reconstruction of them, have described several examples of the potential of analogies (Dreistadt, 1968; Hesse, 1966; Oppenheimer, 1956) in the practice of science within the scientific community. A study carried out by Clement (1988) on problem solving strategies used by physics experts in an artificial setting pointed out the spontaneous use of analogies. Evidence provided by thinking aloud revealed three different methods of analogy generation: generation via a principle, generation via an association, and generation via transformation. The uselfuness of some analogies appeared to lie in the "provocative" function of activating additional knowledge schemes. This was different from the direct transfer function where knowledge was mapped directly from the analogous case to the original one. In some cases an analogy could lead to the discovery of new causal factors in the examined system and to the development of a new mental model for understanding the system.

Analogy is also valued for producing meaningful school learning understood as a generative process in which students construct relations among experiences, concepts, and higher-order principles (Wittrock, 1985). It can act as a valuable tool to teach and learn complex concepts in curricular domains (Bransford et. al., 1989; Duit, 1991; Glynn, 1990, 1991, 1994; Prawat, 1989; Stepich & Newby, 1988; Suzuki, 1994). Several empirical studies have addressed the role of instructional analogies in teaching and learning contents of different science fields. They have indicated the conditions under which analogies may be effective aids in building richer representations of new concepts by enhancing the connection of information and the elaboration of more comprehensive and integrated knowledge structures (i.e. Clement, 1989; Newby, Eartmer, & Stepich, 1994; Simons, 1984; Zook & Di Vesta, 1991). In particular, some studies have recently pointed out the success of analogy in conceptual change. Innovative research has been carried out on the effects of analogy in

ERIC

learning science concepts by taking into account students' preexisting knowledge (Brown, 1994; Joshua & Dupin, 1987; Mason, 1994 a, b; Stavy, 1991; Treagust, Harrison, & Venville, 1993). One of the most influential instructional approaches designed to use analogies to overcome learners' alternative conceptions in physics, successfully employed by Clement and his collaborators, is the "bridging analogies" approach (i. e. Clement, 1993; Brown & Clement, 1989).

It is noteworthy that research on instructional analogies has focused on analogies provided by teachers or experimenters as aids to construct and remember newly learned information. Only very recently the potential of *self-generated analogies*, that is when learners use their *own* analogies as opposed to analogies provided by an adult, has begun to be investigated. Cosgrove (1991) has analyzed eighth graders-suggested analogies in learning about electricity, domain in which a major obstacle to learning the scientific view concerns the belief that electricity is used up, so resistors are thought of as consumers of charge rather than as hindrances to its flow. Within a non direct teaching episode, the students were encouraged to propose their own analogies to deal with an aspect of electricity, the notion that moving charges are conserved. The development of a particular analogy as a part of the process of making sense of the phenomenon led to the construction of a transitional framework, that is, an intermediate position in which the conservation of current could be recognized. Zook and Maier (1994) have investigated the generation of own personal analogies as elaboration devices by analyzing the features of those analogies and the interpretations novice and expert middle school students provided for them. The results of their study demonstrated that novices often generate analogies for themselves that are superficially similar to the examples that they have already experienced. Moreover, their analogies may often fail to account the essential target-domain features, thus minimizing their effectiveness as explanatory models. Young novices are more likely to form misconceptions because of their difficulties to construct relational interpretations of analogies. However, it is noteworthy that this study did not take into account students' prior knowledge on the target science contents which could have strongly affected the production of their own analogies. Wong (1993 a, b) has investigated the self-generation of analogies as a means for advancing conceptual understanding in college students. The participants were asked to create, apply, and modify their personal analogies as a heuristic for constructing, evaluating, and modifying their own explanations for the given scientific phenomena. Remarkable changes in explanations were observed, which ranged from the creation of new ones to the raising of important questions about the nature of the examined phenomenon.

These three studies indicate that students approaching new science contents may take advantage from the systematic production and application of their own analogies. Self-generated analogies can be seen as a kind of self-explanation produced to integrate new information into existing knowledge, which according to the recent research carried out by Chi and collaborators (1994), enhances learning and understanding even when it is conceptually inaccurate. Therefore, students can be encouraged to use personal analogies, as experts spontaneously do in scientific problem solving (Clement, 1988), to generate explanations of given phenomena. Evaluating the success of their project "Community of

ERIC

learners" they are implementing in inner-city elementary and middle schools, Brown and Campione (1994) found that the quality of students' analogies increased as they progressed in critically thinking about knowledge. In particular, they progressed from using surface similarities to using deep similarities between situations and phenomena. If initially they could draw simple analogies, such as between human eyes and car headlights, later they made advanced analogies, such as between a car engine and the human heart to explain the underlying mechanisms.

The three above mentioned studies on the self-generation of analogies have addressed older students who were involved, with the exception of the first study, only in individual activity. It seemed relevant to expand the focus of research towards younger students who, in a Vygotskian frame of reference, are supposed to better perform in a collaborative learning environment since reasoning in children is mainly manifested in the externalized form of discussing and arguing with someone else. According to the social constructivist perspective, the present study assumes that knowledge growth occurs as a result of personal interactions in social contexts (Vygotsky, 1978; Wersch, 1985; Resnick, Levine, & Teasley, 1991). Social interaction in the classroom takes place in collaborative situations such as discussions, both between peers and between teachers and students, giving learners cognitive apprenticeship opportunities to acquire cultural reasoning and argumentation ways (Collins, Brown, & Newman, 1989). Research has pointed out that argumentation processes in classroom discussions can foster the acquisition of conceptual knowledge (Brown & Campione, 1990, 1994; Brown & Palincsar, 1989; Driver et al., 1995; Kobayashi, 1994; Mason, submitted; Pontecorvo, 1997, 1990). Giving students opportunity to explicit their own explanations, in this case through self-generated analogies, and then compare, challenge, evaluate, and modify them collaboratively on the interpsychological plane to reach better understanding of the examined phenomena may be a fruitful breeding ground for individual conceptual growth, that is, more advanced knowledge may be appropriated on the intrapsychological plane by socio-cognitive interaction on a conceptual content. According to Larreamendy-Joerns and Chi (1994) the effectiveness of social interaction in enhancing science learning can be attributed to the fact that a collaborative learning context encourages production of self-explanations about information which is unavailable and yet required to completely understand the concept to be learned. Therefore, if a student explicits a self-generated analogy to explain a scientific phenomenon he or she can be required to give reasons supporting it and if it happens to be wrong after a critical examination, subsequent more correct information can be constructed with peers in order to give a more satisfying account of the examined situation. In other words, collaborative reasoning and arguing can increase the positive effect that self-explanations produce when there is no social interaction (Larreamendy-Joerns & Chi, 1994). In that respect a complementary point of view on the effectiveness of social interaction refers to the fact that a collaborative learning context by assuring the confrontation of different ideas can foster metacognitive awareness of one's own conceptions. By sharing with and for others the inquiry about what lies behind their own conceptions, the discussion participants bring to the surface the representations and presuppositions on which their conceptions rely. In such a way each interlocutor has the opportunity to be aware of his or her own ideas and to transform them into "reasoned theories" (Kuhn, 1993). Students' metaconceptual awareness of their own representations through which they interpret and make predictions about the world has recently been acknowledged as crucial in conceptual change (Hennessey, 1993; Mason, 1994 a, b; Roth, 1990; Vosniadou, 1991, 1994) since it is the fundamental condition to experience the need for knowledge revision while trying to integrate new information into preexisting conceptual structures. Therefore, collaborative reasoning on self-generated analogies may be a useful tool in creating and refining metaconceptual awareness about one's own representations and the reasons on which the given self-explanations are based.

The aim of this qualitative and quantitative study was to analyze the production and use of analogies self-generated by children in self-explaining the examined scientific phenomena, and to evaluate the effects of their collaborative reasoning and arguing on those analogies.

The answers to the following questions were the objectives of the study:

(a) Do fourth graders explicitly encouraged to create and apply self-generated analogies produce and use them to construct accounts of scientific phenomena?

(b) Are these self-generated analogies influenced by learners' personal knowledge base?

(c) How, if at all, does a collaborative reasoning context facilitate the evaluation of individually self-generated analogies and construction of more advanced explanations of the examined phenomena?

(d) Does collaborative reasoning improve explanations at individual level? In other words, what conceptual growth can be identified in learners' individual explanations of the examined scientific phenomena as appropriation of knowledge through socio-cognitive interaction in group discussions?

(e) Is there any evidence that learners are metaconceptually aware of their conceptual growth?

Method

Subjects. A whole class in a public elementary school in the Padova area (Northern Italy), made up of 18 fourth graders, took part in the implementation of a curriculum unit within a wider science curriculum. The children, half girls and half boys, shared a homogeneous middle class social background.

Material. The science curriculum unit dealt with air properties, in particular air pressure, a very important topic throughout school science (Brook & Driver, 1989; Ruggiero et al., 1985; Séré, 1985) as it is at the basis of many more or less simple phenomena. Three air pressure phenomena were introduced to the children.

(1) A glass is filled with water and covered with a piece of cardboard. Then, it is turned upside down keeping a hand on the cardboard. Then the hand is removed. Why does the water not come out?

(2) A sink plunger is pushed hard on a smooth surface. Why is it very difficult to pull off?

(3) A can of drink (iced tea) is turned upside down to pour the tea into a cup from a hole on its upper surface. Why does nothing come out? A second hole is made on the opposite side of the same surface. Why does the tea come out?

ERIC

Educational setting. An innovative teaching-learning context was created to implement the complete science curriculum by stimulating socio-cognitive peer interaction: large-group discussions, the whole class, and small-group discussions, four or five students who held different conceptions on the same topic. The researcher fitted in with this educational setting in each session devoted to the science curriculum unit (two hours twice a week for about one month and half).

Procedure. At the beginning the children were individually interviewed on the topic of air characteristics to ascertain their prior knowledge. In the first session they individually experienced with concrete objects the three phenomena on air pressure. Then they were asked to give an explanation for each of them and to "think of something similar" (not to use the term "analogy") that could help to better understand each phenomenon. Moreover, they were asked if they perceived any similarities between the phenomena, and if so, which. In the next three sessions the children were divided in four small groups (two made up of four and two of five learners) ensuring that each group included children who had given different individual explanations. Within each group, the children were ask d to compare their accounts to collaboratively reach a shared explanation of each phenomenon by evaluating and modifying the already self-generated analogies or creating new ones. In the next session a whole-class discussion took place to give each group the opportunity to present to the others the explanations it had collaboratively reached and for a further exchange and comparison of interpretations. In the final session the children were again individually required to give their explanation of the three air pressure phenomena. As in the initial session they were also asked which similarities they perceived between the phenomena. Moreover, they were asked three questions to ascertain, in an exploratory way, their metacognitive awareness (if any) of the growth in their conceptual structures (Do you think your ideas about the phenomenon x, y, z have been changed? If so, in what way they changed? Why do you think they changed?)

Data source and analysis. Data were collected by audiorecording each session. Discussions were totally transcribed as were the initial and final individual interviews. The data underwent both a qualitative and quantitative analysis. The first aimed at identifying and examining: (a) the individual self-generated analogies and explanations given for the scientific phenomena by each child before and after socio-cognitive interaction. The think-aloud methodology was used to allow them to express their thought processes; (b) the collaborative discourse-reasoning developed in the various gr p discussions, in which the individually self-generated analogies and explanations were evaluated, modified or abandoned in favor of new ones, in socially constructing sharable knowledge; (c) the explicitation of metacognitive awareness of one's own conceptual growth in understanding the phenomena. The quantitative analysis aimed at verifying whether there were statistically significant differences between the individual explanations given before and after the collaborative reasoning and arguing on the phen mena To this aim the data underwent the McNemar test.

BEST COPY AVAILABLE

Results

Prior knowledge: Air exists and takes up space

Before introducing the phenomena to the children, in the initial interview they were asked some questions on air characteristics, to see whether they held the idea that air exists, took up space, and weighed. Shown an empty water bottle, 14 of them said there was no water inside but air and Sebastiano added: "If there was no air it would be squashed". It must be said that in third grade, while learning the metrical decimal system, in particular capacity measures, the children had experienced the existence of air inside empty bottles when they could not pour water from one container to another under certain conditions. To verify whether they could apply the idea that air took up space, they were shown a picture of an empty bottle with a funnel and a tight-fitting rubber around its neck to prevent the air from escaping. The picture showed that the water poured into the funnel could not pass through. The children were asked why. In this case, only 4 of them gave the correct explanation. Another question was aimed at investigating if the children recognized that air weighs by showing them a picture of two balloons equally inflated on a simple balance. The question was what would happen to the balance if one of the balloons were more inflated. Thirteen children said that the balance would go down on the side of the more inflated balloon as "Air weighs because it exists although we can't touch and see it". Of the remainder, 1 child clearly maintained that "air doesn't weigh", 1 said that it depended on the air inflated "... because if it's cold the balance tends to go down but if the air's warm, it tends to go up". Clear answers were not given by 3 children. As concerns the physical properties of air, as we can see below, some of the alternative conceptions highlighted by previous studies involving students of secondary school age range (i.e. Engel-Clough & Driver, 1986; Ruggiero et al., 1985; Séré, 1985) and elementary school age range (i.e. Brook, Driver, & Hind, 1989; Mason, 1986, 1988) were at the basis of many explanations given to the phenomena examined here:

- a strong tendency to associate air with movement so "air does nothing" when not in motion;
- a strong tendency to focus on an active agent inside containers rather than atmospheric pressure outside;
- no reference to pressure differences to explain phenomena, but rather to a sucking, pulling air idea or to a sucking vacuum.

Individually self-generated analogies and explanations

First phenomenon: The glass and the cardboard

Each child was invited to perform the first phenomenon, designed to elicit his or her ideas about air pressure in equilibrium, by introducing a phenomenon which was unfamiliar and contrary to intuition

and experience. Ten different analogies were individually self-generated in producing explanations.

1. Water is like glue (6 children).
"It glues the cardboard as it does a sheet of paper".

2. Water is like a magnet (4 children).
"It's like a magnet but magnets attract iron. It's like the water was the magnet and the cardboard was the iron".

3. It's like small suction cups on toys (2 children).
"When we play we push the small cups and they stick".

4. It's like a pen cap on the lips (2 children).
"If you put a pen cap on your lips and then you suck, it stays up because of lack of air ... the pen cup's like the cardboard and the water's like the vacuum in the middle, the pen cup's like the edge of the glass, the difference's that here instead of air pressure there's water pressure doing the sucking".

5. It's like a glass on the mouth (1 child).
"A glass can be made to stick to the mouth after drinking".

6. Water is like saliva which sticks (1 child).
"When I don't want to use glue I lick the paper and it sticks for a while. The water inside the glass glues the cardboard as if it was saliva."

7. It's like when a piece of paper sticks to the TV screen (1 child).
"Sometimes when you touch the TV screen you can hear a buzz (zzzz). One day I was holding a piece of paper. I was in front of the TV screen. I didn't lay it on the screen but it stuck to it".

8. It's like when a piece of cellophane sticks to my hands (1 child).
"If there's a piece of cellophane on the table and I put my hand on it, it sticks and it doesn't fall".

9. The cardboard is like a bung which prevents water from falling down (1 child).

10. The cardboard is like a sponge holding water (1 child).

The self-generated analogies were affected by the children alternative conceptions and they varied in validity and quality of explanation. As can be seen, three (3, 4, 5) are acceptable, although at different levels, from a scientific point of view as air pressure phenomena are involved. However, these analogical sources were not understood in scientifically appropriate ways. Interestingly, in this phase none of the children who self-generated these three analogies referred to the explanatory structure in terms of air pressure difference. The other analogies revealed that in trying to figure out the mechanism which produced the phenomenon, the children focused on its tangible aspect, so the fact that water did not come out reminded them of other phenomena in which something else stuck. The following is a part of the explanation offered by Andreina who produced several analogies in trying to figure out the result of the experiment.

Water doesn't come out because the cardboard, I think, absorbs water; it's like a sponge holding water ... [after replicating the phenomenon by using a piece of paper] also paper absorbs water, maybe water with paper or cardboard's like a magnet, a magnet which attracts iron, a magnet's hard instead water's liquid ... I remember that sometimes after drinking I play in this way with the glass. I'll show you it [she shows]. I put it on my mouth and the air inside the glass keeps it on the mouth, here the air's outside ... I don't know ... But I have to do this (she sucks) with my mouth to keep the glass on. Here you push the cardboard on the glass, there's air inside the glass, no, no. I don't think so, no ... the glass is filled with water yet it stays up, this means that here air doesn't matter.

ERIC

All the individual explanations given to the phenomenon were as follows.

- Water attracts the cardboard (5 children).

- Water glues the cardboard (4 children).

- Air inside the glass sucks the cardboard up (4 children).

- Air cannot get in to replace water (2 children).

- Outside air pushes the cardboard up and holds it up (4 children).

The most advanced initial explanation was given by the few children who changed their representations of the phenomenon during the interview. They started with one of the above reported alternative explanations but they realized it was not effective, so while trying to figure out the phenomenon better they were able to reach an acceptable, although partial, explanation. An example is Elena's reasoning:

Let's see. I don't think that the cardboard absorbs water because I also used a piece of newspaper and the water didn't come out, practically it's the same. Probably there's a force inside the glass, it's filled with water, water can have a force, that is water's like a glue for the cardboard ... Let's see ... When it's wet the cardboard sticks better ... I'm not very sure, convinced about that ... I must do the experiment again [she does it]. I'm thinking that it could be a force that pushes the cardboard to stick to the glass ... let me see again ... yes! The air outside the glass pushes the cardboard to stick to the glass.

Second phenomenon: The sink plunger

Each child was invited to test out the plunger on different surfaces and then to explain why it was difficult to remove it from a smooth surface.

Seven analogies were individually self-generated in producing explanations.

1. It is the same mechanism as the small suctions cups on soft toys (5 children).

2. It is like the glass inverted with the cardboard attached to it (3 children).

3. It is like a pan with a lid (1 child).
"When you put a lid on a pan on the fire, the lid traps some air and when you lift it there's a little vapor inside and it's quite difficult to pull off".

4. It is like a parachute (1 child).
"Both the plunger and a parachute get inflated".

5. It is like when you press something on the ground (1 child).
"When something's pressed hard on the ground it breaks, here it's the same but the pushed air doesn't break on the surface".

6. It is like super-glue (1 child).
"When you spray super-glue, if there's air in few seconds it hardens, but it doesn't if there isn't any air. When the plunger's pushed down it's like super-glue when there is air".

7. It is like a balloon inflated with air (1 child).
"Both the plunger and a balloon have air inside and are closed".

The children's self-produced analogies in trying to figure out this air pressure difference phenomenon were based on what they conceived was the underlying mechanism, that is the presence of air under the plunger cup. It is interesting to note that one of the children who drew the analogy between the current phenomenon and the previous one had explained the latter in terms of lack of air inside the

ERIC

glass and the former in terms of air trapped inside the cup. In making the correspondences between the two analogs she was therefore "forced" to change her representation of the source itself in order to avoid a conceptual conflict and manage to combine contradictory evidence. She said: "... maybe there was air inside the cardboard which keeps it up ... Here, when you press the plunger in such a way air is kept inside the red cup. Yes, there's air in both." Also the other two children who made connections with the glass and cardboard phenomenon perceived the similarity only in terms of internal air that kept the cardboard attached to the glass and the plunger attached to the surface.

All the individual explanations given to the examined phenomenon were as follows.

- Air trapped inside makes the plunger stick (10 children).
- No air inside the plunger (5 children).
- The plunger is made of a special rubber (1 child).
- No air inside the plunger and outside air pressure (1 child).
- I don't know (1 child).

None of the children understood the phenomenon in terms of difference in air pressure inside and outside the plunger cup. The most advanced explanation was given by Giovanni who mentioned the outside air opposing resistance. While reasoning on the phenomenon he said:

Air's against you. Yes, it's logic, air would be against to you. But I'm thinking that the air should make resistance to every object in here, but it doesn't. Why? Why?

This is a clear example showing the children's difficulty of thinking in terms of relationships between internal and external air pressure. Giovanni held the idea of vacuum inside the cup and the idea of pressure exerted by the external air in the room but he could not figure out how the latter did not affect the other objects that he could pull up easily. He was not able to combine the two aspects of vacuum inside and external pressure outside in a relationship based on pressure difference. Significant is his metacognitive reflection on experiencing conceptual difficulty. The two most popular interpretations assigned the air inside the plunger cup a crucial role in "sticking", "holding", "pulling down. A typical one was: "Air's trapped inside the cup, there's a force inside that makes it difficult to pull it up".

Third phenomenon: The can with one or two holes

In explaining why the tea came out only when there were two holes in the upper surface of the can, the children individually self-generated the nine analogies that follow.

1. It is like the situation of the bottle with the funnel and a tight-fitting rubber around its neck (3 children).

2. It is like when you open a can of oil (motor oil or cooking oil, 2 children)
"I see my father when he changes the oil in his car He makes two holes and he told me that one hole is to allow the air to come out and the other to allow the oil to come out. Two things can't go out at the same time through the same hole. A big whole would be necessary as with pull-ring cans.

"Also my mother makes two holes when she opens the oil can to cook chips, it's the same".

3. It is like what happens when we pour wine from a bottle to another (2 children).

4. It is like a water-clock (1 child).
"I tried to make a kind of water-clock by using two bottles, but the water trickled through very slowly, so I made a hole in the upper bottle and the air came out".

5. It is like emptying something (1 child).
"When you pull a lid off to empty a tank for example, all the stuff comes out and the air goes in it".

6. It is like when a pool is emptied of water (1 child).
"I saw two plunges being opened to empty a pool. There was air underneath and only one plunge was not enough" (1 child).

7. It is like when there's a narrow door and two people want to pass through together (1 child).

8. "It is like when we use armbands for swimming. The air doesn't come out even the small hole is open. In the meanwhile there's air around us, the air should go into the armbands and the air inside come out. So it's quite difficult, you have to squeeze them if you want the air to go out from the small hole" (1 child).

9. It is like what happens in the inverted glass experiment (1 child).
"There's air outside the cardboard and it helps it to remain attached, here the air wants to go in the can and the tea go out, the air helps both, there to stay up, here to pour the tea out".

The analogies self-generated to give an account of this phenomenon, compared with other ones self-generated to explain the first and second phenomenon, although varying in quality of explanation, were the most valid and appropriate. They indicated how the children had some intuitive knowledge which could be used as an anchor for new knowledge. Of the three children who made the analogy with the bottle-and- funnel situation referring to the idea that both air and water take up space, two pointed out that in this situation the air was outside while in the previous one it was inside the bottle. For example, Irene said:

The last time I told you that air has to go out for the water to go in and then when the rubber was between the bottle opening and the funnel, the air could not go out. Here it's similar, but the opposite because the air goes in and the water, not the tea, comes out.

In referring to the same source situation, the third child, Martina pointed out that air was both inside the bottle and inside the can and that from both places it had to go out to allow a liquid to enter. She then produced the analogy with armbands to strengthen and support her idea that the air inside a container cannot go out from a very small hole unless you push it out.

All the individual explanations given to the examined phenomenon were as follows.

- If there is only one hole the outside air, that has to go in to allow the tea to go out, and the tea clash. If there are two holes the air goes in through one hole and the tea goes out from the other (9 children).

- If there is only one hole the tea and the air inside the can have to go out from the same hole. If there are two holes the air inside goes out from one hole and the tea goes out from the other (3 children).

- If there is only one hole the outside air and the tea push on the same hole. If there are two holes the outside air pushes and goes in through one hole and the tea pushes and goes out from the other (3 children).

- If there is only one hole the tea gets less force to go out. If there are two holes the tea gets more force to go out (2 children).

- I don't know (1 child).

The most popular reason referred to a correct intuitive representation of the phenomenon although not expressed in terms of pressure equilibrium and difference. Apparently this third experiment was more easily explained by the children as it was not contrary to intuition and more familiar. In fact it reminded some children of the situation introduced in the initial interview where water could not go into the bottle because of the rubber between the funnel and the bottle opening, and their experience of pouring liquids.

The initial perception of similarities between the three phenomena

After explaining the three phenomena individually, the children were asked if they could identify any similarities between them and, if so, which. All of them were able to recognize some similarities although not all between the three phenomena and at different levels. The similarities between the three phenomena perceived by 14 children are as follows.

- In all the phenomena there is air which does something (5 children).
"From the plunger air escapes, there it helps the cardboard to stay up and in the can it goes in to allow the tea to come out".

- In all the phenomena there is air inside a container (4 children).
"All the objects holding something have air inside them".

- In all the phenomena something does not happen.
"The water doesn't go down, the plunger doesn't come off, and the tea doesn't go out" (2 children).

- In all the phenomena there is the same mechanism, that is "the ordinary air pressure which continuously pushes on something" (2 children).

- In all the phenomena there is no air inside a container (1 child).

The higher-level identified similarities were expressed by the two children who mentioned the underlying mechanism caused by air pressure. They were the children who gave the most advanced explanations of each phenomenon.

The similarities between two of the three phenomena perceived by the other 4 children are as follows.

- "The plunger and the glass are similar because they stick, the can's different" (1 child).

- "There's something which acts as a magnet in the plunger and in the inverted glass but not in the can, it's different" (1 child).

- "The experiments with the plunger and the can are similar because they don't allow what's inside to go out" (1 child).

- "The glass and the can are similar because they can make a liquid go out" (1 child).

The social construction of knowledge: Collaborative reasoning and arguing on individually self-generated analogies and explanations

The children, divided in four small groups, each including learners who had expressed different individual conceptions in the previous individual sessions, were asked to compare their personal explanations by evaluating the already generated analogies and creating new ones to collaboratively reach a shared explanation of the three phenomena. The teacher participated in the group discussions only if the children required her presence at some point of their reasoning and arguing.

First phenomenon: The glass and the cardboard

The following excerpts are drawn from the sequence of discourse-reasoning about the phenomenon of the inverted glass[1] developed within one of the small groups.

(1) *Giovanni*: First of all we've got to decide why the water doesn't come out from the inverted glass. Let me see ... The explanation I can give you is that the air pushes, that is, the air's under the glass, it goes to the cardboard and the cardboard to the glass and it remains attached. The air pushes.
(2) *Matteo*: No, no, the air's inside the glass, it attracts the cardboard.
(3) *Giulio*: I think it's like a magnet.
(4) *Jenny*: Yes, the water in the glass attracts the cardboard.
(5) *Giovanni*: Well, so I'm the only one who says that the outside air pushes. You've said that the water attracts, so we've got to decide. But let me ask you a question: "How can water attract? What force does it have? It's the air that pushes.
(6) *Matteo*: I've explained that once I licked a piece of paper and it stuck, so water could be a kind of glue.
(7) *Andreina*: But how can water or outside air attract the cardboard? I don't understand.
(8) *Jenny*: Because the water ... no, in the glass there's air, it attracts the cardboard. This's what I say.
(9) *Giovanni*: Do you remember that nobody at school told us that air attracts? By reasoning during the interview I understood that the outside air pushes, it has a pressure.
(10) *Andreina*: When I put the glass here, on my lips, and I do this movement [she shows it], it's the air which sucks it up.
(11) *Giovanni*: I'm sorry, but it's you who's sucking ... you and the glass's kept up. It's different in that case, here nothing does that, nothing sucks, instead we know that air pushes but there's also the water with its pressure which pushes, so ... Giulio, what do you think?
(12) *Giulio*: maybe you're right, maybe ... but it's pretty difficult to figure out.

This first part of the discussion shows how its dynamics was characterized by oppositions and counter-oppositions. Giovanni, who initially had individually given the most advanced explanation contrasting any other supported by his classmates, will scaffold their reasoning to make more acceptable the external air pressure idea. Water as a glue was not developed any more in favor of the idea that something must suck, be it water or supposed internal air as Jenny's assertions show. The analogy drawn by Andreina, that will surface again during the discussion, was rejected by Giovanni who pointed out that the examined phenomenon did not involve any form of sucking inside the glass and

1 The number in parentheses refer to the statements uttered in the discussion in the same order as they were made. The children's sentences were translated trying to keep the same "style" as in the original Italian version. Grammar and style errors were not corrected unless prejudicial to understanding.

then he underlined the fact that two forces were involved. Here another sequence from the same discussion is reported.

(55) *Giulio*: I think that the cardboard's wet, it's like if it was against the water in the glass and so this doesn't come out because there's water against water.
(56) *Gio·anni*: But then the water in the glass would win because it's much more, if it was water against water the cardboard would drop.
(57) *Giulio*: When the cardboard's wet it gets heavier.
(58) *Giovanni*: Even better!! It will fall down. Instead there must be another force which pushes in the opposite direction.
(59) *Giulio*: Ah ... I'm thinking about this. Maybe it's true, maybe it's the air.
(60) *Giovanni*: The outside air. Neither wins because if the air won the cardboard would be in this position [he shows it], instead if the water won it would fall down.
(61) *Giulio*: You mean that there are two equivalent forces, water and air are two equal forces.
(62) *Jenny*: Maybe I understand why the water doesn't go down: the air pushes to the glass edge and in this way the cardboard stays up.
(63) *Andreina*: I'm puzzled because I don't understand why the cardboard sticks to the glass because of the external air under the glass. There's air also above the glass.
(64) *Giovanni*: Yes, the air pressure above pushes the glass and the air pressure under pushes the cardboard on the glass. It's right.
(65) *Matteo*: There's air but if you put a hand under the glass you don't feel the air, it's transparent, it's a very particular thing.

The sequence is the furthering of Giovanni's claim about two opposing forces which helped the children to accept the new idea of external air pressure. Interestingly, Giulio, who probably because of an implicit presupposition of his was looking for another force also exerted by water, was scaffolded by Giovanni's counter-opposition to change his mind. Moreover, also Andreina's metaconceptual reflection shows that she was busy connecting new developing knowledge. She could then experience difficulties in combining and integrating it all as well as Matteo who pointed out that air is "a very particular thing" meaning that it was still implausible to believe that a "transparent" thing could push on something. The next sequence is focused on the evaluation of some analogies that had been individually self-generated.

(78) *Giovanni*: Those comparisons [written on a poster] aren't valid any more.
(79) *Giulio*: Yes, right, we've got to find a better one fitting our new explanation.
(80) *Matteo*: I think that the comparison with the TV [he had generated this analogy] is right because the water sticks the cardboard like glue and there because there's electricity.
(81) *Jenny*: No, I don't agree with you it isn't the same, no. We've got another explanation now.
(82) *Giovanni*: I didn't agree with you at all, Matteo, because water and electricity are two different things.
(83) *Andreina*: Yes, it's true, they've got nothing in common.
(84)*Giulio*: Maybe I've got a comparison, it isn't right but it can explain: it's like a tool made up of two forces, for example two pieces of iron. The air pushes upward and the water downward.
(85) *Andreina*: Saying that water's like glue or a magnet's totally rejectable, instead the comparison with the cellophane could be good, as it stays attached to our hands.
(86) *Giovanni*: No, I disagree, the paper sticks to our hands but the air doesn't matter, air doesn't push in that case, and the idea that water's like a magnet is completely crazy.
(87) *Jenny*: Yes, I 've thought over this idea and it isn't very good.
(88) *Giovanni*: I think that the glass-on-the-mouth situation, reported by Andreina, could appear similar but in our experiment inside the glass there's no vacuum, there's water, but when we try to attach the glass to our mouth there isn't anything outside that pushes ... Oh no, good grief! Also there

ERIC

there's air outside, yes, the external air pushes on everything, also in that case. Oh good grief! Yes, OK, they are similar.

The excerpt shows that some of the individually self-generated analogies were abandoned and that the analogy with the situation of a glass on the mouth was accepted by Giovanni who, trying to demonstrate a major difference between the analogs, came to find out their similarity in terms of external air pressure.

The next extracts come from another small-group discussion on the same experiment which did not come to share the idea reached by the previous group. The children started to reason and argue together after reading all the different explanations given, written on a poster.

(30) *Valentina*: The idea that the air inside the glass sucks the cardboard up isn't right because we've seen that the glass was filled with water and so there couldn't be any air inside it. The other one that external air pushes the cardboard to the glass isn't correct either because the outside air has nothing to do with this, so all we can say now is that water's like a plunger for the cardboard, it sucks.
(31) *Christian*: I think that also the other comparison's right because the cellophane stays attached like the cardboard to the glass, it's the same situation.
(32) *Alessandro*: I think water's s like a suction cup on a toy, you stick it to the window. It's the same thing done with other stuff.
(33) *Martina*: I agree with the idea that water's like a suction cup because the glass sucked the cardboard, the water acted as a cup.
(34) *Alessandro*: Yes, the glass was full of water so it couldn't have any air inside.

The idea that water in the glass "sucked" the cardboard up, which reminded them of the action of a suction cup, was initially accepted by the group who then called the teacher to express their shared explanation of the phenomenon.

(41) *Teacher*: Why are you rejecting the other ideas?
(42) *Valentina*: The idea of external air pressure's absolutely wrong because external air has nothing to do with the glass.
(43) *Teacher*: You say the external air has nothing to do with this situation.
(44) *Christian*: I'm changing my mind. I want to say that the outside air pushes the cardboard to the glass, towards the glass, and in this way it helps it to stay up.
(45) *Martina*: I disagree, air can't push the cardboard because the external air's normal, that is, it isn't all concentrated on the cardboard.
(46) *Valentina*: Maybe there was a small draught and so the cardboard stays up.
(47) *Martina*: It doesn't make me understand the matter, I don't agree, I need someone to persuade me.
(48) *Christian*: I'll try: Imagine that this is the glass. I turn it upside down, the air which's around here pushes, it pushes the cardboard.
(49) *Martina*: But how is it possible? All the air go against the cardboard? It must be very strong.
(50) *Alessandro*: It doesn't seem to me very ...
(51) *Teacher*: What about other similar situations?
(52) *Valentina*: We've decided that water was like a suction cup which sucks, practically the water attracted the cardboard.
(53) *Alessandro*: Yes, I'll go back to my previous idea, the water attracts the cardboard.
(54) *Christian*: I want to say this new idea's the best. Air pushes and another situation's similar, that is, when you've eaten candies, then the cellophane around them stays attached to your hands because also there the air pushes.
(55) *Alessandro*: No, no, the comparison with a magnet's much better, it's closer to the idea that water attracts the cardboard.

In giving the teacher their reasons for rejecting the other ideas, the children maintained again their alternative explanation, well expressed in Alessandro's words, through the comparison with the action of a magnet. Christian, the only child who tried to think of the phenomenon in terms of atmospheric pressure, interpreted also the inappropriate analogical source in terms of the new developing idea. It can be seen, and better still in the next excerpt, that Martina and Alessandro could not integrate in their conceptual ecology the idea of external air pressure given their ontology of air, that is, the implicit presupposition that air can exert a force only if it is in motion in an open space.

(67) *Martina*: I can't understand how this idea's true.
(68) *Christian*: May I explain something to you? This is the free air and this is the cardboard, the air pushes it and it makes it stick.
(69) *Martina*: Yes, but how can it do that? I'm not yet convinced about that.
(70) *Alessandro*: Christian, we've understood your idea but you have to explain to us why it happens, why it happens. Why?
(71) *Christian*: Air pushes.
(72) *Alessandro*: Why does it push?
(73) *Martina*: Explain it to us in simple words if you can't explain it very well.
(74) *Christian*: Because air goes fast, it seems to go slowly but it goes very fast.
(75) *Martina*: Anyway, how is it possible that there's always a draught here? Tell me!
(76) *Alessandro*: I think the water attracts the cardboard and by attracting it the water in the glass keeps it up. The inside and outside air have nothing to do with it.
(77) *Christian*: Guys, let's pretend that this is the cardboard, under it there's the air which pushes it. It's this, only this.
(78) *Martina*: But is there always a draught? How is it possible that there's a draught under the cardboard?
(79) *Alessandro*: So far, Christian, you've been able to tell us only this.
(80) *Martina*: How can I understand what you say? Because, my friend, there isn't always a draught which pushes the glass.
(81) *Christian*: The air in the room pushes the cardboard against the glass. That's all.
(82) *Alessandro*: What Christian said's wrong. A very strong draught would be necessary, otherwise the normal air's to weak. The experiment's like a whirlpool, if you throw something, it sucks it in. It's the same here. Water, not air, has a force.

Christian was not able to support his intuition about external air pressure to persuade his classmates of its plausibility. He was challenged to explain it better, that is, the opposers required him to give them sharable reasons for the idea to be accepted. Indeed, it would be a very hard job since his idea was so implausible and alien to their representations of the air properties, based on the ontological belief that only air in motion can exert a force. The end of the group discussion pointed out the alternative conception about the sucking action exerted by the water in the glass emphasized through the analogy of the whirlpool. The explanation shared by the group will be argued over in the final whole class discussion that will help Martina and Alessandro to revise their entrenched belief about what static air can and cannot do, that is, their personal ontology of air.

Second phenomenon: The plunger

The following excerpt is part of a small-group discussion on the plunger phenomenon. It begins after a child, Sebastiano, noticed the air noise made by the plunger pressed on a smooth surface.

(28) *Sebastiano*: May I say something? Try to put your hand here. I'd argue that it made a noise because there was a little air in the middle of the cup and it was pushed out.
(29) *Enrico*: If air remained inside, the plunger would pull off, the air's forced to go out by pushing the plunger down.
(30) *Sebastiano*: Yes, as I said there's no air inside.
(31) *Elisa*: But why does then the plunger pull off?
(32) *Giacomo*: Why? Tell us why.
(33) *Enrico*: Outside air makes resistance, it wants to go in where there's nothing.
(34) *Giacomo*: Yes, it would like to go in.
(35) *Enrico*: The external air does this and that [he shows what] so we find it very difficult to pull the plunger up. Here, on the wall, instead, it's very easy because there are little bulges on the surface, it doesn't stick well.
(36) *Elisa*: You mean that there's always air inside the cup here?
(37) *Sebastiano*: We've got to explain better. Let me try again. If here there's a little bulge you can't push down, it doesn't stick well, the air can come out but also go in.
(38) *Enrico*: The very same thing happens with the toy suction cups on the windows.
(39) *Elisa*: Thus, the comparison with super-glue has nothing to do with the plunger.
(40) *Enrico*: It's simply what happens to a material in the air, it has nothing to do with this.
(41) Elisa: What do you think about the comparison with the lid sticking to a pan?
(41) *Sebastiano*: No, it isn't right because the lid doesn't stick perfectly.
(42) *Enrico*: Besides, it isn't right because you put a lid to stop the vapor from coming out, the vapor goes up so you don't have difficulty in removing the lid; air helps you, it pushes you, it isn't difficult at all. The situations are similar only because there's something to be pulled up but they are opposite. Here it's very difficult to pull the plunger up because there's a force opposing the force you exert. There, you don't have difficulty because there's a force, the vapor, which lifts the lid.
(43) *Giacomo*: I agree with Enrico and Sebastiano, it isn't similar.
(44) *Enrico*: It's correct to make a comparison with the situation we've already discussed, that is, that of the inverted glass. There, there was water inside the glass and no air, here, there's nothing in the cup and the outside air pushes here but also there.
(45) *Sebastiano*: That's OK.
(46) *Giacomo*: Yes, OK, those things are similar.

The argumentation dynamics in this discussion sequence was characterized by co-construction of the new knowledge that the children were trying to integrate in their own conceptual structures. Two of the individually self-generated analogies were critically examined and considered as not valid in explaining the mechanism underlying the phenomenon. A new appropriate shared analogy was finally identified, although not clearly and completely explicited, which helped them to connect two of the experienced phenomena in a wider and more integrated framework about internal and external air pressure.

Third phenomenon: The can with one or two holes

The two following excerpts come from different group discussions. The first shows that the collaborative discourse-reasoning led the children to construct and share an essentially correct explanation of the phenomenon (although with no scientific words) which necessary asked for a new sharable analogy. The second reports the children's criticism of some analogies based on the new developing knowledge and the identification of new structural similarities between the examined situation and a previously analyzed one.

(4) *Elena*: From one hole the tea comes out, from the other the air goes in, it doesn't come out.
(5) *Francesco*: It isn't right to say that the air's inside and it can't go out because there's only one hole. No air's inside and so it can't go out from one hole and the tea from the other.
(6) *Igor*: When there's only one hole nothing comes out because the air can't go in the can, it would need another way.
(7) *Francesco*: When there's only one hole, the air and the water meet.
(8) *Elena*: The external air makes pressure on the tea and so it can't go out, but also the air can't go in.
(9) *Francesco*: The air and the tea clash.
(10) *Elena*: Neither goes in and neither comes out.
(11) *Francesco*: We don't see air but it exists, it does something. I've had a brainwave!
(12) *Irene*: While in the bottle neck there was the rubber and the water didn't go in, here the rubber is when there's only one hole and nothing happens.

(8) *Sebastiano*: The oil can situation isn't a similar thing, it's the same thing.
(9) *Sonia*: Yes, the same. There's one hole through which the air goes in and another through which the oil comes out.
(10) *Elisa*: It's the same when we pour water from a liter and half bottle.
(11) *Enrico*: You mean that the bottle opening's big and so the water can pass through. All the things could be ... all cases where water or any liquid has to go out, air has to go in.
(12) *Sebastiano*: To go in and out from a container.
(13) *Enrico*: Yes, if the opening is large enough it allows the air to go in and the liquid to go out, but if the opening's narrow ... It's necessary for every substance to have its own route.
(14) *Sonia*: I can explain another comparison, it's about a waterclock made by two bottles. You have to make one hole between the two bottle caps but also another hole in the bottle otherwise water finds it hard to flow.
(15) *Sebastiano*: Yes, but the oil can situation isn't similar, it's just the same.
(...)
(24) *Elisa*: A liter and half bottle of water has a large opening, if it wasn't so large, if there was only a small opening, we wouldn't be able to pour the water.
(25). *Enrico*: Yes, it would be clogged with the entering air and the escaping water. It's like what I've said: if there's a narrow door and two people pass through it in two opposite directions, they get stuck. Two doors are necessary, one for the person who goes in and the other for the person who comes out. It's also like the bottle with the rubber around the funnel.
(26) *Sebastiano*: If there wasn't the rubber, the air would escape from the little space around the funnel, but if you put the rubber the air's blocked, it can't go out and the water can't go in.

It is noteworthy that the more the children approached the scientific explanation of the phenomena, the more they were able to recognize the structural similarity between the three, which in the most advanced learning products will be figured out in an integrated and comprehensive conceptual structure.

Changes in explanations: Individual knowledge growth

BEST COPY AVAILABLE

After the whole-class discussion which followed the small-group discussions, each child was again individually asked to give his or her explanations of the three air pressure phenomena in the light of what he or she had learned by collaboratively reasoning a d arguing on their initial self-explanations. For the quantitative analysis, the data underwent the McNemar test to see whether there were statistically significant differences between the individual explanations given before and after the collaborative reasoning and arguing on the phenomena.

The first phenomenon. As concerns the first phenomenon, Table 1 shows the conceptual progress emerged in the final individual explanations. As can be seen, while in the first individual session only 4 children mentioned the outside air (among them one child had used the word "pressure") which pushes the cardboard to the glass, in the final individual session 16 children explicitly referred to the atmospheric pressure, X^2 (1) = 12, p<.001.

The second phenomenon. Conceptual growth in the final individual explanations of the second phenomenon is shown in Table 2. While in the initial individual session 10 children interpreted the phenomenon of the sink plunger by referring to the fact that the air trapped inside would make the plunger stick, in the final individual session only 2 children did, X^2 (1) = 8, p<.005. On the contrary, while at the beginning only 1 child referred not only to the vacuum in the cup but also to the external air pressure, after the peer interaction 10 children gave this explanation, X^2 (1) = 9, p<.005. Moreover, another 3 children were also able to explicit the direction of the air pressure difference between the outside and the inside of the plunger cup.

The third phenomenon. Table 3 shows conceptual growth in the final individual explanations concerning the third phenomenon. While in the initial individual session 3 children gave a scientifically acceptable explanation, in the final individual session 11 children did, X^2 (1) = 8, p<.005. In addition, another 4 children referred to the idea of pressure "balance" or difference between the outside air pressure and the pressure of the liquid inside the can. Examples of three children's initial and final individual explanations of the phenomena are shown in Fig. 1.

In giving their final explanations of what happened in experiencing the phenomena, the children drew analogies again. Some were a new individual product to give a better account of the newly learned material. For example, Igor generated the following analogy to explain what happened with the one hole can:

It's like a medicine dropper. It lets out one drop at a time not all the liquid together. It's like the can when it has only one hole, we have to squeeze it to have more liquid come out.

Other analogies were those who had been accepted as valid after their critical examination during the discussions. Moreover, in some cases, the children spontaneously explicited again the reasons which led them to reject some analogies, mainly the analogy between water (or air) and glue and between water and a magnet. For example, Francesco -after criticizing his own analogy between the situation of the inverted glass and the one with a piece of paper attached to a TV screen by saying that air had nothing to do with it but rather it was a kind of shock- expressed his belief that the best analogy produced was that of a pen cap on the lips:

It does happen to me when I try ... It's like the glass, the outside air exerts a pressure on the cardboard and on the cap, inside it there isn't any air. When you put the cap on your lips, the air goes out, you have to suck before and then in the cap, or a glass, there's a vacuum or less air, so it remains attached to your mouth. It's also like what happens with the plunger.

It is worth pointing out that reaching more scientifically accepted explanations of the phenomena, the children were able to perceive them within the same explanatory framework referred to the effects of air pressure, as we can see below, and to use the same analogy to account for all or two of the phenomena (i.e. the analogy with a glass which sticks to the mouth was referred to explain the mechanism of pressure difference for the second and third experiment).

The similarities between the phenomena. As table 4 shows, the children progressed in perceiving the structural similarity between the three examined phenomena. While at the beginning only 2 children maintained that all the phenomena had to do with external air pressure, in the final individual session 12 children explicited that the mechanism of atmospheric pressure was at the basis of the three phenomena, X^2 (1) = 10, p<.005. Fig. 1 shows an example of a similarity perceived by a child in the initial and final session.

Three children were able to recognize similarities only between two phenomena. Interestingly, two of them had explicited at the beginning a similarity between all the phenomena based on the fact that air did something, pointing out that especially in the glass and in the plunger cup the air was very important. By group discussions they were convinced about the incorrectness of their personal ideas, so they conceptually progressed understanding that inside the glass there was only water and that inside the plunger cup pushed on a smooth surface there was the vacuum. This new understanding was so salient that in the final session they highlighted a similarity only between the phenomena of the inverted glass and the plunger. The other child explicited the same similarity recognized in the initial session between these two phenomena by saying that "they stick".

Metacognitive awareness of conceptual growth

Through the final individual interviews it was possible to investigate, in an exploratory way, whether the children thought they had changed their ideas about the phenomena, in what way, and why. All but one said that they had changed explanations and were able to explicit and motivate, although not all completely, the changes in their conceptual structures. Moreover, several children referred to the reasons behind their previous conceptions, deeply routed on their personal ontology of air which associated it with motion.

First of all, noteworthy are the metaconceptual reflections expressed by the children, who experienced a successful revision of their own ideas, on the plausibility of the newly constructed knowledge which was not easily combinable with their preexisting beliefs. For example, Giovanni explicited the reasons behind his previous conception based on his entrenched belief about air:

ERIC

I didn't know about the internal vacuum and so I didn't know that in the plunger cup there wasn't any air pressure and outside there was instead a greater air pressure ... we can't see the air so it's difficult. For example, when there's a flood you can see the water sweeping everything away and so you can easily understand the concept of water pressure, but air isn't visible, you can perceive it when you breathe but it's very difficult to perceive its pressure here, in this room. Sometimes also for water you can't see that it's pushing but I know that if I went to the deep abysses I'd feel water pressing on my skin.

Also Giulio maintained:

We had to understand that air's all around us and presses us and the objects in the room. We can't touch the air but anyway it does its job ....It isn't easy to be aware of it because we don't see it, we don't perceive it, and so we don't consider it.

In explaining the difficulties he had experienced in changing the alternative theory that air can act only if in motion, based on the epistemological presupposition that something happens, exists only if detectable through the senses, Christian said:

The outside air pushes. I only thought that air attracted. When I'm outdoor and there's a strong wind I feel that it comes towards me, I feel the air in motion. Here, in this classroom it's difficult to feel the air, at least it would be necessary to have a window open, otherwise it's very hard. Even with the windows closed there's air here, obviously, which allows us to breathe but its pressure's quite difficult to understand.

Also Martina and Irene stated they had taken much time to understand what happened in the experiment with the inverted glass:

I bel ved that air existed but that it wasn't so powerful. I didn't know why I believed that. Now I'm convinced but before doing the experiments and discussing a lot I thought it was impossible to believe that air, the air in this classroom, exerts a pressure, it's continuously pushing.

After discussing I understood that the external air's pushing on everything and it keeps the cardboard on the glass. I thought that one of my classmate's idea of a magnet, water's like a magnet, was right but then I saw that idea was misleading. But I've got to say that it's very difficult to think of air, the normal air in this room, because now, here, there's air pressure but we are used to this pressure so we don't perceive it, we don't think of it.

Other metacognitive reflections expressed by the children concerned the analogies self-generated in understanding the scientific phenomena. Sebastiano commented the abandon of his initial analogy:

The comparison with super-glue, which doesn't harden without air, came to my mind because I thought that the air trapped in the plunger cup kept it stuck so the super-glue was a goo' comparison. I held a wrong idea but if somebody had some wrong ideas he could change them by list-ning to the explanations given by the others. My idea that the air remained in the plunger cup, that the air sucked it down on the smooth surface, was so strong. I wasn't able to give another explanation, but then by thinking of what my classmates were saying, by comparing the different ideas, I understood that there were more logical reasonings in what they said, that a better, more correct answer existed.

Also Valentina explained the rejection of one of the first self-generated analogies:

ERIC

I found out that the comparison between water and a magnet was completely wrong, it could lead you to the wrong way. I understood that water didn't have any effects against the cardboard, it pushes down but it doesn't attract. The glass's completely full with water, there isn't any air inside, the outside air's important not the water that isn't neither a magnet nor a glue.

In appreciating the role of the collaborative discourse-reasoning, Giovanni pointed out the help he had got from a particular analogy discussed in his group:

If an idea was wrong, somebody could say that an experiment worked that way, but by discussing with the others he could recognize that the things hadn't happened in that way. The others didn't tell you "no, no, you're wrong", they persuaded you. Discussing's a different thing, it makes you understand much better. Also the comparisons we discussed in group helped me to figure out the experiments. One thing very difficult to understand is made much more understandable by another thing that's similar and easier. The comparison with the glass on your mouth helped me very much. I knew the situation with the glass on a mouth. I had tried it many times but I though that my mouth attracted the glass and nothing more. I didn't recognize that something pushed the glass against my mouth. After the experiments and discussing with the others I totally changed my mind and now I know there's air which pushes continuously on everything.

The metacognitive reflections show that the children were able to self-regulate their own learning process through the metacognitive awareness of the need of changing conceptions and beliefs to integrate old and new information in their conceptual ecology In such a way, they experienced a successful revision of their knowledge. In the final individual interview only one child said that he had not changed his ideas "because they were always correct". He generated several analogies based on his alternative conceptions, which then were critically examined and abandoned by the others but not by himself. For example, as concerns the first and second phenomenon, he still held the idea that water stuck to the cardboard like it was a kind of glue and that the air inside the plunger cup stuck inside like glue. Indeed, he perceived a similarity only between these two phenomena referred to the idea that both "stick".

Discussion

The first objective of t study was to verify if fourth graders, explicitly encouraged to create and apply self-generated analogies, produce and use them in constructing accounts of scientific phenomena. A total of twenty-seven analogies were self-generated during the children's first individual attempt to understand what had happened when they had experienced the three phenomena. This shows that fourth graders can produce and use own analogies as a kind of self-explanation both to help them to learn new material and to communicate their understanding to others. These analogies varied in validity and in explanation quality. As shown above, they began from being based only on very surface similarities referred to the tangible aspects of the outcomes, detectable through the senses (e.g. the analogy between the cardboard attached to the inverted glass and glue) and ended being based on a relational structure to explain the underlying mechanism in terms of air existence and its pressure (e.g. analogy between the can with one hole and the bottle with the funnel or the analogy between the inverted glass with the cardboard and a glass on the mouth).

As concerns the second objective, aimed at verifying if the self-generated analogies were influenced by the learners' personal knowledge base, it can be stated that their already possessed knowledge, mainly characterized by alternative conceptions of what air could do, affected the self-production of analogies. From this point of view, even the most incorrect analogies were consistent in the children's conceptual structures. For example, the first phenomenon was initially conceptualized referring to the water action, either as a glue or a magnet, since the children could not think of any kind of action exerted by the external air on the cardboard. Likewise, the second phenomenon, initially conceptualized in terms of trapped air in the plunger cup, was compared to other situations in which containers were filled with air, such as a parachute or a balloon because air "keeps things up".

The third objective aimed at verifying how a collaborative reasoning context facilitated the evaluation of individually self-generated analogies and the construction of more advanced explanations of the examined phenomena. The qualitative analysis concerning reasoning and arguing in group discussions indicated that through steps of critical opposition and of co-construction, the learners' negotiated and renegotiated meanings and ideas to share a common knowledge based on the explicitation of more appropriate analogies supporting more advanced explanations. Students who are given the opportunity to explicit, compare, criticize, and evaluate their verbal explanations can be facilitated in the process of knowledge growth. In particular, a more knowledgeable and competent student could be successful in scaffolding the group process of scientific understanding helping his or her classmates recognize the limitations of representations through which they interpreted facts. Being challenged in their personal ideas about what air could do, the learners could elaborate and integrate knowledge at a more advanced level experiencing the need for conceptual revision. Analogies individually self-generated were collectively critically examined in the light of the new developing understanding. Therefore, some analogies were easily abandoned as considered completely incorrect while some others, the most appropriate, were accepted or refined as they had passed the collaborative critical examination.

The fourth objective aimed at investigating whether collaborative reasoning was fruitful at the individual level. In other words, whether conceptual growth was identifiable in the individual learners' explanations of the three phenomena as an effect of knowledge appropriation by socio-cognitive interaction in group discussions. The quantitative data indicated that the children significantly progressed in understanding each scientific phenomenon by appropriating knowledge from the collaborative discourse-reasoning, although not all conceptually grew at the same rate. Most of the children at the beginning knew that air existed everywhere but the idea of air around us "pushing in" constantly from all directions seemed to them difficult to be accept as some child maintained. The fact that air is all around us and that it is an intimate part of our environment but invisible and "even you touch it you don't get anything", at the beginning hindered the recognition of some of its properties by almost all the children. In many cases, indeed, in their conceptual structures air was associated with its motion so it was very complicated, for example, to figure out how the air in the room, where there were no draughts and breezes, could push on the cardboard and make it attach to the glass. The major qualitative change in the children's' individual explanations for all the three phenomena concerned the reference to the atmospheric pressure whose action was recognized by ne overwhelming majority. All but two recognized it in the first phenomenon and, explaining the second and the third one, one sixth of the children were also able to think of air pressure difference and explicited its direction. Conceptual advances were also detected in the identification of the similarities between the three phenomena: from a similarity based on the presence of a common element, the air acting on the objects involved, for example in holding something (the cardboard, the plunger, the tea) to a similarity based on the underlying principle of atmospheric pressure. As the children progressed in the scientific understanding of the three phenomena they were able to represent them within a more integrated and comprehensive explanatory framework. Moreover, in the final interviews almost all the children reported the criticism to some of the initial analogies discussed in group and the acceptance of others, and they also produced new appropriate analogies to communicate their new understanding.

The last objective concerned an exploratory analysis of the children's metacognitive awareness about their own current representations and their experience of conceptual growth. All but one explicited metacognitive reflections. By referring to their initial ontological beliefs about air, some of the children pointed out that the idea about air pressure in a closed container such as the classroom was initial implausible to their conceptual structures. The change of explanations was reported by seventeen children and several of them provided the reasons behind their current representations. Metaconceptual reflections were also expressed on the function of analogy and on the self-generated analogies to motivate the rejection or the validation of some of them in the light of the new shared knowledge. The explicitation of successful knowledge revision revealed they had experienced the need for changing conceptions in integrating the new developing material by self-regulated learning.

Educational implications

From the findings of this study two main educational implications can be drawn. First, the results provide evidence that the self-generation of analogies is a means through which students explicit their own representations appealing to the already possessed knowledge, as a starting point for conceptual growth. Self-analogizing, as a kind of self-explaining, is thus a constructive activity which encourages the integration of new developing material with existing knowledge, that is, it helps meaningful learning. Encouraging individual generation as well as collaborative development and modification of own analogies to explain scientific phenomena in the classroom is an appropriate way of giving students the opportunity to acknowledge and practice a kind of heuristic recognized as powerful in the practice of science. In everyday life individuals have to cope with problems and activities. Learning to produce, use, evaluate, and modify own analogies and explanations in classroom science learning is a personal resource which may be of great value also out of school.

Second, the results highlight a way to promote new levels of competence in learners operating within their zone of proximal development: to create a social constructivist learning environment based on classroom discussions in which students can question, criticize, and evaluate their different existing ideas brought to the science class. Teachers should consider that in becoming socialized to the complex scientific culture of our society, students need to be engaged in sharing meanings, ideas, and ways of reasoning and arguing. A new way of explaining scientific phenomena can be developed through socio-cognitive interactions in students' group discussions which is then appropriated on the individual plane. Collaborative discourse-reasoning distributes the thinking burden and makes new knowledge socially shared scaffolding the cognitive activity. Deeply engaged in taking charge of their own understanding process, students use arguments as tools to critically evaluate the status of own and others' self-explanations. Argumentation practice stimulated in a peer discussion on a knowledge object supports students in reflecting and being aware of the value or the limitations and inconsistencies of personal explanations promoting their metaconceptual awareness, crucial to conceptual development.

References

Bransford, J.D., Franks, J.F., Vye, N.J., & Sherwood, R.D. (1989). New approaches to instruction: Because wisdom can't be told. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 470-497). Cambridge, MA: Cambridge University Press.

Brook, A., & Driver, R. (in collaboration with D. Hind) (1989). *The development of pupils' understanding of physical characteristics of air across the age range 5-16*. Centre for Studies in Science and Mathematics Education, University of Leeds.

Brown, A.L. (1995). The advancement of learning. *Educational Researcher*, 23 (5), 4-12.

Brown, A.L. et al. (1993). Distributed expertise in the classroom. In G. Salomon (Ed.), *Distributed cognitions. Psychological and educational considerations* (pp. 188-228). Cambridge, MA: Cambridge University Press.

Brown, A.L., & Campione, J.C. (1990). Communities of learning and thinking, or A context by any other name. *Human Development*, 21, 108-126.

Brown, A.L., & Campione, J.C. (1994). Guided discovery in a community of learners. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 229-270). Cambridge, MA: MIT press/Bradford Books.

Brown, A.L., & Palincsar, A.S. (1989). Guided, cooperati learning and individual knowledge acquisition. In L.B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 393-345). Hillsdale, NJ: Erlbaum.

Brown, D.E. (1994). Facilitating conceptual change using analogies and explanatory models. *International Journal of Science Education*, 16 (2), 201-213.

Brown, D.E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science*, 18, 237-261.

Chi, M.T.H., de Leeuw, N., Chiu, M.H., & LaVancher, C. (1994). Eliciting Self-explanations improve understanding. *Cognitive Science*, 18 (3), 439-477.

Clement, J. (1988). Observed methods for generating analogies in scientific problem solving. *Cognitive Science*, 12, 563-586.

Clement, J. (1989). Learning via model construction and criticism. Protocol evidence on sources of creativity in science. In J.A. Glover, R.R. Ronning, & C.R. Reynolds (Eds.), *Handbook of creativity* (pp. 341-381). New York: Plenum Press.

Clement, J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. *Journal of Research in Science Teaching*, 30 (10), 1241-1257.

Collins, A., Brown, J.S., & Newman, S.E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L.B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453494). Hillsdale, NJ: Erlbaum.

Cosgrove, M. (1991). Learning science - a place for learners' analogies. Paper presented at the Annual Meeting of the Australasian Society for Educational Research. Brisbane, Queensland.

Dreistadt, R. (1968). An analysis of the use of analogies and metaphors in science. *Journal of Psychology*, 68, 97-116.

Driver, R. et al. (1995). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23 (7), 5-12.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education*, 75, 649-672.

Engel-Clough, E., & Driver, R. (1986). A study of consistency in the use of students' conceptual frameworks across different task contexts. *Science Education*, 70 (4), 473-496.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*, 7, 155-170.

Gentner, D. (1989). The mechanisms of analogical learning. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 199-241). Cambridge, MA: Cambridge University Press.

Gick, M.L., & Holyoak, K.J. (1980). Analogical problem solving. *Cognitive Psychology*, 12, 306-355.

Gick, M.L., & Holyoak, K.J. (1983). Schema induction and analogical transfer. *Cognitive Psychology*, 15, 1-38.

Glynn, S.M. (1990). The teaching with analogies model. In K.D. Muth (Ed.), *Children's comprehension of text: research into practice* (pp. 185-204). Newark, DE: International Reading Association.

Glynn, S.M. (1991). Explaining science concepts: A teaching-with-analogies model. In S.M. Glynn, R.H. Yeany, & B.K. Britton (Eds.), *The psychology of learning science* (pp. 219-240). Hillsdale, NJ: Erlbaum.

Glynn, S.M. (1994). *Teaching science with analogies. A strategy for teachers and textbook authors.*

Athens, GA: National Reading Research Center.

Hennessey, M.G. (1993, April). Students' ideas about their conceptualization: Their elicitation through instruction. Paper presented at the annual meeting ogif the National Association for Research in Science Teaching, Atlanta, GA.

Hesse, M. (1966). *Models and analogies in science*. South Bend, IN: Notre Dame University Press.

Holyoak, K.J. (1985). The pragmatics of analogical transfer. In G.H. Bower (Ed.), *The psychology of learning and motivation*, Vol. 19 (pp. 59-87). New York: Academic Press.

Joshua, S., & Dupin, J.J. (1987). Taking into account students conceptions in instructional strategy: An example in physics. *Cognition and Instruction*, 4, 117-135.

Kobayashi, Y. (1994). Conceptual acquisition and change through social interaction. *Human Development*, 37, 233-241.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education*, 77 (3), 319-337.

Larreamendy-Joerns, J., & Chi, M.T.H. (1994). Commentary. *Human Development*, 37 (4), 246-255.

Mason, L. (1986). Elaborazione ed acquisizione di conoscenze in classe: i concetti scientifici (Processing and acquisition of knowledge in the classroom: The scientific concepts). *Orientamenti Pedagogici*, 33 (3), 469-486 (In Italian).

Mason, L. (1988). Pre-conoscenze e apprendimento in bambini di scuola elementare (Prior knowledge and learning in elementary school children). *Scuola e Città*, 9, 374-387 (In Italian).

Mason, L. (1994 a). Analogy, metaconceptual awareness and conceptual change. *Educational Studies*, 20 (2), 267-291.

Mason, L. (1994 b). Cognitive and metacognitive aspects in conceptual change by analogy. *Instructional Science*, 22, 157-187.

Mason, L. (submitted). An analysis of children's reasoning and arguing in classroom discussions to construct new knowledge.

Newby, T.J., Eartmer, P.A., & Stepich D.A. (1994, April). Instructional analogies and the learning of concepts. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA.

Oppenheimer, R. (1956). Analogy in science. *American Psychologist*, 11, 127-135.

Prawat, R.S. (1989). Promoting access to knowledge, strategy, and disposition in students: A research synthesis. *Review of Educational Research*, 59 (1), 1-41.

Pontecorvo, C. (1987). Discussing for reasoning: The role of argument in knowledge construction. In E. De Corte, H. Lodewijks, R. Parmentier, & P Span (Eds.), *Learning and instruction. European research in an international context* (vol. 1, pp. 239-250). Oxford: Pergamon Press and Leuven University Press.

Pontecorvo, C. (1990). Social context, semiotic mediation, and forms of discourse in constructing knowledge at school. In H. Mandl, E. De Corte, S.N. Bennett, & H.F. Friedrich (Eds), *Learning and instruction. European research in an international context. Analysis of complex skills and* *complex knowledge domains.* (Vol. 2.1, pp. 1-26). Oxford: Pergamon Press.

Resnick, L.B., Levine, J., & Teasley, S.D. (Eds.) (1991). *Perpsectives on socially shared cognition.* Washington, DC: American Psychological Association.

Roth, K.J. (1990). Developing meaningful conceptual understanding in science: In B.F. Jones & L. Idol (Eds.), *Dimensions of thinking and cognitive instruction* (pp. 139-175). Hillsdale, NJ: Erlbaum-NCREL.

Ruggiero, S., Cartelli, A., Duprè, F., & Vicentini Missoni, M. (1985). Weight, gravity and air pressure: Mental representations by Italian middle school pupils. *European Journal of Science Education*, 7 (2), 181-194.

Séré, M.G. (1985). The gaseous state. In R. Driver, E. Guesne, & A. Tiberghien (Eds.), *Children's ideas in science* (pp. 105-123). Milton Keynes, UK: Open University Press.

Simons, P.R.J. (1984). Instructing with analogies. *Journal of Educational Psychology*, 76 (3), 513-527.

Stavy, R. (1991). Using analogies to overcome misconceptions about conservation. *Journal of Research in Science Teaching*, 28 (4), 305-313.

Stepich, D.A. & Newby, T.J. (1988). Analogical instruction within the information processing paradigm: Effective means to facilitate learning. *Instructional Science*, 17 (2), 129-144.

Sternberg, R.J. (1977). *Intelligence, information processing, and analogical reasoning.* Hillsdale, NJ: Erlbaum.

Sternberg, R.J. (1982). Reasoning, problem solving, and intelligence. In R.J. Sternberg (Ed.), *Handbook of human intelligence* (pp. 225-307). Cambridge, MA: Cambridge University Press.

Suzuki, H. (1994). The centrality of analogy in knowledge acquisition in instructional contexts. *Human Development*, 37, 207-219.

Treagust, D.F., Harrison, A., & Venville, G. (1993, April). Using an analogical approach to engender conceptual change. Paper presented at the annual meeting of the American Educational Research Association, Atlanta, GA.

Vosniadou, S. (1991). Designing curricula for conceptual restructuring: Lessons from the study of knowledge acquisition in astronomy. *Journal of Curriculum Studies*, 23 (3): 219-237.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, 4 (1), 45-69.

Vygotsky, L.S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds. and Trans.). Cambridge, MA: Harvard University Press.

Wertsch, J.V. (Ed.) (1985). *Culture, communication and cognition: Vygoskian perspectives.* Cambridge, Ma: Cambridge University Press.

Wittrock, M.C. (1985). Learning science by generating new conceptions for old ideas. In L. West & A. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 259-266). Orlando, Academic Press.

Wong, D.E. (1993 a). Self-generated analogies as a tool for constructing and evaluating explanations of scientific phenomena. *Journal of Research in Science Teaching*, 30 (4), 367-380.

Wong, D.E. (1993 b). Understanding the generative capacity of analogies as a tool for explanation. *Journal of Research in Science Teaching*, 30 (10), 1259-1272).

Zook, K.B., & Di Vesta, F.J (1991). Instructional analogies and conceptual misrepresentations. *Journal of Educational Psychology*, 83 (2), 246-252.

Zook, K.B., & Maier, J.M. (1994, April). Effects of learner schemata and self-referencing on analogical mapping processes. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA.

Author note

This article was written while I was a resident at the Rockefeller International Study and Conference Center in Bellagio (Como), Italy. To the Rockefeller Foundation I express my very grateful thanks.
I also wish to thank the elementary school teacher, Marina Egano, for her interest and precious cooperation with this study. Moreover, special thanks to all the children.

ERIC

First phenomenon

Initial session	Final session
Igor: The cardboard stays attached because the water in the glass produces pressure ... No, the air inside the glass keeps it, there's air inside which sucks the cardboard up in a certain way. In the glass there are both water and air.	*Igor*: There isn't any air inside the glass, where there's only water, but the air's outside and, from under the glass, it pushes the cardboard against the glass. Water pressure pushes down and air pressure up so the water doesn't fall out.

Second phenomenon

Initial session	Final session
Francesco: Now I'm trapping air, a little of it goes out but much more remains in the cup. There, on the rough wall, there are many very small holes so the air can escape.	*Francesco*: The air inside escapes and the air outside has a pressure on the plunger when I try to pull it off. It doesn't stay attached to the rough wall because the air can get into the cup and push but the outside air also pushes, so the forces are balanced.

Third phenomenon

Initial session	Final session
Giacomo: When you buy a can it's never full of something, there's always a little space for the air, so the air inside the can blocks the tea or coke from going out when you make one hole.	*Giacomo*: If there's only one hole, the tea pressure pushes to go out, the outside air pressure pushes to go into the can, the air can't go in and the tea go out because both find an obstacle.

Similarities between the phenomena

Initial session	Final session
Martina: There's always air inside, the air's the fundamental element: there, the air's inside the can because when in the factory the machines put the tea inside the can, while they put the tea in, the cans fill with air; in the other one the air's in the glass, it's not visible but it's there; here in the plunger, the air's here, inside the cup. All the objects that want to hold something have air inside.	*Martina*: What they have in common is the pressure of ordinary air. Outside air pressure makes things do what we've just seen. In the first experiment the outside air pushes the cardboard against the glass rim and the water doesn't come down. In the second experiment the outside air pressure keeps the plunger attached to the smooth surface, inside the cup there's no air and no pressure. In the third experiment the outside air pushes on the same hole on which also the tea pushes to come out and nothing comes out from the can.

Fig. 1. Examples of changes in the individual explanations

ERIC

Table 1. Frequency distribution of the different individual explanations given for the first phenomenon before and after group discussions (n=18)

	Before	After
- Water attracts the cardboard	5	0
- Water glues the cardboard	3	1
- The air inside the glass sucks the cardboard up	4	1
- Air cannot get in to replace water	2	0
- Outside air pushes the cardboard up and holds it up *	4	16

(*) *Significant difference at the .001 level (McNemar test).*

Table 2. Frequency distribution of the different individual explanations given for the second phenomenon before and after group discussions (n=18)

	Before	After
- I don't know	1	0
- The plunger is made of a special rubber	1	0
- The air trapped inside makes the plunger stick *	10	2
- No air inside the plunger	5	3
- No air inside the plunger and outside air pressure *	1	10
- Outside air pressure is greater than inside air pressure	0	3

(*) *Significant difference at the .005 level (McNemar test).*

Table 3. Frequency distribution of the different individual explanations given for the third phenomenon before and after group discussions (n=18)

	Before	After
- I don't know	1	0
- If there is only one hole the tea gets less force to go out. If there are two holes the tea gets more force to go out	2	1
- If there is only one hole the tea and the air inside the can have to go out from the same hole. If there are two holes the air inside goes out from one hole and the tea from the other	3	0
- If there is only one hole the outside air, that has to go in to allow the tea to go out, and the tea clash. If there are two holes the air goes in through one hole and the tea goes out from the other	9	2
- If there is only one hole the outside air and the tea push on the same hole. If there are two holes the outside air pushes and goes in through one hole and the tea pushes and goes out from the other *	3	11
- If there is only one hole the outside air pressure and the tea pressure are balanced. If there are two holes the tea pressure on a hole is greater than the air pressure.	0	4

(*) *Significant difference at the .005 level (McNemar test).*

Table 4. Frequency distribution of the different similarities identified between the three phenomena before and after group discussions (n = 18)

	Before	After
- There are no similarities between the three phenomena (only between two phenomena)	4	3
- In all the phenomena something does not happen	2	0
- In all the phenomena there is air inside a container	4	0
- In all the phenomena there is air that does something	5	3
- In all the phenomena there is no air inside a container	1	0
- In all the phenomena there is the same mechanism, that is, the ordinary air pressure which pushes continuously on something *	2	12