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Construction of a Precursor Model for the Concept of Rolling Friction in the Thought of Preschool Age Children: A Socio-cognitive Teaching Intervention

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Abstract The aim of this study was to explore the extent to which the characteristics of two teaching interventions can bring about cognitive progress in preschoolers with regard to the factors rolling friction depends on, when it is applied to an object that is freely rolling on a horizontal surface. The study was conducted in three phases: pre-test, teaching intervention, and post-test. Two teaching strategies were compared: one inspired by Piaget's theory (Piagetian approach) and one inspired by post-Piagetian and Vygotkian assumptions (socio-cognitive approach). A statistically significant difference was found between the pre-test and post-test, providing evidence that the socio-cognitive approach allows for the creation of a more appropriate teaching framework compared to the Piagetian one.

Keywords Preschool education · Friction · Precursor model · Teaching strategy · Socio-cognitive approach

The Research Framework

International organizations and educational systems (e.g., American Association for the Advancement of Science (1999); European Commission (2003); French Ministry of Education 2006) are emphasizing the need for science to constitute a subject to be taught to more and more citizens at increasingly younger ages. Within this framework, science is emerging no longer as a poorly defined entity in the various preschool curricula, but as a distinct subject, and indeed one that is often equal to language and mathematics. More and more studies concerning Science Education are exploring the epistemological and educational aspects of

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the introduction of science in preschool education (Fleer and Robbins 2003; Howe 1993). A part of these studies is related to the representations by preschoolers of natural phenomena and the concepts through which these are explained. Some recent studies on children aged 5–6, showed exactly the same results as relevant studies which used older children as their subjects. On the one hand, these studies showed that alternative representations in the thought of preschoolers are marked by characteristics that are fairly distanced from the characteristics of science models, while on the other hand they demonstrated the possibility to transform them through properly designed teaching interventions (Kampeza 2006; Koliopoulos et al. 2004; Zogza and Papamicael 2000; Ravanis 2005; Robbins 2005).

In preschool education, the nature of science activities differs greatly from the rest of the education levels. While having different pedagogical and educational starting points, kindergarten curricula theoretically cater for the overall, balanced development of preschool children's personality and thought and not so much for specialized knowledge. By studying a vast range of preschool curricula, teaching activities and relevant research reports we have been able to discern significant differences with regard to targets, content and organization of pedagogical applications, but also concerning instructional materials, children and teacher roles and means of assessment. This analysis led to a classification of the tendencies and trends leading to science teaching activities for preschool education (Ravanis 1994), which was developed over the following years based on research data as well as theoretical tools (Ravanis 2005). This classification distinguishes different approaches which can be grouped into three broader categories. The first category comprises suggested activities that are not systematically related to education research, while the other two categories consist of suggested activities related to the findings of specialized studies.

The first group of approaches leads to activities developed within theoretical frameworks dominated by empiricism and behaviorism. The teacher chooses the activity topic, prepares the materials and devices, presents the activity, coordinates the work done in class, raises questions, formulates the problems and provides explanations. These activities are developed based on the conviction that providing children with organized stimuli from science is enough to ensure successful learning. So the attempt to convey knowledge is based on a traditional concept about communication and learning in class, that of the teacher–transmitter and the pupil–receiver. All these choices suggested to teachers are almost never justified as to the logical capabilities of children's thought or their representations of the natural phenomena being examined (Paulu and Martin 1992; Hibon 1996; Conezio and French 2002).

The second category comprises studies and teaching activities inspired by Piaget's theory. As we know, a basic point of Piaget's epistemology is that the development of human intelligence is the result of the establishment of intellectual structures through the activity of the subject on the objects of the material world, and not of the shapeless, sensory perception of data from the physical and social environment. It is, therefore, expected that didactic approaches based on Piaget's theory should lead to strategies which provide children with the possibility of manipulating material objects and experimenting, that is, the possibility of intellectual activity capable of leading to the assimilation of physical knowledge. In particular, with respect to the construction of physical knowledge, the educational procedures suggested for pre-school children display the characteristics mentioned above. With that in mind, it is suggested that special environments be created in which the possibility of assimilation of physical knowledge can be maximized. The activity topics as well as the overall organization of each activity are chosen in order for young children to have the opportunity to handle specially chosen teaching materials and to experiment on their own or in collaboration with others. The teachers design the main axes of the activity, encourage the children, ask them questions, and intervene when they judge that a child is facing insurmountable obstacles, without of course offering solutions or answers, but by enriching the environment and posing questions that can facilitate a child's thought process. Finally, the educators assess the results of the children's work as well as their own planning with a view to modify whatever they deem necessary for the improvement of the activity (Kamii and De Vries 1978; Kamii 1982; Crahay and Delhaxhe 1988; Inagaki 1992; Kamii and De Vries 1993; Metz 1995).

The third group of approaches consists of all those research attempts and science teaching activities that are inspired by post-Piagetian and Vygotskian assumptions (Doise and Mugny 1984; Rogoff 1990). These approaches are either socio-cognitive or as sociocultural (Fleer 1991; Ravanis and Bagakis 1998; Robbins 2005) and stress the following two points: on the one hand the child's initial cognitive state and its change, and on the other, making use of all communication and interaction possibilities, as well as the effects of the greater cultural environment, so as to lead a young child to the construction of its individual cognitive tools.

A special strategy along these lines is based on the hypothesis that learning is the product of systematic socio-educational interaction, performed on targets which we have designated by research to constitute obstacles to children's thought (Martinand 1986). This perspective renders it possible to work with young children in order not only to make some simple progress but also to build precursor models in their thought. Precursor models are cognitive entities of limited range as far as use and practice are concerned, which include a restricted number of elements from and relationships between the actual scientific models (Lemeignan and Weil-Barais 1993; Weil-Barais 2001; Ergazaki et al. 2005). Thus, if precursor models are successfully constructed, since these become established as intermediate entities between the children's first representations and the scientific models, they may offer certain crucial possibilities: namely, the systematization and explicit expression of personal representations, the understanding of simple causal relations and the identification of variables. It is exactly for this reason that precursor models fittingly prepare young children's thought for the construction of actual scientific models. The research presented herein is based on this context and is related to the construction of a precursor model for rolling friction in preschool children's thought.

No relevant research data was found with respect to the issue of understanding the concept of rolling friction. However, some few studies do exist on the subject of children's understanding of sliding friction and these allow us pinpoint the issues on which we need to focus. A relevant study conducted on students aged 10–11 attempted to achieve conceptual change through a special teaching intervention in the understanding of the variables on which friction depends (Tsagliotis 1997). According to the findings of the study, which were in agreement with those of Stead and Osborne (1981), the children were led from an intuitive approach towards weight and the nature of the surfaces in contact to an approach that recognizes these two parameters as the decisive variables for frictional forces to be present. Another study performed on students aged 9–13 showed that children of that age can easily recognize weight as the variable friction depends on (Kanari and Millar 2004). In one of our own studies, conducted on 5- to 6-year-old children, we tried to find out whether the children were capable of constructing a precursor model for sliding friction. Indeed, after detecting the difficulties in the children's thought, we used a socio-cognitive teaching intervention, leading them to understand the effect of the weight of the rolling object and the nature of the surfaces in contact have on the distance the object travels on a horizontal surface (Ravanis et al. 2004).

Let us take a look at the problem the current study deals with. Whenever an object (a sphere, for instance) rolls upon a surface, a moment of force occurs that resists the motion and this moment is called rolling friction. Rolling friction exhibits properties similar to those of sliding friction (meaning the force exerted on an object that is sliding upon a surface). In proportion to sliding friction, rolling friction depends on: (a) the vertical force exerted on the rolling object by the surface it is rolling upon and (b) the plasticity of the materials that the object and surface are made of. Moreover, the plasticity of these materials is responsible for generating a vertical force between the surfaces which, together with the object's weight, form a force pair. This force pair resists the motion and rolling friction is, in effect, its moment. And when the problem is restricted to the rolling of an object upon a fixed horizontal surface, then the numerical value of the vertical force equals the value of the rolling object's weight.

Thus, in the effort to construct a precursor model for the concept of rolling friction in children's thought, we must achieve the conceptual construction of: (a) the weight of the rolling object, as estimated by the children in a qualitative scale of 'lighter–heavier' and (b) the nature of the surfaces in contact, again qualitatively assessed by the children as 'smoother–rougher', as the two parameters affecting the resistance to the free rolling of an object on a horizontal surface. This resistance can be related to the distance traveled by the object.

But the question arising here is, by which teaching approach do we attempt to bring about this conceptual transformation in the children? For if we exclude the empiricist approaches, we can turn to the two other frameworks dealing with such studies: the Piagetian and the socio-cognitive ones. Which teaching strategy would best construct precursor models for rolling friction in preschool age children? A strategy that uses Piagetian pedagogical tools, according to which the environment must facilitate systematic interaction between the child and the teaching material, or a socio-cognitive strategy, which promotes the notion of organized cooperation between the teacher and the children trying to respond to the challenge of the problem they're faced with?

The research carried out over the past few years in this field and which we have already referred to stresses the effectiveness of socio-cognitive strategies. Thus it may be hypothesized that such a framework will lead us to better results than would a Piagetian strategy, when used with a teaching intervention regarding the concept of sliding friction. We hypothesized, therefore, that the children of the experimental group (who took part in a socio-cognitive teaching activity aiming for systematic interaction with the teachers) would be able to better understand the role that weight and/or the nature of the surfaces in contact have on the rolling of objects, compared to the children in the control group (who participated in a Piagetian process of discovering the properties and function of materials and objects).

Methodology

Sample

The sample of the study consisted of 88 subjects aged 5–6, with an average age of 5 years and 8 months. There was an equal number of boys and girls, all coming from Greek state kindergartens of the same area, bearing the same middle socioeconomic background. The experimental and control groups involved 44 subjects each and were both balanced as to the children's age, gender and cognitive ability according to their responses to a pre-test they took. The children were randomly chosen among those who volunteered to take part in 'the game'. All the children had already attended at least 1 year of kindergarten, so that they were already familiar with the conditions of teaching interaction with adults. They were also checked as to their use of the concept of distance ('far–near') without any difficulty.

Design

The research was conducted in three phases (pre-test, teaching interventions and post-test) with the sample split into the control group and the experimental group. During the pre-test and post-test, the subjects' reasoning was recorded through personal interviews, each of which lasted 20 min and took place at a specially designated area in the kindergarten. The pre-test was carried out 4 weeks prior to the teaching interventions, while the post-test was administered 4 weeks after the interventions, for all subjects of both groups. The data analysis was based on the transcriptions of the recordings as well as the personal observation protocols.

Material

Throughout the process, a simple slinging apparatus was used (Fig. 1).

The apparatus consists of a fixed and a moving part. The fixed part is an elongated metal track that can be coated with different materials so that the objects moving on it stop at different points due to varying friction. The moving part ends in a vertical metal plate that is freed through use of a lever, pushed up to a certain point by two compressed springs and then strikes objects that have been placed at that point. We have already established in a previous study (Ravanis et al. 2004) that through the use of this apparatus children do not attribute the different distances traveled by the objects moving on the track to any possible difference in initial impulse. This is so because children recognize that all the objects receive the same initial 'force' by the moving part of the apparatus, the word 'force' being used in its everyday sense, of course.

Three balls of equal volume are also used during the pre-test and post-test. The first one (ball 1) is relatively light and has a smooth outer surface, the second one (ball 2) is much heavier than the first and has the same surface, while the third (ball 3) has the same weight as the first one but its surface is made of a very rough material.

The following materials were used throughout the teaching intervention:

(a) Two identical toy-cars (C_1 and C_2) which store energy when rolled backwards, so that they can then spring forward when released. We attach a small yet heavy box to one of the two toy-cars (C_2).

Fig. 1 The projecting apparatus

(b) Two elongated tracks, one made of smooth plastic and the other made of carpeting, both placed parallel to the floor. The rolling of the cars on the surface of these tracks takes place under different conditions of rolling friction.

Tasks Used in the Pre-test and the Post-test

Before suggesting the two tasks to the children, an attempt was made to familiarize them with the apparatus and its operation:

> We have created an apparatus so as to always push the objects with the same force. By pulling this metal rod, the lever, the machine strikes all the things placed on it just as hard. So when we use this machine we all hit things with the same force.

Then a discussion took place with the children about the constant force the apparatus exerts on the objects. Before moving on to the next phase, it was made certain that the children were comfortable with the reasoning that recognizes the constant initial impulse. Following that, the three balls were given to the children and they were encouraged to handle them and tell the differences between them. During the handling the researchers talked with them until they were sure the children would make proper use of the qualitative scales of 'lighter–heavier' and 'rougher–smoother'.

After verifying that all children are familiar with the balls and their differences, the researcher asked each child to pick the "shiniest and lightest ball" and roll it using the apparatus. The children were encouraged to mark the place on the track where the ball stops by placing a peg at that spot.

Task 1. The children are asked to predict and mark where ball 2 (which is heavier than ball 1) will stop and after they do so they're asked to explain why they believe ball 2 will reach the chosen spot compared to the spot they marked for ball 1. What we are attempting here is to detect the reasoning formulated by the children regarding the distance traveled by the two similar looking balls on the same track, when these balls do not weigh the same. In this task, by conversing with the children we can find out whether they still correlate the distance traveled with the weight of the object; that is, whether they recognize the greater weight as a cause of greater resistance to the rolling of ball 2 with respect to ball 1.

Task 2. In this task the children are asked to predict and mark the location where ball 3 will stop (ball 3 weights the same as ball 1 but has a rougher outer surface). When a child designates the place where ball 3 will stop, he/she is asked to explain this prediction in relation with the spot he/she marked for ball 1. Through this procedure we try to approach the kind of reasoning children formulate when comparing the distances traveled by balls 1 and 3, which have the same weight but are made of materials whose roughness is obviously very different.

Teaching Interventions

Teaching interventions were made on a one-to-one basis by teachers who had been trained for this purpose (teachers–researchers). Each child is given two cars and has their operation explained to him/her, though all children proved familiar with that type of toy. Then they are left to play with the cars freely for a while. After talking with them we make sure that they can distinguish, in a qualitative manner, between the lighter (C_1) and the heavier (C_2) car. Then we hand them the two tracks on which the cars will move, the smooth plastic track and the One made of carpeting, and discuss the different nature of the surfaces with them.

The general context of the activity is a short story in which we get the children involved. In reciting this story, we tell the children that a man leaves his home, which is at point H, and drives his car in order to get to his office, which is at point B. All the relevant questions deal with whether the man will reach the office. The process is realized in two phases and is the same for children of both groups up to a certain point (Fig. 2).

First Phase: The Motion of Car C_1 on the Two Different Tracks

The teacher–researcher explains to the children that there is a man who every morning leaves home and drives to work. She asks them to drag the light car, C_1, from position D to position A of the plastic track and then release it. The car rolls until it reaches position B where the office is. Straight after that the child is asked to replace the plastic material with the carpet and repeat the same procedure, dragging the car from D to A and releasing it. Before the child proceeds with doing so, he/she is asked to state whether he/she thinks the car will now reach office B, stop short of it or move past it, and also to justify his/her answer. Then the child proceeds with the activity, the car rolls and stops at a shorter distance than it did before. The child is then asked, “why did it reach that position and not the previous one?”

If the child can correlate the difference in the distance traveled by the car with the material of the two tracks it moved upon, then the teacher–researcher discusses with the child further, so as to verify that he/she indeed attributes the observed change to the different nature of plastic and carpeting.

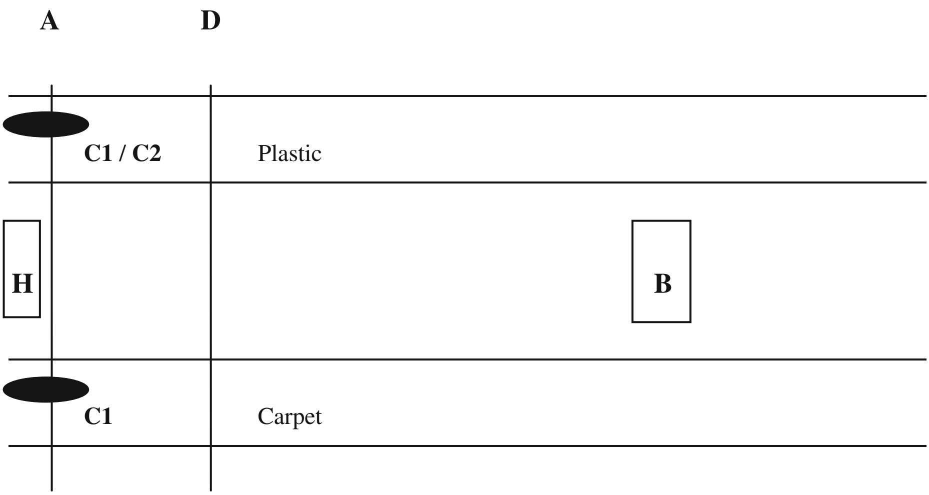

Fig. 2 The experimental situation

If the child does not refer to the difference in the surfaces then the teacher–researcher follows different strategies in dealing with the two groups of children:

Experimental group In order to promote communication and interaction oriented at turning the child's thought to the nature of the surfaces, the teacher–researcher triggers a conversation with the child by saying: "I think the car stopped before it reached the office because this road is not as slippery as the previous one... but then again... I'm not sure, could you maybe help me out?" Having started the discussion with this question, if the child seems to simply agree with this rationale, he/she is reminded of his/her previous answer and asked "why he/she changed his/her mind." The child then gives this some thought and proceeds to answer the question. Thus a short conversation ensues, during which thoughts and arguments are exchanged based on the different rationales put forth. Over the course of this discussion the child's thought is destabilized and reconstructed, since the technique with which his/her reasoning is confronted necessarily causes distance of opinion and intervention by the researcher so as to shift attention to the role of the nature of the surfaces, while at the same time preventing the child from consenting to the researcher's view merely due to social decorum.

Control group In this case, when the children's responses were not satisfactory, the teacher–researcher asked the children to look at the overall situation afresh and consider the differences between "the first time when the man sets off and reaches his office and the second time when he does not make it." From that point on, the children were encouraged to work with the teaching material in any way they wished; this was the main activity in this group. When they were deemed to have completed their activity, they were asked once again whether they had come up with any new ideas about the difference in the car's two motions.

Second Phase: The Motion of Cars C_1 and C_2 on the Plastic Track

After completing the procedure with the two different tracks and with the children present, the teacher–researcher places the plastic track on the apparatus. She tells the children that "one day, the man wishes to carry a heavy cupboard to the office using his car" and ask them to use car C_2, on which the 'cupboard' has been steadily fastened. After agreeing to move this car in the same way, each child is asked to predict whether it will reach office B and to explain his/her prediction. The child drags the car from point D to point A and releases it. The car then stops short of office B and we ask the child to tell us "why did it reach that spot and not the office, like it did before?"

If the child mentions the difference in weight between cars C_1 and C_2 then the conversation continues in order to ascertain that he/she is indeed capable of formulating qualitative speculations based on the 'greater weight–shorter distance' pattern.

If the child does not refer to the weight difference between the two cars then the teacher–researcher follows different teaching strategies for the two groups of children:

Experimental group For the children in the experimental group an attempt is made to create conditions of communication that will lead their thought to focus on the weight of the moving car. Thus the teacher–researcher tells the child: "I think the car did not make it to the office because this time it is loaded with weight... it's heavier than the previous one... but then again... I'm not sure, could you help me?" In the conversation that follows, the same technique is used as in the first phase. If the child mentions the significance of weight now, he/she is reminded of his/her previous answer and exchange arguments and thought based on his/her two conflicting answers. Conversation with the child continues until the teacher–researcher establishes that the dynamics of interaction have been exhausted.

Control group When the children's responses do not turn to the role of weight the teacher–researcher asks them to describe how the two cars moved and where they stopped and to reflect on the differences between "the first time when the man started off and made it to the office using the first car and the second time when he did not manage to reach it using the second car." The children are then encouraged to freely work with the teaching material; this was the main activity in this group. When they are thought to have completed their activity, they are asked once again whether they have come up with anything relevant to the difference in the two cars' motions.

Criteria of Evaluation

In order to evaluate the changes in the reasoning of the subjects of the two groups in the pre-test and the post-test, in relation to the two variables, weight and the nature of the surface, we used a scale consisting of two levels: *progress* and *no progress*. *Progress* from the pre-test to the post-test is defined as the transition from the reasoning that does not take into account the factors friction depends on to the reasoning that does include those factors, even if it does not result precisely in the desirable prediction. *No progress* refers to the reasoning that bears the same qualitative attributes in both the pre-test and the post-test. The evaluation of the children's performance was carried out by the teacher–researchers and then by a third, external researcher. The degree of agreement between the evaluations of the teacher–researchers and the external researcher was over 93%.

When examining the changes in the responses of the subjects between the pre-test and the post-test, accounting for both variables simultaneously, a three-level scale was used for the analysis: *progress, partial progress, no progress.* In this case, *progress* is marked by the transition from reasoning that mentions neither the weight of the objects nor the nature of the surfaces during the pre-test, to reasoning that includes both parameters during the post-test. *Partial progress* is made when there is transition from reasoning accounting for either one or none of the variables to reasoning accounting for both or one of them, respectively. Finally, what is meant by *no progress* is that the responses remain at the same level.

Results

The Mann–Whitney test was applied in order to establish whether the differences between two independent samples coming from the same population were statistically significant or not. The level of statistical significance was set at 0.05.

In Task 1, where the car weight constitutes the variable, the answers and justifications provided by the children are classified into two categories:

(a) The first category comprises answers that acknowledge the weight of each ball as a factor affecting the distance it travels. To quote an example (student number follows in brackets):

> ...this one (ball 2) will not go that far because it is heavy... the first one (ball 1) goes fast because it is light... I don't know how short it will fall (ball 2)... but it won't reach the peg (marking the position of ball 1) (7).

We also included in this category two answers that recognize the significance of the ball weight but do not clarify with any certainty its part in the distance traveled by the lighter and heavier ball. For example, “When this ball goes (ball 2) it will go farther... because it’s heavier... no... nearer, it seems to me...” (36). Similar responses are included in the first category because what we are concerned with in the first task is mainly the acknowledgement of the importance of the ‘weight’ factor and not simply the formulation of ‘correct’ replies.

(b) Answers that do not recognize the ball weight as a factor affecting the distances traveled fall into the second category. It consists of responses whose justification is not based on the weight, irrespective of whether the subjects predict the distances traveled correctly. For instance, “It (ball 2) will reach the same spot... the machine will hit it with the same force and it will reach here again (points at the peg marking the arrival point of ball 1)” (61).

In Task 2, where the variable is the nature of the balls, the replies and explanations provided by the subjects are classified into two categories:

(a) The first category consists of answers in which the nature of the surface on which the car moves is recognized as a factor affecting the distance it travels. Quoting a few examples “This ball (ball 3) will not get to where the other one (ball 1) did... it’s not shiny, it’s hard” (41), “...I think this one (ball 3) won’t be able to get there (position of ball 1) like the other one did... it’s different somehow... it’s not shiny so as to roll easily...” (27).
(b) Answers that do not acknowledge the effect of the surface nature of the balls on the distances traveled fall into the second category, irrespective of whether the estimations are ‘correct’ or ‘wrong’. For instance, “It (ball 3) will reach the peg... it can get there because it’s light, not heavy like the one before (ball 2)” (36), “it (ball 3) can go as far as the other one (ball 1)... and even farther... nothing stops it on its way” (7).

Table 1 shows the changes in the responses of the subjects in both groups, as observed between the pre-test and the post-test.

The changes in the children’s estimations seem to confirm our hypothesis, whether with respect to recognizing the effect of the ‘surface nature’ variable or that of the moving objects’ ‘weight’ variable. More precisely, in both tasks 1 and 2, more subjects from the experimental group made progress in the post-test compared to those from the control

Table 1 Changes in the responses of children of the experimental and control groups, as observed between the pre-test and post-test

	Change	Experimental group	Control group
Task 1	Progress	33	7
	No progress	11	37
Task 2	Progress	29	4
	No progress	15	40

Task 1: U=396, p<0.003. Task 2: U=198, p<0.001.

Table 2 Changes in the responses of every subject, as observed between the post-test and the pre-test for both tasks simultaneously

	Change	Experimental group	Control group
Tasks 1 and 2	Progress	26	2
	Partial progress	10	7
	No progress	8	35

U=473, p<0.003.

group and these differences were statistically significant (Task 1: U=396, p<0.003. Task 2: U=198, p<0.001).

In Table 2 we present the changes in each subject's reply in both tasks simultaneously, as observed between the post-test and the pre-test. Thus, through studying all this data, we determine the number of subjects attaining recognition of both variables on which the friction between the two surfaces depends.

Our hypothesis seems to be verified by the discovery of both changes simultaneously in the thought of all the children who managed to attain them. This was based on the assumption that the experimental group's subjects simultaneously recognize both factors that friction depends on, compared to the control group's subjects, and that these differences have statistical significance (U=473, p<0.003).

Conclusions and Discussion

This study shows that children aged 5–6 are capable of approaching certain qualitative attributes of rolling friction. Indeed we have seen that, with the appropriate teaching intervention, more than half the children in the experimental group exhibit total progress. This means that they are able to describe and account for the factors affecting the rolling of an object on a horizontal surface and thus are led to the conceptual construction of a precursor model. The results also verify the assumption according to which the socio-cognitive approach allows for the creation of a more appropriate teaching framework compared to the Piagetian one; using the socio-cognitive approach, 59% of the children made progress while this percentage was less than 5% when using the Piagetian one. So we see that in order to overcome children's learning obstacles in science, it does not suffice to foster an environment that abounds in materials, facilitations and opportunities for interaction between children and objects. On the contrary, the children's progress is significant when placed in an environment with a systematic teaching intervention that is oriented at constructing the characteristics of a precursor model for rolling friction. This study's findings lead to the acknowledgement of the particular contribution of teaching activities in which the interaction is achieved based on existing obstacles in children's thought.

The substantial difference between the two teaching interventions appears when we discover that the children deal with the issue of the rolling cars without focusing their reasoning on any of the two variables discussed. In the experimental group, the researcher tries to create an environment that is suitable for discussion and turn the children's thought to the variable under discussion. This aims at rendering the variable an object of socio-educational interaction as well as an object of particular cognitive processing on the children's part. On the other hand, in the control group, the researcher tries to facilitate the children in handling the materials again and detecting in them the differences that cause the distances traveled by the cars. Thus he helps them organize their reasoning based on their interaction and handling of objects and the results of those manipulations.

At this point we could mention the different perspectives in the two approaches and their importance in gradually constructing models in the thought of young children that are related to becoming acquainted with the natural world. The direction the Piagetian approach follows, leads to the conceptual construction of properties through the results of the children's actions with the teaching material, the material's response and their subsequent efforts to modify the objects. The teachers' influence is limited to the systematic preparation of the teaching material, to providing support and to expanding the children's own activities. In the other direction, the teachers–researchers' dominant activity is handling any difficulties they discover the children are facing. This leads to exhausting all means of interaction so as to render the children capable of achieving patterns of action upon the objects in their environment, the use of which will allow them to handle similar problems later on. This is in effect an effort which, according to Vygotskian terms, could be described as a teaching attempt to move children's thought into the zone of proximal development (Vygotsky 1962).

Thus, from an instructive viewpoint we could assert that a Piagetian strategy, even when leading to satisfactory results, which was not the case in our study, aims at understanding the properties of the material world while anticipating their future reconstruction into higher and higher levels. On the contrary, a socio-cognitive strategy aims at shaping precursor models in children's thought. On the one hand these models are, in principle, compatible with the scientific ones and on the other hand they are restricted to a limited range of application, whose constant upgrading and expansion is, however, anticipated.

Nevertheless, the overall organization of the activity for the experimental group's children differs greatly from the actual conditions under which activities are implemented in kindergarten, even though we could say that the findings of this study offer some interesting ideas. However, the decision not to carry out our research in the classroom constitutes a conscious methodological choice on our part, designed to offer us certain possibilities. Indeed, our choice to work individually with each child allows us to systematically study whether, from a cognitive point of view, it is possible for children to be led to understand the two parameters we examined and therefore to build a mental precursor model for rolling friction. Thus, once we have established that the children are able to approach the cognitive parameters of this precursor model, we can then design teaching procedures which, within the same theoretical context, will evolve into actual kindergarten classes.

How should we go about developing related activities? First of all, we can offer the children objects that differ in terms of weight and the nature of their surfaces and roll along different horizontal surfaces. By creating an improvised game and by gradually suggesting various tests in the classroom in which we interact didactically with the children, we may be able to lead their thought to the discovery of the basic parameters in rolling and to create a qualitative mental scale of variables (heavy–light rolling object and/or smooth–rough surface on which the object is moving). On this scale, the children would be able to find the necessary relation between the distances covered and the variables. In this way, we may well be in the position to develop, in children's thought and in regular kindergarten classes, a precursor model that links the distances covered to the two variables. This possibility, combined with the respective findings regarding rolling friction (Ravanis et al. 2004), leads young children to the appropriation of the world of friction without the teacher even having to mention the concept. The research we are currently pursuing is moving in that direction.

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