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What factors does friction depend on? A socio-cognitive teaching intervention with young children

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The objective of this study was to investigate the effect of a socio-cognitive teaching strategy on young children. It tests their understanding of the factors that friction depends on when an object is projected across a horizontal surface. The study was conducted in three phases: pre-test, teaching intervention, and post-test. The sample consisted of 68 preschool children who were assigned to two groups according to age and cognitive ability, based on their responses to a pre-test. The children in the experimental group participated in activities that were approached from a socio-cognitive perspective while the children in the control group participated in the same activities but from a Piagetian perspective. A statistically significant difference was found (Mann–Whitney *U*-test), between the pre-test and the post-test, providing evidence for the effect of the socio-cognitive strategy on children's understanding of a 'precursor model' for the concept of friction.

Introduction

Over the past two decades there has been a great interest in studying pupils' misconceptions and the process of conceptual change in the area of science education. However, very few studies have been conducted with preschool children. A number of recent studies, involving children aged 5–6 years, have reported misconceptions in their thinking, which, as with older children, differ from accepted scientific ideas. They have also presented teaching interventions that have been designed to change these misconceptions (Hadzigeorgiou 2001, Ravanis 1999, Sharp 1995, Solomonidou and Kakana 2000, Zogza and Papamichael 2000).

In the context of preschool education, studying science differs in both form and structure from the work carried out in secondary or even primary education. Here, science activities are approached in the context of the whole curriculum and children's overall development. Consequently, only a small portion of these activities is devoted to the discovery of the natural world.

Given, however, the great number of pedagogical ideas and teaching beliefs upon which various curricula and programmes are based, there are also various and different approaches to working with science content. After studying a wide spectrum of curricula and programmes of science activities for preschool education, we have proposed a classification of three pedagogical schools, in the contexts of which both the design of teaching activities for preschoolers and the design and implementation of related research takes place (Ravanis 1994, 2000).

Activities that are characterized by their empirical perspective in presenting experimental processes and teaching material belong to the first category

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(Chauvel and Michel 1990, Halimi 1982, Harlan 1976, Hibon 1996, Paulu and Martin 1992). The main idea behind these activities is the importance of the provision of stimuli through which the senses register new data. What is of particular interest is the fact that the proposed activities derive from the empiricist epistemological point of view rather than research aiming to explore children's thinking processes.

Those activities that are developed on the basis of the Piagetian perspective on the construction of knowledge belong to the second category. This concerns a framework that was created by pedagogists who accept the basic principles of Piaget's theory and work in the field of preschool education. In other words, this amounts to a specialized teaching strategy, which we call 'Piagetian'. Although one of the basic targets of this approach is the construction of physical knowledge, it has not, up to now, had any interaction with Science Education research. In this context, and according to research results, the proposed activities help children interact with the selected pedagogical material in appropriately designed educative environments. Thus children are helped to construct physical knowledge (Crahay and Delhaxhe 1988a, 1988b, Kamii 1982, Kamii and De Vries 1978). Given, however, that the teacher plays mainly a supportive and encouraging role, and that the pedagogical material should be such that children themselves can manipulate it, the Piagetian perspective on developing activities has certain limitations.

Activities that are based on a broad context of theoretical approaches fall within the third category. In this context learning is understood as a product of social interactions taking place around target concepts that, according to research, are obstacles to children's thought (Martinand 1986, 1989). Therefore the proposed activities are developed on the basis of a series of organized teaching interventions. These facilitate the interaction between teachers and children with the aim of overcoming predetermined cognitive obstacles (Coquidé-Cantor and Giordan 1997, Katsiavou et al. 2000, Ravanis 1996, Ravanis and Bagakis 1998, Robbins 2002).

These kinds of activities can lead, under certain conditions, to the construction of 'precursor models'. These are compatible with scientific models, since they are constructed on the basis of certain elements included in the scientific models, and have a limited range of application (Lemeignan and Weil-Barais 1993). 'These precursors are cognitive constructions (concepts, models, procedures, etc.) generated by the educational context. They constitute the moulds for subsequent cognitive constructions, which without their help, would be difficult, or impossible' (Weil-Barais 2001: 188). Our own research work falls within this category. The research we are reporting here concerns the construction by children of a precursor model for the concept of friction.

As is well known, the interaction between two objects in contact, sliding in relation to each other, can be described as the resultant of the parallel to the common surface force, which is called 'friction', and the force that is vertical to that surface. The appearance of the frictional force depends on a number of factors, most of which play a role in certain cases. Usually, in science education, the force of friction is studied in relation to two factors: the vertical force, and the nature of the surfaces in contact. When the whole problem is limited to the movement of an object on a horizontal and fixed surface, then the force applied by that surface on the object is equal to the weight of the object. We can therefore assume the weight of the moving object is a variable in determining frictional force.

Thus the attempt to develop a precursor model for approaching friction focuses on the construction of two factors affecting the motion of an object projected across a horizontal surface that relate to the distance travelled by the object: (a) the estimated weight of the moving object on a qualitative scale 'lighter–heavier', and (b) the nature of the surfaces in contact assessed on a qualitative scale as 'smoother–rougher'.

There have been a few studies regarding the understanding of the force of friction by young children. In a study with 9-year-old to 13-year-old pupils in England, it was found that children of that age range easily recognize weight as a variable upon which friction depends (Kanari and Millar 2000). In another study with 10-year-old to 11-year-old pupils, there was an attempt to induce, through a special teaching intervention, cognitive change with regard to the factors upon which the force of friction depends (Tsagliotis 1997). According to the results of that study, which were similar to those reported by Stead and Osborne (1981), the children were led to an approach that recognizes the weight and the nature of the surfaces as variables of crucial importance for the appearance of the force of friction. In a study conducted with preschool children on the understanding of the two factors to which friction on objects moving on a horizontal surface is attributed (i.e. the weight and the nature of the surfaces in contact), cognitive obstacles in children's thinking were registered: about one-third of the children predicted and attributed the change in the distance covered by the moving objects to the change in weight, while only two children out of 42 (5%) recognized the change in the nature of the surfaces in contact as a factor to be considered (Apostolidou et al. 1998).

Which strategy, however, will we adopt to approach the transformation in children's thinking? If we exclude the empiricist approach, we can turn to the two theoretical frameworks that may support the development of related activities: the Piagetian and the socio-cognitive. Differences characterizing the two approaches led us to formulate a research question concerning the change of that kind of thinking: Which instructional strategy would be more effective in helping children construct a precursor model for the force of friction? A Piagetian strategy favouring children's interaction with the pedagogical material, or a socio-cognitive strategy that promotes systematic cooperation between teacher and children trying to respond to the challenges of posed problems?

Research conducted recently in this field stresses the effectiveness of socio-cognitive strategies (Howe 1993). This allowed us to formulate the hypothesis that, in the case of friction, the results of such a choice as a teaching strategy would be better than the results reached through a 'Piagetian' strategy. We hypothesized, therefore, that the children of an experimental group participating in an instructional activity aiming at their systematic interaction with the teachers would more easily understand the role of weight and/or the nature of the surfaces compared with the children of a control group participating in a Piagetian activity concerning the discovery of the properties and function of objects.

Methodology

Sample

The sample of the study consisted of 68 subjects, 34 male and 34 female (age 5–6; average age, 5.7 years), who were children attending public kindergartens. Of those

Figure 1. The projecting apparatus.

children 34 were assigned to the experimental group and 34 to the control group. Children were grouped by age and cognitive ability according to their responses to the pre-test. All children had already attended 1 year in kindergarten, and had become familiar with teaching interactions taking place in the classroom setting. All children could use the concept of distance ('far–near') without difficulty.

Design

The study was conducted in three phases (pre-test, teaching intervention and post-test). The data of the study consisted of children's responses and explanations to two tasks used during both the pre-test and post-test. These were collected through individually structured interviews that took place in an especially arranged area in the kindergarten. The pre-test took place 10 days before the teaching intervention and the post-test 15 days afterwards. The analysis of the data was based upon the recorded discussions (between children and the researcher) and individual observation protocols.

Materials

Throughout the study a simple projecting apparatus, as seen in figure 1, was used. The apparatus consists of a mobile part, which (a) is released through a lever, (b) is pushed up to a certain position by two springs and (c) strikes objects placed on a fixed point. The immobile part of the apparatus consists of a track that can be covered with various materials. Objects can move and come to a stop on the track due to the frictional force developed between it and the moving objects. This apparatus was used because in a preliminary study, we found that several children attributed the changes to the distances covered by the moving objects when pushed to the different magnitudes of the initial forces applied on these objects. It is well documented by research that intuitive thinking can lead even older children to infer that 'the quantity of motion is proportional to the quantity of the force' (Gunstone and Watts 1985). When this apparatus was used, all children in our sample accepted that the applied force always remained the same. For both the pre-test and the post-test, three cardboard cubes of equal dimensions were also used. The first cube (cube 1) was quite light and covered by a smooth paper, the second cube (cube 2) was much heavier than the first one and was covered with the same material, while the third cube (cube 3) had the same weight as the first cube but it was covered with sandpaper.

During the teaching interventions the following materials were used:

(a) Two dolls, one bigger and heavier than the other. We chose dolls of different size since for children a difference in size often means a difference in weight.
(b) A cardboard box intended to move along the track, inside which the two dolls were placed, one at a time. The use of the box was justified on the grounds that both dolls could move in the same way since the factor of 'surface of contact' with the track, remained constant.
(c) Two strips, one made of smooth plastic and the other one of carpet, which were laid on the fixed part of the projecting apparatus, to allow the motion of the object to take place under different frictional conditions.

Tasks used in the pre-test and the post-test

At first the researcher presented children with the projecting apparatus and explained its function: 'We have made this machine that pushes with the same strength every time we use it. By pulling this (piece of iron), the machine hits all objects placed on it with the same strength. So when we use the machine we all hit the things with the same strength'. Subsequently she asked children to comment on the action of constant force and continued when we were certain that their explanations were satisfactory. She then gave each child three cubes and urged him/her to hold them in his/her hand and play with them so that he/she became aware of their differences.

As soon as the researcher made sure that each and every child had become familiar with the cubes and their differences, she asked children to give her 'the smooth and light cube' (cube 1) and predict the point on the track it would stop if struck by the moving part of the apparatus. She encouraged children to mark that point by placing a peg.

- *Task 1.* The researcher asked children to predict and mark the point on the track at which cube 2 (which is heavier than cube 1) would stop. As soon as children did that she asked them to explain why they believed that cube 2 would reach the position they marked in relation to cube 1. Through this task she tried to probe children's thinking in regard to the distance travelled on the same track by the two objects of different weight. This way enabled her to determine whether children related the distance to the weight of the object; that is, whether they recognized the greater weight as a cause of the more limited motion of cube 2 in comparison with cube 1.
- *Task 2.* Finally, the researcher asked children to predict and mark the point at which cube 3 (of the same weight as cube 1 but with a rougher surface) would stop, and to explain their predictions by reference to cube 1. With this task, she tried to ascertain children's thinking when a comparison was made between the distances travelled by cubes of the same weight but different surface roughness. Given that during the projection and movement of the two cubes the only variable was the material of their surfaces, she could judge the causal relationship between different distances travelled by cubes 1 and 3 and the nature of their surface.

Table 1. First phase of the teaching intervention: the different tracks.

Experimental and control group
The researcher asked each child to place the box with the light doll in it on the plastic track and pull the lever. Thus the system (box and doll) was propelled up to a point that the child marked by placing a peg on the wall of the track
She then asked the same child to replace the plastic material with the carpet, to place the box with the same doll in it at the same starting position and place a chocolate where the peg was 'so that the doll would take it'
As soon as the child placed the chocolate, the researcher asked him/her whether 'the box with the doll would stop, before the chocolate, or past it'; she also asked the child to justify his/her prediction
Immediately after that the researcher pulled the lever and the box stopped having covered a smaller distance than before. The researcher then asked the child: 'Why did it go there and not to the same point as before?'

⇓

Experimental group		*Control group*
When the child made caperence to the change in the nature of the material with which the track was covered, a discussion followed in order to ascertain whether the child attributed the observed change to the difference in the nature of the materials	When the child did not caper to the change in the nature of the surfaces, the researcher said to him/her: 'I think that it did not arrive at the point it did before, because this floor is not . . . like the previous one . . . but . . . again, I am not sure, could you help me?'. When in the discussion that followed it was simply ascertained the child's agreement with her/his previous response, the researcher asked her/him why she/he changed her/his mind. The child thought and responded, and a short discussion took place, during which there was an exchange of arguments. Thus children were led to some form of cognitive dissonance, since on the one hand the technique whereby the researcher confronted children's thinking inevitably created a disagreement of perspectives, while on the other hand it did not allow the development of a consensus	When children's answers were not satisfactory the researcher simply encouraged them to manipulate the different material of the track and talked with them until she was certain they recognized those differences and the importance they attached to those differences. The children manipulated the materials and some of them asked for more information about their nature and their characteristics while they kept on manipulating them

Teaching interventions

Teaching interventions took place individually. The researcher explained again to every child the function of the projecting apparatus and discussed the idea of the constant force exerted by the machine on the projected objects. In a first phase, the children were given two dolls, and as soon as they became familiar with them they identified, in the course of a discussion with the researcher, the lighter and heavier doll. Subsequently, in a second phase, the researcher gave children two strips, one

Table 2. Second phase of the teaching intervention: the different weights.

Experimental and control group
The researcher asked children to place the plastic track on the apparatus and, in using the box with the light doll in it, to pull the lever
After they marked the position reached by the box, they repeated the process, this time using the heavy doll
The researcher, just like before, asked each child why the box had reached that position instead of going as far as it had before

⇓

Experimental group		*Control group*
When the child mentioned the difference in the weight of the second doll an in-depth discussion followed	When the child did not caper to the factor of the weight, the researcher said to the child. 'I think that the box did not stop where it had before, because now it has the heavy doll inside . . . the box is heavier than before, . . . but . . . again . . . I am not sure, could you help me?'. In the discussion that followed the researcher asked the child to explain why the box did not reach the chocolate and when a consensus had been reached, the researcher herself defended the child's initial thought until the child formed some definite view	When children's answers were not satisfactory the researcher simply encouraged them to feel the different weights of the two dolls and discussed it with them until she was certain they recognized those differences and the importance they attached to those differences. The children manipulated the materials and some of them asked for more information about their nature and their characteristics while they kept on manipulating them

consisting of smooth plastic material and the other of carpet, and discussed with them the different nature of those materials. The two strips would cover the track on which the box with the doll would move. Tables 1 and 2 present the basic points of the two phases of teaching intervention.

Criteria of evaluation

A scale consisting of three levels (progress, no progress and regression) was used to assess conceptual changes between the pre-test and post-test phases, in the children of both groups. We defined 'progress' as a shift from not taking into account the factors that friction depends on to taking those factors into account, even if this does not result in a precise prediction. The level of 'no progress' was defined as a representation that has the same qualitative characteristics in both the pre-test and the post-test. Finally, 'regression' was defined as a conceptual shift from taking into account the factors on which the friction depends during the pre-test to not taking these into account in the post-test.

Results

The Mann–Whitney *U*-test was utilized for calculating the statistical significance of the observed changes. The selection of this kind of test was justified on the grounds that our measurements were performed on an ordinal scale and we used two independent samples drawn from the same population. The level of statistical significance was set at 0.05.

In the first task involving the weight of the moving object as a variable, children's responses and explanations fell into two categories:

(a) The first category of responses includes those that took into account the weight of the cubes as a factor influencing the distances travelled by the cubes. For example, 'the other cube (that is, cube 2) will arrive nearer because it is heavier . . . whereas the first one (cube 1) was lighter'. Included in this category is a small number of responses that considered the role of the weight but it was not clear whether the distance the lighter or heavier cube would travel was attributed to the role of that variable. For example 'it will not go to the same position because it is lighter (cube 2) . . . it will go nearer . . . no . . . farther . . . I don't know . . . I am not sure but it will go elsewhere'. Such responses were included in this category given that what interested us in the case of the first task was not simply the 'correct' responses, but whether children ascribed significance to the factor of 'weight'.

(b) Responses that did not take into account the weight of the cubes as a factor influencing the distances they cover when moving on the track belong in the second category. Responses in which the explanations were not based on the factor of the weight, regardless of whether or not the children made the correct prediction about the distances they travelled, are also included in this category. For example, 'Since the boxes are identical they will go to the same position', 'This box (cube 2) will arrive where the other one (cube 1) will, because the machine pushes them the same'.

In the second task, in which the nature of the surface was a variable, children's responses and explanations, also fell into two categories:

(a) The first category comprises of responses that considered the nature of the surface in contact as a factor influencing the distances travelled by the cubes on the track (before they come to a stop). For example, 'this box (cube 3) will stop nearer than the other (cube 1) because it cannot slide wel l . . . it is not smooth . . .', 'no this one (cube 3) will not arrive there (where cube 1 did) because . . . it has that black paper on the outside (sandpaper), which is not slippery'.

(b) In the second category we included those responses that did not consider the differences in the nature of the surface of the cubes when estimating the distances travelled by the cubes, irrespective of the 'correctness' of the responses. For example, 'this (cube 3) will arrive nearer . . . this is what I believe as I hold it', ' it (cube 3) will reach the end (the child points to the end of the track), because that is where the road ends'.

Table 3 presents the changes observed in the responses of children of the experimental and control group between the pre-test and the post-test.

Table 3. Changes in the responses of children of the experimental and control group between the pre-test and the post-test.

	Change	*Experimental group*	*Control group*
Task 1	Progress	23	11
	No progress	11	21
	Regression	0	2
Task 2	Progress	21	3
	No progress	13	31
	Regression	0	0

These changes appear to confirm our hypothesis regarding the consideration by children of both the 'weight' and the 'nature of the surfaces in contact' as variables in predicting the motion of an object on a track. More specifically, in tasks l and 2, more subjects from the experimental group made progress in the post-test compared with those from the control group, and those differences were statistically significant (Task 1, $U = 363, p < 0.01$; Task 2 $U = 272, p < 0.003$).

Table 4 presents the changes in the responses of every subject, as they were observed between the post-test and the pre-test, simultaneously, for both tasks. Through this reading of data we attempt to identify the number of the subjects that recognize both variables upon which friction between two surfaces depends.

On the basis of those responses, it appears that the hypothesis that more children from the experimental group recognize both factors that friction depends on simultaneously is confirmed. The difference between the two groups is statistically significant ($U = 282, p < 0.003$).

Conclusions and discussions

The results of this study provide strong support for our initial hypothesis: preschool children are able to approach the problem of a moving object coming to rest as the result of friction. This study also showed that both the overcoming of cognitive obstacles and the construction by young children of a precursor model for friction require systematic guidance of their activities. Thus, after the teaching intervention with both groups we can detect that it was six out of 10 children (or 61%) in the

Table 4. Changes in the responses of every subject, as they were observed between the post-test and the pre-test simultaneously for both tasks.

	Change	*Experimental group*	*Control group*
Tasks 1 and 2	Progress	21	3
	Partial progress	2	8
	No progress	11	21
	Regression	0	2

experimental group who made progress compared with the 9% in the control group. These results lead us to recognize the significant contribution of the teaching activities involving interactions structured around the existing obstacles to children's cognitive development.

Here we could take a closer look at the two different teaching approaches, especially at their significance in the process of constructing mental models for understanding the natural world. The first approach (i.e. the Piagetian approach) leads to the mental construction of the properties (of materials) through children's interaction with the pedagogical material and their subsequent efforts to detect differences and similarities in the behaviour/reaction of that material. The teacher's influence encompasses systematic preparation of pedagogical material, support and extension of children's activities. In the other approach, construction of the properties of the materials, which constitute the fundamental elements of a precursor model, is dominated by the teacher's effort to deal with the difficulties encountered by children. This effort explores all possible means of interaction in order for children to become capable of constructing action schemes about the objects of the environment and then using them to solve related problems. Thus, from an instructional perspective, we could affirm that a Piagetian strategy, even if leading to satisfactory results (something that was not achieved in our study) aims at the understanding of the properties of the material world with the expectation of their reconstruction at a higher level. In contrast, a socio-cognitive strategy aims to develop in children's thinking precursors models; that is, models that on the one hand are compatible with the scientific ones, and on the other hand have a limited range of application. At the same time, however, they could anticipate their continuous improvement and the broadening of their range of application.

It was also found that the dynamics of the interactions between the experimenters and the children favoured the cognitive progress of the latter. However, the entire organization of the activity with the children of the experimental group is too far from the actual conditions in the kindergarten, no matter how interesting the results of this study. Nevertheless, these results allows us to hypothesize that the possible can be transformed to the feasible. If we find that children are able to approach the cognitive parameters of that precursor model, we can subsequently design instructional processes that gradually approach the actual conditions in a kindergarten from the same theoretical perspective.

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