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Exploring the Classroom: Teaching Science in Early Childhood

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Abstract: This study tested and integrated the effects of an inquiry-based didactic method for preschool science in a real practical classroom setting. Four preschool classrooms participated in the experiment (N = 57) and the children were 4–6 years old. In order to assess children's attention for causal events and their understanding at the level of scientific reasoning skills, we designed a simple task in which a need for information gain was created. Compared to controls, children in the post-test showed significant learning gains in the development of the so-called control of variables strategy. Indeed, they executed more informative and less uninformative explorations during their spontaneous play. Furthermore, the importance of such programmes was discussed in the field of STEM education.

Keywords: *Inquiry, preschool science, STEM-education*

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Introduction

There is a general belief that when a child is exposed to science early in his/her childhood, it will be more comfortable for him/her later on in life. Furthermore, early experiences are assumed to be critical for both school readiness and as foundations for future learning (Brenneman, 2011). In addition, early engagement in science stimulates the development of concepts of oneself as a science learner and a participant in the process of science (Mantzicopoulos & Samarapungavan, 2007). However, the first problem is that science in preschool classrooms often does not receive a sufficient amount of attention compared with other subjects. One of the reasons is that teachers are not familiar with the basic knowledge that preschoolers have about science concepts, the reasoning skills they possess and the potential limits of those skills (Brenneman, 2011). Young children then have few or no opportunities to learn science compared with other subjects in their early years of education, meaning that the cognitive skills that form the basis for scientific thinking and learning are clearly underestimated (Sackes, Akman, & Trundle, 2010).

Another problem is that few studies show how teaching interventions are translated into the classroom. Indeed, training studies frequently involve many labour-intensive and time-consuming methods. They are often minimally guided as well. It is difficult to translate a laboratory method into the practical setting of the classroom (e.g. class organisation), and the central aim is focussed on conceptual understanding (Lorch, et al., 2008; Zohar & Barzilai, 2013).

In order to avoid the aforementioned problems, compact didactic methods can be designed in which the child plays an active role in its own learning process. This process ideally does not involve many instructions and builds on the child's curiosity and its urge to interact and inquire. These principles can be found within an inquiry-based pedagogy in science. Indeed, scientific inquiry is primarily about the process of building understanding by collecting evidence to test the possible explanations in a scientific manner. It explains how smaller ideas (e.g. stand-alone observations) have the potential of growing into big ideas (e.g. theories and phenomena that are related to each other) (Harlen, 2013). Activities are then designed in such a way that children are intellectually engaged and challenged through questions and extended interactions and by giving responsibility for what is accomplished. It is clear that an inquiry-based approach offers possibilities for children to make sense of the world and their environment rather than learning isolated bits and pieces of phenomena.

Science in preschool should not be an obstacle. It is a fact that humans are born inquirers. For instance, when a young child is trying to find out how a sound box must be held in order to generate a pleasant melody, it may pay attention to the relation of its actions and the effects that follow. It is plausible that

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the child detects that orientation is a significant action, instead of tapping on the box. Similar experiences combined with other aspects may be generalised, which may lead to the recognition of regularities or the understanding and expectations of actions within the child's everyday world. However, the aforementioned example is in contrast with scientific inquiry. Indeed, the development of understanding should depend on the processes that are involved in making predictions, seeking solutions and gathering evidence to test whether they are being carried out in a scientific way (Harlen, 2013). Children do not do this automatically (e.g. Klahr & Nigam, 2003; Lorch et al., 2008; Chen & Klahr, 1999; Masnick & Klahr, 2011). Sometimes children may focus on the wrong variable or they may vary more than one variable at a time, which results in incorrect and inconsistent conclusions. Many studies have shown that children normally do not test their initial ideas and that even when they do, they may not do it scientifically. Within scientific learning, it is therefore certainly important that children are helped to develop the skills they need in scientific investigation (Harlen, 2013). Teachers should design environments in which scientific activities occur when the child explores, plays and learns. They should guide them by supporting self-regulation skills (e.g. planning), asking probe questions, focussing the children's attention to causes and effects or helping them reflect on what was found. In this way, the focus is on process skills rather than on formal knowledge and conceptual change. However, in this study we are not considering children's understanding of inquiry but rather their ability to conduct, engage and act in inquiry activities. Action provides information. In exploratory activity, the act of children spontaneously seeking information about the properties of events in their worlds is important. Young children learn to control action intentionally, learn to control external events and thus learn to gain information about the world around them and their own capabilities. For instance, what is being learned in causal relations is to differentiate events into subevents in which objects have different functions (Gibson & Pick, 2000).

In the present study, we design didactics based on the inquiry pedagogy of science for preschool children of 4–6 years of age. The didactics consider the following characteristics: (1) scientific activities are meaningful through the use of rich contexts and build on the natural curiosity of early learners, (2) children are challenged with questions that make them think and rethink, (3) children are allowed to interact with one another and (4) research activities encourage the child to collect the data in a systematic way.

By means of 15 activities, children explore different scientific phenomena. For instance, they are encouraged to explore the effect of weight and position on a balance or they are engaged in exploring the sound effect of filling water in glasses of various dimensions. A teacher then uses probe questions in order to direct the attention of the child to the event, its properties, the relations or higher-order relations between these properties or sets of properties. In addition, the teacher poses questions at crucial moments, inviting the children to reflect. Through this act of scaffolding, a deeper level of learning is promoted, which may encourage children to make or to understand predictions about what will happen next or what will happen if something else happens (French, 2004).

Assessing scientific reasoning skills

Using inquiry-based science education at preschool level is one thing, and assessing the subsequent learning and skills is another. Indeed, science is not among the domains that are well represented in the catalogue of reliable and valid assessments available to educators and researchers. In other words, few comprehensive tools exist (Brenneman, 2011). However, such instruments would be interesting when for instance teachers want to assess the effectiveness of a curriculum or a particular programme or when they want to find out to what extent individual children has acquired the desired skills.

However, this entails a number of issues. The first problem is that children's causal reasoning skills are often underestimated because of their overreliance on domain-specific prior beliefs, masking its formal reasoning abilities (Cook, Goodman, & Schulz, 2011). Indeed, even when children are capable of using scientific processes in some circumstances, they do not necessarily do so in other circumstances (Harlen, 2013). In other words, the nature of the context in which they use scientific processes matters. The second problem is that when children are tested on real-world phenomena where complex and multivariate problems occur or with contexts that do not fit in with young children's natural way of processing experience, the test will probably once again underestimate the children's capacities. This is in accordance with information processing theories such as cognitive load theory, arguing that environmental complexity overloads working-memory capacity, which is pronounced more in younger children (Sweller, 1988).

In order to circumvent these problems a task can be designed in which the context is less crucial, reflecting the children's real formal reasoning abilities. Gopnik, Sobel, Schulz, and Glymour (2001) have already tested whether young children are able to make causal inferences on the basis of simple patterns of variation and covariation. When two variables together cause an effect but only one variable generates the effect independently, children reason that the other variable cannot be the cause. In another example, Cook et al. (2011) show that preschoolers spontaneously select and design actions in order to effectively isolate the relevant variables in cases where information is to be gained. The authors use an experimental method in order to find out whether preschoolers are able to distinguish informative from uninformative interventions in a simple exploration environment. The authors manipulate the base rate of candidate causes, affecting the potential of information gain. It is then hypothesised that when children understand that causal variables need to be tested separately, they have to design actions in order to effectively isolate the relevant variable of cause.

Although these methods are promising, they have never been used in combination with inquiry-based science programmes. In the present study we therefore investigate to what extent there is a transfer between interventions that encourage children's exploration behaviour in rich and authentic contexts with complex relationships between different variables (the usual classroom) on the one hand and their formal reasoning abilities in simpler contexts on the other.

To that end we use a less context-dependent assessment method in which a need for information gain is created. We demonstrate that a box lights up when a wooden block is moved while it is put upright; thus, the variables block position and block orientation are varied at the same time. At the first sight, it is not possible to infer the real cause of the box lighting up unless one examines the effect of the variables one by one. In our opinion, a similar assessment tool not only informs us about the extent to which a child learns from exploration during the intervention phase but also gives us information about a child's understanding at the level of scientific reasoning skills, which happens to be an important aim of an inquiry-based approach.

Inquiry-based programmes for science are not really new. For instance, van Schijndel, Singer, Van der Maas and Raijmakers (2010) show that preschool science consisting of guided play can improve young children's spontaneous exploratory behaviour at a higher level. This is especially the case in children with low exploratory play levels before the observations are started. The authors used a 6-week programme with 2- and 3-year olds in a day-care centre. Children's exploratory play was observed in a pretest and a post-test. The programme consisted of guiding spontaneous play activities in the sandpit. Two science subjects, 'sorting and sets' and 'slope and speed', were alternated week by week and were connected to the themes that had been elaborated on in the children's classrooms. For sorting and sets, objects had to be sorted according to colour, size or function. The experimenter let the children play and let them repeatedly sort, vary and observe the obtained effects. For slope and speed, the slope of the piles and the position of the tubes were varied, while the speed of the balls was monitored. For both the activities, the experimenter asked the children for explanations and guided them by varying the different variables while monitoring the effect. In a pretest and a post-test, exploratory behaviour was observed. Exploratory behaviour was classified as scientific if the following four conditions are met: (1) manipulation, (2) repetition, (3) varying and (4) observing the effects. In the post-test, the authors found a higher proportion of high-level exploratory play compared with children who did not receive the instructions.

In another study, French (2004) describes the ScienceStart! Curriculum. The programme consists of different activities with a four-part cyclic structure: (1) ask and reflect, (2) plan and predict, (3) act and observe and (4) report and reflect. All the activities involved open-ended investigations of materials and phenomena. After that, explorations were discussed and other questions that children wanted to address were generated and executed. Everything ended with a culminating activity. In order to assess the effectiveness of the programme, quality measurements were carried out for teacher impressions and parent impressions. Furthermore, a significant increase in receptive knowledge of vocabulary and mastery of science content in the areas of colour, shade and air was found.

Both the approaches bring children into contact with scientific environments that are rich in both experience and language (French, 2004). An experience-rich environment leads to a better understanding of events and materials, and a language-rich environment allows for authentic communication with adults who support the children's acquisition of meaning and pragmatic functions of language (French, 2004).

In the present study verbal instructions and comments form part of the intervention. In accordance with French (2004) we assume that language in scientific contexts (teacher–child and child–child) is essential for children in order to acquire content knowledge and strategy learning by listening to each other. Furthermore, through the use of language, explanatory language (Peterson & French, 2008) and the ability to talk about concepts (Gelman, Brenneman, Macdonald, & Roman, 2009) are encouraged.

Although the aforementioned studies are promising, our study distinguishes itself from the above in various ways. A first difference is the fact that our intervention is integrated in a real practical classroom setting. Secondly, the age of the children varies from 4 to 6 years. Furthermore, we assess the scientific reasoning skills by means of a quantitative method, and lastly, we use a less context-dependent test in which the child is less inclined to rely on prior knowledge.

Methodology

Research goals

The present study offers an inquiry-based didactic method encouraging scientific reasoning in children of

4–6 years of age. It includes 15 activities that aim to provoke a set of domain general process skills such as observing, describing, comparing, questioning, predicting, experimenting, reflecting and cooperating. Secondly, we design a test in order to quantify learning gains at the level of inquiry. The main research question in this study is whether the inquiry-based teaching affects real experimenting. On the basis of this, we formulate three hypotheses:

H1: Children who receive the intervention will carry out more meaningful and informative experiments in a post-test relative to a pretest and relative to controls.

H2: It is expected that the amount of uninformative post-test experiments relative to all experiments carried out decreases in experimentals but not in controls.

H3: It is expected that children with the lowest exploratory levels in the pretest will benefit most from the intervention in experimentals but not in controls.

Sample and Data Collection

Fifty-seven children participated in the experiment, in which 31 were boys and 26 were girls. The age of the children ranged from 48 to 72 months (M = 60.3; SD = 5.4). Children came from four different classrooms from two Dutch-speaking schools (Belgium). Schools were selected randomly. The children were selected on the basis of the permission of the parents, the age of the child (4–6 years), the language of the child (Dutch), participation in both the pretest and the posttest and, finally, child's willingness to show involvement during the interventions. Two classrooms (one group of 4/5-year olds and another group of 5/6-year olds) were allocated to the intervention group (27 children), the two other classrooms (again one group of 4/5-year olds and another group of 5/6-year olds) were allocated to the control group (30 children). All the children met our selection requirements. Children were not tested on any field in advance.

Materials

Activities. The intervention phase consisted of 15 activities that were spread over 7 consecutive weeks (see Table 1 for an overview). All the 15 activities were designed and coordinated closely with the pre-service teacher and with the actual teachers of the classes. As a result, activities were more closely connected to the children's interest and curiosity. Further activities were selected when more than one variable at a time could be controlled and when the child was well stimulated, visually or auditory.

Light box and block. A custom-built wooden box of 23 × 23 × 6 cm dimension was set up. The top of the box had a semi-transparent platform (21 cm diameter). A light bulb was fixed in the box itself. With the aid of a hidden remote switch, the experimenter could turn the box off and on. When the switch was in on mode, the light bulb in the box was lighted up. When the switch was set to the off position, the light was turned off.

In addition, one wooden red block of 15 × 3 × 3 cm dimension was used.

Procedure

The experiment consisted of a pretest, a 7-week intervention period and a replication of the pretest, that is the post-test. The control group did not receive the interventions but only performed the pre- and post-tests.

Pretest and Post-test. The pretest (and the post-test) was designed in order to detect patterns in children's exploratory behaviour. The pretest was assessed in a separate room of the child's school.

The experimenter was a final year pre-service preschool teacher. In the context of her research stage, she assessed and coded both the pretests and the post-tests. The experimenter followed a protocol.

The child sat on a table upon which the light box was positioned. On the left side of the box a wooden block was laid (counterbalanced across the children). The experimenter showed the child the red block and the light box (see Figures 1 and 2). The child was first allowed to touch, to play and to inspect the red block as long as he or she liked. Then the experimenter introduced the 'magic box' and told them that there were strange things going on with that box and that she needed the child's assistance. This playing and magic introduction increased the child's commitment. In addition, the possible intimidating effect of being interviewed by an adult in a one-on-one situation was limited. Then, the red block was placed to the left side of the light box (start position). The experimenter told the child to look very carefully. She took the red block and placed it on its long side on the transparent platform of the light box, this was in the lower left corner (from the point of view of the experimenter). Then, the experimenter placed the red block back to its start position. Then the block was placed again on the light box; however, this was now on the other side of the light box (the upper right corner) while the block was put upright (these actions were counterbalanced). The box immediately lighted up. When the light box was activated, the experimenter said, 'Wow, look at this, I wonder what makes the machine go?' Then, the experimenter laid the block to its original position (light went off) and said, 'Go ahead and play, you can try'. The child was left to play for 75 seconds, the experimenter pretended to be busy with other things (reading a book or writing a text).

Table 1: Used materials and investigation objectives for 15 activities

Subject	Materials	Investigation objectives
Sinking and Floating	An aquarium filled with water, 1 cork, 5 coins, 1 jar with lid, 1 jar without lid, 1 ball, several paperclips, marbles, 1 sponge	Investigating the effect of combinations of weight and size on floating and sinking
Swing	One wooden construction with two swings (height is made adjustable), several large and small marbles, different metal weights	Investigating the effect of weight and rope length on its swinging speed
Magnifying glasses	Three different types of magnifying glasses, several books, several pictures that were enlarged, were made smaller or that were distorted	Investigating the effect of different types of magnifying glasses on the visibility of objects. Investigating the effect of holding distance on the visibility of scanned objects
Magnets	One wooden rod, several paperclips, 1 bucket with sand, several buttons, coins, pieces of paper, aluminum foil in spheres, several pebbles, 1 iron bolt, 1 wooden block, 1 magnet, 1 tea light	Investigating the effect of type of material on its magnetic attraction force
Keys and locks	Different keys and padlocks, 1 wooden board	Learning to test systematically different keys in order to in order to find the right lock.
Balance scale	One wooden shelf with fulcrum in the middle, 1 wooden shelf with fulcrum on one side, 4 wooden blocks with different weights	Investigating the effect of weight and position on the balance
Slopes	One wooden shelf, different wooden blocks, sugar cubes, toy cars, marbles and a ping pong ball	Investigating the effect of slope on rolling speed with different types of objects
Magnets in water	One fishing rod with a large magnet, 1 fishing rod with a small magnet, a jar filled with water, 1 paperclip, 1 marble, 1 coin, 1 magnetic letter, 1 metal key, 1 clothespin	Investigating what materials are magnetic and which not
Musical glasses	8 glasses with two different sizes, 1 wooden stick, 1 plastic stick, 1 measuring cup filled with water	Investigating the effect of filling different glasses with different amounts of water on the sound that is produced by tapping on the rim
Color filters	A box painted in black inside with a peephole, different torches with different sizes, different plastic color filters, 1 white sheet of paper	Investigating the effect of wearing different colored glasses on colors of objects in the environment
Gears	Plastic gears with different sizes, plastic gears with different pictures, a plastic board equipped with holes	Investigating the effect of different gear sizes on its rotation speed. Investigating the effect of number of gears on the direction of rotation
Shadows	One white projection screen made of cardboard (30 cm x 20 cm), different colored objects, 1 torch (white light), 1 torch (colored light), 1 candle light	Investigating the effect of size and distance on the size and position of a projected shadow
Bolts and Nuts	Several bolts and nuts, 2 wooden boards	Investigating the strongest way to fit 2 wooden boards tightly together
Rubber bands	Different pockets. One wooden strut. Different rubber bands. Several flints of different weights and sizes, wooden blocks of different weights and sizes, marbles of different weights and sizes	Investigating the effect of weight on the degree of stretching of different rubber bands
Dropping objects	One bucket filled with sand, different marbles, 1 ping pong ball, 1 pencil, 1 metal ballpoint pen, 2 wooden blocks, 1 spoon, 1 measuring rod	Investigating the effect of weight and start position on the size of hole that is caused by its impact

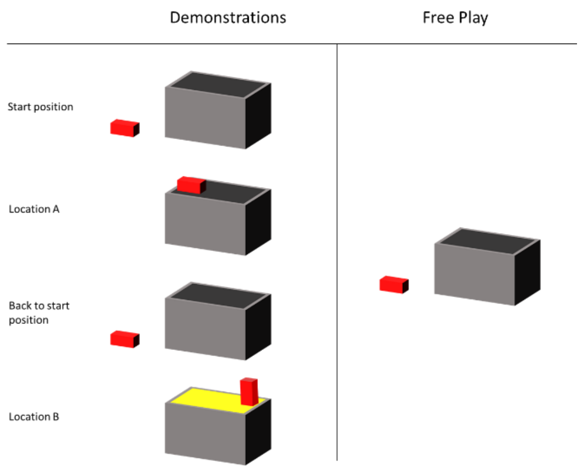

Figure 1. Procedure of the pretest (and posttest)

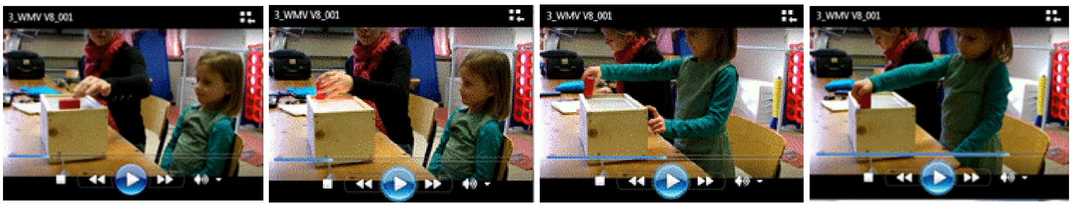

Figure 2: Pictures of different stages of the pretest (and posttest)

The dependent measure of interest in the pre- and post-test was whether children performed informative and meaningful experiments or actions. An experiment was meaningful when the child tested one variable at a time. For instance, the child varied block orientation while keeping block position constant or otherwise, it was counted each time the child did this. We also observed whether the child performed other informative actions. For instance, the child moved the box, while keeping other variables constant, or the child hit on the top of the box while keeping other variables constant. Another dependent measure of interest was the number of uninformative or confusing experiments. An uninformative experiment was counted each time a child tested *more* than one variable at a time. For instance, moving the block while moving the box, moving the block while changing its position on the box surface, moving the block while hitting harder/softer with the block on the box surface and so on. The post-test was conducted 2 or 3 days after the intervention was finished. The post-test procedure was identical to the pretest. Controls were also tested within the same period of time.

After the post-test, the videotapes were coded by the second author and by a coder blind to both the hypotheses and the conditions to determine interobserver reliability. Interobserver reliability was 0.88 (Pearson r). For the oldest children of the control group (N = 16), results of the math subtest of the Toeters (Dudal, 2000) were available.[1] The Toeters is often used to determine school readiness in 4- to 6-year-old children. We found a significant correlation between our pretest results for these children and their conservation scores ($r = 0.39$; $p < 0.05$) but not for identifying numbers (0–10) nor for understanding math concepts (e.g. tallest, smallest, more, less, and one more). Furthermore, the actual teachers recognised pretest (and post-test) results from the experiences they had with the children. In particular this was the case for the cognitively strongest and the weakest children. Both the sources of information indicate some validity of the pretest and post-tests used in the present study. The pretests and post-tests were recorded with a Sony digital camera, type DCR-HC23.

This block test measures the objectives we intended to. The way children design interventions in a simple toy world implies something about their ability to attend to the kinds of evidence that distinguish states of knowledge from states of uncertainty (Cook et al., 2011). Such skills are encouraged during the training interventions. In the box test, we expect that children test several hypotheses repeatedly since is the child has the motivation to light up the box; the experimenter asked the child to find out how the box was lighted up. Of course, the child will fail to do, which stimulates to try/design other actions/experiments. This is also encouraged within our training interventions: '*when something does not lead to a good*

[1] This subtest was assessed 2 months after the post-test was completed and was executed by a teacher.

result, try something else'. Of course, a child's exploration behaviour will extinct because the box will never light up. However within a time period of 75 seconds, most of the children are still motivated to find out the hidden mechanism or rule. In such a way counting the number of informative experiments that are executed implies something about the ability to design and to execute valid and logic experiments, that is formal reasoning.

Intervention. The intervention was only for the experimental group. Controls could not play and experiment with the different activities; they only performed pre- and post-tests and followed their normal classroom courses. During the intervention of the experimental group, 15 activities were used. In each session, two to four activities were selected at the same time. Each activity was selected at least twice. Activities were presented in a separate corner of the preschool classroom and could be chosen by the children during the course: *free playing initiative*. For all the activities, the contexts of science subjects were connected to the themes that were going on at that moment in the classrooms in order to reach a maximal immersion in the environment. Each child played at least 10 times in the science corner (see Figure 3 for an example).

The activities during the intervention consisted of three different phases. In the introduction phase (the whole class group), the teacher presented the materials for the selected activities. It was shown what one could do with these materials, and a link was established with the child's actual knowledge. For instance for floating and sinking, it was asked what rubber ducks do (floating or sinking) or it was asked what kind of materials should sink or float, and so on (see Table 2 for an overview). No instructions were given. The second phase is the exploration phase, where children could freely play with the materials. This was done in small groups of children (three to five children) and took place in one to two science corners. Children played in each session for about a maximum of 40 minutes. The third part was called the trigger phase, in which the teacher posed probe questions in order to focus the exploration activities to the causal and non-causal variables (see Table 2 for an enumeration of the probes for each activity).

The teacher was a final year student of our teacher education department. The purpose and goals of our study were explained to her, and she received specific guidelines to organise and follow up the 15 activities. She received all the probe questions for each activity. Different activities had to be video-recorded. Then, after the post-test, it was verified whether these activities were delivered according the guidelines (this was a part of the evaluation of the student).

Findings / Results

Firstly, with the aid of a multiple analysis of variance (MANOVA), the extent to which children explored more in the posttest than in the pretest relative to controls was calculated. Therefore, the sum of informative *and* uninformative explorations in the pretest and posttest was calculated. Pretest versus posttest acted as an independent variable (within subjects), group (controls vs. experimentals) and gender acted as independent variables (between subjects), whereas the mean number of explorations in pre- and post-test acted as a dependent variable. An effect of group on the number of explorations was found in the post-test ($Mcontr$ = 4.30; SD = 3.13; $Mexp$ = 6.63; SD = 2.54), $F(1, 56) = 9.74$, $p < 0.003$, partial $\eta^2 = 0.20$, but not in the pretest, $F < 4$. No effect of gender was found, $F < 2$.

A second MANOVA verified the extent to which children executed more informative explorations for the variables orientation, position or other variables relative to controls, in both the pretest and the post-test. The mean number of informative exploration trials was calculated, which acted as a dependent variable. Pretest versus post-test acted as an independent variable (within subjects), and group and gender acted as independent variables. Results revealed a main effect of group, $F(1, 52) = 7.8$; $p < 0.007$, partial $\eta^2 = 0.13$. Gender proved not to be significant, $F < 1$. The interaction of pretest/post-test × group for exploration trials was significant, $F(1, 52) = 31.58$; $p = 0.000$ (see Figure 3). In addition, the interaction of gender × pretest/post-test showed significance, $F(1, 53) =$; $p < 0.015$, partial $\eta^2 = 0.108$.

Figure 3. Trigger Phase: Children were asked what they could do in order to hit the wall of sugar cubes with more power. It was asked how they would investigate this. These children tried different objects in order to observe the effect on the sugar wall

Table 2. Guidelines for introduction and probe questions for the trigger phase

Subject	Introduction	Probe questions (trigger phase)
Sinking and Floating	-Enumerating examples of floating and sinking objects: e.g. rubber duck, stone, wooden materials, shells etc. -Brainstorm with the children. The explanation of concepts of floating and sinking. -Short demonstration: objects were laid one by one into the water while its floating and sinking characteristics were observed. -The oldest children could search for a particular object in the classroom that was expected to float or to sink.	Show me an object that will sink. Show me an object that will float. Can you select an object that will sink fast? Can you select an object that will sink slowly? Can you change this object so that it will float instead of sink? Do large objects always float? How would you investigate this?
Bolts and Nuts	-The teacher explained what bolts and nuts are and where these things could be found. -It was discussed in which situations bolts and nuts are of importance. -Objects in which bolts and nuts were used were then observed (e.g. chairs, tables etc.). -Children were encouraged to enumerate objects that could contain bolts and nuts.	Try to find out which bolt fits with this nut. Try to find out which nut fits with this bolt. Can you select a bolt that fits in the different wholes? Try to find out the best way to fit these two wooden boards together, as tightly as you can. How would you investigate this?
Magnifying glasses	-Different magnifying glasses were shown and it was discussed what these things were used for. A link was laid with wearing glasses. -A collection of prints of objects (very small prints) was shown.	Which magnifying glass would you use to look for a large object? Which magnifying glass would you use to look for a small object? How would you investigate which magnifying glass is best to use?
Magnets	-The teacher gave a number of examples of things that are known to be magnetic. Children could give their own examples. -The teacher discussed what it meant that an object is magnetic.	Can you find out whether an object is magnetic or not? How would you investigate this?
Keys and locks	-Applications of keys and locks were given. -Children were encouraged to give examples of keys and locks and when these things are needed (e.g., doors, closets, lock on a journal, lock on a treasure chest).	Can you find out which key you need for the different locks? How would you investigate this?
Balance	-Materials were presented and it was explained what a balance was. -A link with the children's environment was laid (e.g. in playgrounds)	Try to lift both sides of the balance. What happens with the point of balance when the blocks are moved? When one block is placed on this side, how much blocks should be placed on the other side (pointing to another place on the balance)? Can you find out why this is the case?
Slopes (see Figure 3)	-Materials were presented. -A link with children's environment was laid (e.g. in playgrounds)	Can you find out what makes the ball rolling faster? Can you find out which object will roll the fastest? Which slope will lead to faster rolling speeds? What can you do in order to hit the wall of sugar cubes with more power? How would you investigate this?

Table 2. Guidelines for introduction and probe questions for the trigger phase (Cont'd)

Subject	Introduction	Probe questions (trigger phase)
Magnets in water	-A connection with the child's play world was laid for magnets. It was asked whether the children were familiar with applications of magnets. -When the activity 'magnets' was not executed already, magnets were first explained and discussed.	Try to find out which fishing rod is needed for heavy objects. Try to find out which fishing rod is needed for light objects.
Musical glasses	Examples of musical instruments and the concept of pitch was discussed. Methods of making music were discussed. Materials were presented.	Arrange the glasses from small to large. What can you do with the materials in order to make a higher sound? What can you do using the materials to make the sound lower? Show me how you make higher and lower sounds with the sticks. How would you investigate this?
Color filters	-Color filters were shown and different colors were named. -It was asked whether the children were able to mix colors and what kind of effects could follow. -Other materials were demonstrated.	Try to find out whether a red color is the same on a white sheet of paper as on a darker surface. Do you know how you can make a purple color? Try to find out the effect of using different lamps. How would you investigate this?
Gears	-A number of gears were shown. -It was asked whether children recognized the objects and whether they knew some situations where gears are used. -A picture of a gear of a bicycle was shown and its function was discussed/explained.	-Let the characters turn in the same direction. -What will happen with more gears for rotation speed? -What will happen with more gears for rotation direction? -What will happen when a gear is added (or removed)?
Shadows	-It was discussed what shadows are and how shadows can emerge (e.g. different light sources were discussed). -Materials were shown.	-Make a large (small) shadow. -Try to make a shadow lighter/darker -Try to deform a shadow What will distance do with your shadow? How would you investigate this?
Swing	A connection between the materials and the child's play world was laid. Other materials were shown.	- How can you make the swing move slower? Why is this so? - How can you make the swing move faster? -Let the swings go with equally speeds. -Try to find out how you can move the swings with to different speeds. How would you investigate this?
Rubber bands	-A rubber band was shown and it was asked whether the children knew what it was and in which situations these things are useful. -Other materials were explained.	-Try to find out how you can see that a pocket contains more weight. -What is the effect of weight on the rubber bands? How would you investigate this? -Try to make the height of the pockets equal
Dropping objects	-Materials were explained.	-Take an object and drop it above the bucket. -Try to find out whether height makes a larger hole. How would you investigate this? -Try to find out whether the weight of the object makes a larger hole when it is dropped into the sand. How would you investigate this?

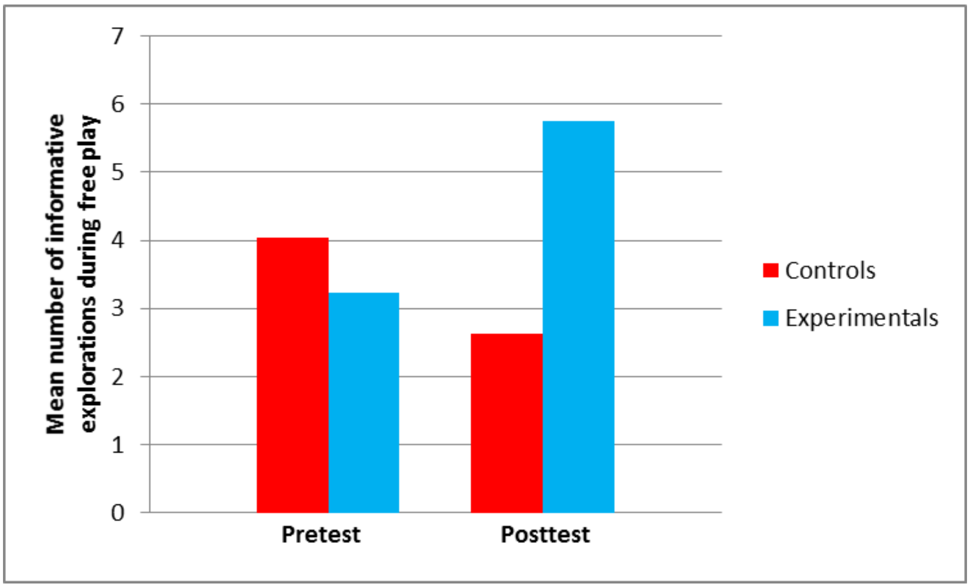

Figure 4: Mean number of informative explorations during the free play phase for controls and experimentals in the pretest and the posttest

$$\frac{number\ of\ uninformative\ explorations}{(number\ of\ informative\ explorations + number\ of\ uninformative\ explorations)} \times 100$$

With a third MANOVA with repeated measures, the ratio between the number of uninformative explorations and the sum of all uninformative and informative explorations was investigated in the pretest and the post-test of the experimentals and controls. To that end, the above formula was used.

Thus this percentage is a measure of error and gives us information about the extent to which a child whether or not ‘act as a scientist’. A high percentage equals a huge amount of confusing and uninformative explorations. On the contrary, a low percentage refers to a high amount of informative experimenting.

The percent of uninformative explorations in the pretest and the post-test (within subjects) acted as a dependent variable, whereas group and gender acted as independent between-subjects variables. The difference between pretest and post-test was not significant, $F < 1$, *ns*. In contrast, the main effect of group (experimentals vs. controls) was significant, $F(1, 49) = 6.09$; $p < 0.02$, partial $\eta^2 = 0.110$. The main effects of gender showed no significance, $F < 1$. However, the interaction of pretest/post-test with group (experimentals vs. controls) for the number of uninformative explorations was significant, $F(1, 49) = 5.57$; $p < 0.022$ (see Figure 4).

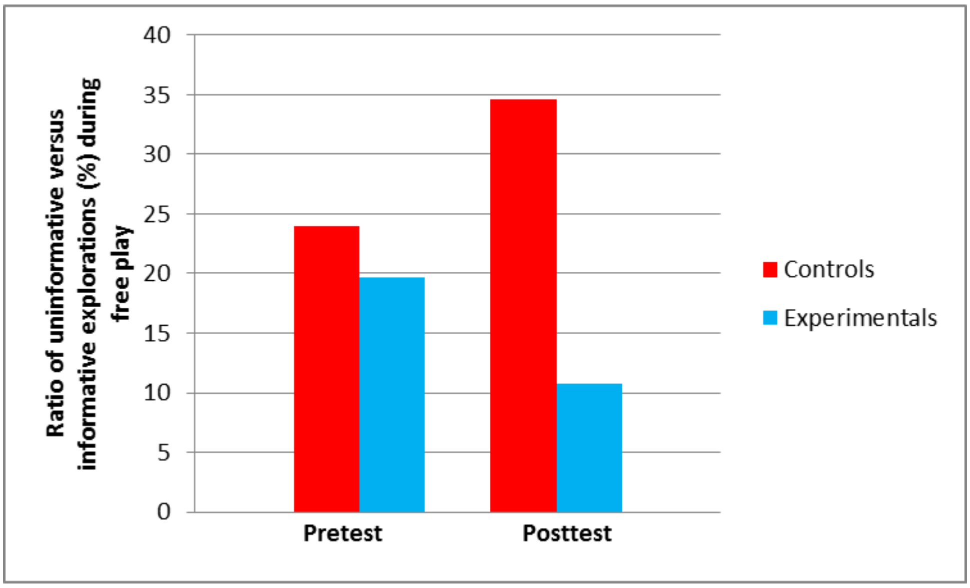

Figure 5. Percent uninformative explorations during free play in pre- and posttest, for controls and experimentals

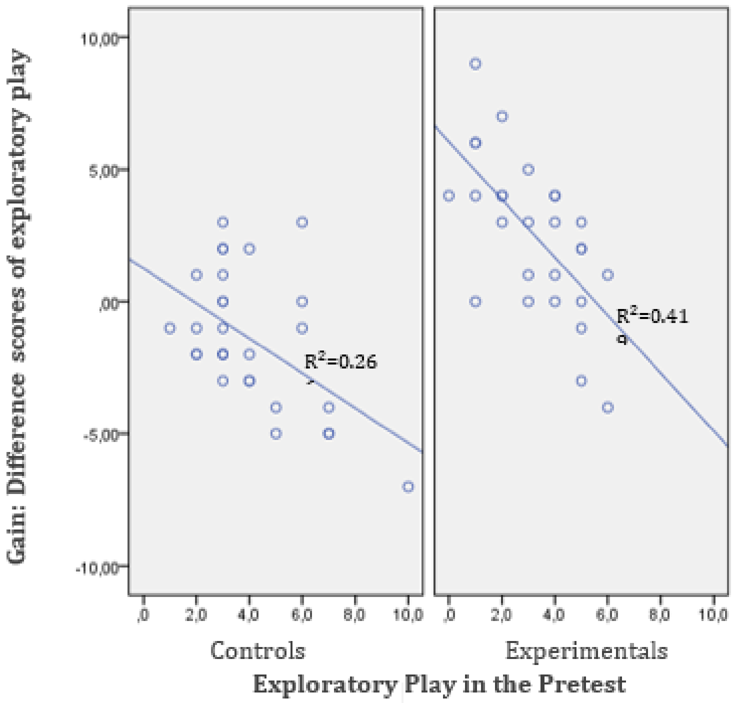

Figure 6. Gain scores are plotted as a function of pretest exploratory play levels. Regression lines are calculated for each group separately

A further one-way analysis of variance (ANOVA) revealed no significant difference between the experimentals and the controls in the pretest, $F < 1$, *ns*, in contrast to the post-test (*Mcontr* = 10.79; *SD* = 16.10; *Mexp* = 34.63; *SD* = 34.54), $F(1, 52) = 10.51$; $p < 0.002$.

A fourth and final analysis examined the effect of pretest exploratory actions during free play on the increase of exploratory play as a result of the program. An ANOVA showed that the initial relationship between group (experimentals vs. controls) and gain (the difference scores of post-test exploratory scores and pretest exploratory scores) was significant, $F(1, 55) = 28.49$; $p < 0.000$. However, when the analysis was repeated and the exploratory scores in the pretest were added as a covariate (ANCOVA) the relationship *remained* significant, indicating that the effect of group on gain was not affected by the initial exploration levels. Furthermore, results showed that the effect of the covariate on gain was significant, $F(1, 55) = 27.17$; $p < 0.000$; partial $\eta^2 = 0.339$ showing that exploratory scores (covariate) in the pretest significantly predicted the difference scores between pre- and post-tests. In Figure 6, gain is plotted as a function of pretest exploratory levels, for both controls and experimentals.

Discussion and Conclusion

The present study offered and tested an inquiry-based didactic method for preschool science at the level of scientific reasoning and showed how it could be translated into the real classroom. Children explored different materials and situations in rich and multivariate contexts with the aid of 15 activities spread over 7 consecutive weeks. All the activities consisted of three phases: an introduction phase, an exploration phase and a trigger phase. In the trigger phase, a teacher asked probe questions to direct the child's attention to the phenomenon that occurred and to stimulate the child to manipulate and explore variables, causes and consequences of the observed event. In a pretest and a post-test each child was tested individually. To that end we used a simple toy experiment with few variables to be manipulated. The extent to which the children's spontaneous explorations were informative and meaningful, reflecting advancements at the level of scientific inquiry and scientific reasoning, was measured.

Firstly, the results showed that after the intervention, the children, relative to controls, explored more with regard to orientation, position and other variables. This means that the programme had encouraged the children's spontaneous exploratory activities in general. Secondly, it was found that the children generated more informative explorations around particular target variables; they were more inclined to set-up experiments that offered new information and they were less inclined to vary more than one variable at a time. In addition, the percentage of uninformative explorations from pretest to post-test decreased in experimentals but not in controls. This means that children not only executed more explorations around target variables, but also that the number of experiments that were uninformative decreased. This can be considered a significant learning gain in the development of the so-called control of variables strategy (CVS). This is in contrast to the finding that most elementary school children are not very adept at designing experiments (e.g. Bullock & Ziegler, 1999; Schauble, 1996) and that experimentation without explicit guidance produces little improvement in CVS understanding (Chen & Klahr, 1999; Klahr & Nigam, 2004). However, these studies typically investigate children's understanding of real-world phenomena in which domain-specific prior beliefs underestimate their formal reasoning abilities (Cook et al., 2011); this is less the case in the present study. Indeed, our results suggest that children learned through exploration: (1) when there is information to be gained, (2) how to differentiate the causal role of different factors and (3) how to manipulate particular features in order to test these factors. According to Lorch et al. (2010), this is in line with the finding that students show better understanding of CVS if the experimenter offers a single variable to be tested in an experiment than if the students are required to determine the goal of an experiment (Kuhn & Dean, 2005). Indeed, children repeatedly designed experiments with small corrections for the same variable in order to provoke an effect (lighting up the box). We often observed that children first tried to imitate the whole act of the experimenter. Of course this was an uninformative experiment because both orientation and position variables were varied at the same time (but they failed to replicate the effect). After this imitation, experimentals more often tried to correct the design of the experiment. For instance, they did so by putting the block upside down or by putting it on its side. When no effects emerged, the child started a new experiment. For instance, the block was positioned 1 or 2 cm further, hoping that a more precise block position would lead to the desired effect. When block position was not effective either, they tried other variables (e.g. putting the block harder and softer on the box platform and moving the complete box). Especially in the pretests, children gave up more often and showed less motivation when they saw that their experiments and explorations did not lead to the desired effect.

The aforementioned results are also in accordance with other studies. For instance, Cook et al. (2011) found that preschoolers already recognise action possibilities that allow them to isolate variables when there is information to be gained in a simple context with little variables to be investigated. Indeed, the present didactic method seems to encourage children to pay attention to the importance of setting up informative experiments and to search for useful and disambiguating information. Our activities let children manipulate various materials, leading to expected and unexpected events, which could be observed. In other words, even when interventions are given with the help of multivariate and complex contexts in real classrooms, learning advancements at the level of experimenting and formal reasoning may be expected.

A significant shortcoming of the present study is that we have not been able to find out what the exact contribution of the particular components of the didactics such as probe questions, introduction activities, demonstrations, cooperative learning and so on is. For instance, is it possible that interventions with a purely free exploration are sufficient to make a difference? Another objection is whether it is necessary for children to engage in all the 15 activities to gain these results.

The present study is unable to offer conclusive answers to these questions. We only know that the didactics resulted in a substantial gain at the level of formal scientific reasoning and that the inquiry skills of the children increased to a higher level of exploratory behaviour. Of course we are not suggesting that children explicitly learned the importance of isolating variables or that they showed metacognitive understanding of how to carry out meaningful experiments. We rather argue that children's perceptual sensitivity was increased and that they were more inclined to pay attention to the underlying structure in which a complex of variables was embedded. In this way, the programme may have the potential to support a child's executive functioning such as sustained attention and inhibitory control (Kerns, Eso, & Thomson, 1999). It is also likely that through the activities, children were more motivated to find solutions for specific (scientific) problems. Together with cognitive capacities, perceptual differentiation and the willingness to pay attention to particular events may pave the way for a child's development of scientific skills and formal development.

For the present study goals, we are not really in favour of free play alone, since it leaves the field too open and does not sufficiently demarcate on what children should focus. In addition, it is probably not necessary to engage in all the 15 activities. However, in a real classroom context, not all children are just as excited about each activity. This means that the 'power' of practicing inquiry skills for a particular activity is different for each child. Therefore, teachers must be aware that variation in subjects over periods of time matters. For instance, children tended to be more enthusiastic about activities such as sinking and floating, keys and locks and balance scales and less about magnets in water and bolts and nuts. In addition, interactions between children matter. Notwithstanding the way children talked to one another and the way a teacher supported these interactions are beyond the scope of the present research, we observed particular interactions during the activities. These interactions were at the level of (1) demonstrating materials ('look at these keys', 'look at my beautiful coloured glasses'), (2) demonstrating effects or causal relations ('I will show you a strange thing, this thing does not stick to the magnet, but this piece of metal does so'), (3) explaining ('I will show you how you can make the swing swinging faster'), (4) talks that reflect expectations and hypotheses ('I wonder what will happen when I drop this heavy ball', 'Can you hold the slope this way, I think the ball will roll faster') and (5) egocentric talks and talks that did not serve the exploratory activities.

Finding the correct solution to the questions that the teacher asked was not of importance. For instance, no children answered correctly to the question 'Do large objects always float? How would you investigate this' during the 'sinking and floating' activity. On the other hand, they easily started to set up experiments for instance by selecting objects and predicting their behaviour in water or by changing particular object properties (e.g. filling the jar with marbles) and observing the effects of it. During the 'dropping objects' activity ('Try to find out whether the weight of the objects makes a larger whole when it is dropped in to the sand'), we saw a similar process. Furthermore, the crave to explore materials strongly depended on perceiving action possibilities (affordances). Not all the 15 activities offered an equal amount of variables that could be manipulated. For instance, magnifying glasses, keys and locks, magnets in water, bolts and nuts, and rubber bands were rather limited compared with other activities. The less action possibilities, the faster children explored affordances that were not offered directly by the teacher (e.g. testing magnets for objects and furniture in the classroom and testing the effect of coloured light on the walls of the classroom and on each other's face). Finally, the degree of novelty and complexity of materials is without doubt a factor of attractiveness and that elicit exploration behaviour. We saw this especially in magnifying glasses, magnets, gears, magnets in water, colour filters and shadows.

A third result of the present study was that lower pretest exploratory levels indicated stronger difference in scores of exploratory play in the post-test. At the visual level, the regression line was steeper for experimentals than for controls. However, the difference was not significant. This is in contrast with van Schijndel et al. (2010), who found that participants with the lowest initial exploratory play levels benefited most from a programme with exploratory play. However, in that study the age of the children was significantly lower (2–3 years old) compared with the children of the present one (4–6 years old). In younger children, individual differences are more likely to occur, which may result in a substantial group performing poorly in an exploratory pretest. Another explanation is that van Schijndel et al. (2010) did not directly measure the child's formal reasoning skills. They only scored if actions like manipulation, repetition, variation and effect observation were present in a child's behaviour during exploratory play.

Although we did not find an effect at exploratory level, it does not mean that early experiences with science outside of school settings do not matter. On the contrary, it is only through action, when children play, they receive opportunities to accumulate experiences over time and to detect higher-order relations between properties or a set of properties in the world (Smitsman & Corbetta, 2010). The more experience a child has, the more abstraction and causal learning can occur. In this way, old knowledge can guide new explorations and the development of further and deeper interest in science (Nayfeld, Brenneman, & Gelman, 2011). Of course, with a concrete didactic method at hand, teachers are more likely to make science both enjoyable and educational. Research has shown that teachers need such guidelines since they often show inadequate knowledge in science content and primarily focus on language arts (Mantzicopoulos & Samarapungavan, 2007). In that case, guidelines can be used in order to create more confidence and willingness to integrate science in the curriculum or in other important subject areas that are covered in preschool. At the same time, attitudes such as curiosity, open-mindedness and a positive approach to failure are fostered (Gallenstein, 2005).

Preschool science fits in seamlessly with the need of strengthening STEM education. STEM refers to science, technology, engineering and mathematics. Since society is highly information-based and technological, children need to develop STEM abilities to levels much beyond those considered acceptable in the past. However, the problem is that the STEM knowledge in college-level courses that are needed to succeed is currently not being obtained. Consequently, there is a particular need for an increased emphasis on technology and engineering at all levels in the current education systems (National Science Board, 2007). It is beyond dispute that there is a link between early childhood and STEM education in primary and pre-primary schools (and beyond). It is especially about early exposure to reasoning, predicting, hypothesising, problem solving and critical thinking, rather than memorising and practicing. It can be argued that encouraging these domain of general skills in primary and pre-primary schools kindles the interest in STEM study and careers later on. Children are born as inquisitive learners. Action plays a fundamental role in learning concepts: the child as a scientist. Scientific programmes should thus be designed in such a way that children are provided with a well thought-out structure, in which they can build their explorations on and in which situations can lead to new questions. Undoubtedly, emerging skills can be used for other content domains too, such as mathematics, technology and language. For instance, when a child learns to compare, sort, count, estimate, classify, measure, graph and even share its explanations with others within its science activities, a transfer to math, language and technology is to be expected.

Most researchers emphasise the need for inquisitive learning. However, the attitude of the child is of equal importance. Through participation in inquisitive learning, children are more inclined to develop an inquiring attitude such as curiosity, open-mindedness, being critical, openness to other perspectives and sharing ideas with others. A child needs these attitudes for further developments in STEM contents and beyond. In other words, inquisitive learning and inquiring attitude influence each other mutually.

It is often argued that scientific activities, either within the domain of knowledge or within the domain of scientific skills, are not suited for young children. Of course, the present study is rather explorative because of a limited sample size, and therefore, one should be vigilant to make generalisable conclusions. Despite this, the present study allows for some optimism. The current results suggest that guided exploratory play in a preschool context is able to support the children's learning at the level of inquisitive learning and scientific reasoning. In this way, the didactics may contribute to support a STEM-oriented education.

Implications for teachers, early years practitioners and researchers

With the present study, we highlight the importance of stimulating children's scientific thinking processes in an attractive context and an age appropriate format rather than putting the focus merely on content and a body of knowledge. Teachers must know that it is not difficult for young children to explore scientific phenomena and to find out how things work as long as it is in accordance with the child's everyday world (meaningful). However, the didactics we presented in the present study should inspire teachers to conduct their classroom activities in order to foster and support domain-general strategies starting from exploratory activities and posing simple research questions. This is not a complete turnaround. Fostering early domain-general strategies imply that teachers pay attention to the process of problem identification, problem analysis, hypothesising, identifying variables, describing effects, gathering evidence, expressing conclusions and so on. The process can be further enhanced by encouraging children to explain the effects, to articulate findings and conclusions and to ask what they are going to do and how they will do this. As a result, children will be more encouraged to develop an attitude of a real scientist. Another important implication of the present study is that teachers are offered ways to use preschool science for the training of early mathematic skills since they are encouraged to express what is happening in terms of numbers, amounts or other concepts (more, less, the tallest, the smallest, the first, the fastest, etc.).

Notwithstanding this is easy to implement, preschool teachers are no scientists and of course they do not need to be a scientist per se. However, insight into the way in which scientific theories develop (even in educational fields) and the way in which discoveries are made may bring the scientific thinking process in the pupils more easily to a higher level. A way to meet this need is to implement scientific courses and knowledge about the scientific process into the curricula of teacher training students since it is rather difficult to reach and inform teachers at work.

Future questions

An important limitation of the present study is which aspects of the training intervention were helpful at the level of children's problem-solving abilities is unclear. For instance it can be questioned to what extent the preschool children are sensitive to the demonstrations of a scientific process, and also to the questions, to cooperative learning, feedback and so on. In addition, the contribution of each of the 15 activities is not clear. One way to get a better view on the contribution of these aspects is to look at the way the teacher, child and tasks influence one another over time. In other words, the extent to which the problem-solving abilities (and eventually content knowledge) emerge from child–teacher interactions (also child–child) in particular contexts should be investigated (Van Geert & Steenbeek, 2005a). By studying children's exploration patterns, their answers to questions, their behaviours and the complexity of their explanations during the training interventions, patterns of growth can be revealed, which provide insight into the nature of cognitive change (Yan & Fischer, 2002) for the different contexts that are used. In addition, it can be argued that an 'equal opportunity policy' is needed to ensure that both children with strong capacities and children who need more support and guidance are stimulated. Again, a focus on the embedded knowledge and skills that are created in real-time child–teacher–task interactions could give insight into the way the present didactics should be adjusted, so that all the children are stimulated in an equal way.

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