Preschool science learning: The construction of representations and explanations about color, shadows, light and images

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ABSTRACT

The present work shows the construction that preschool students can make about conceptions of color, light, formation of shadows and images in a plane mirror, with the application of a didactic proposal (EduCienPre) in which didactic sequences and materials are developed and which can be introduced to a classroom under normal conditions. The characteristics of the didactic proposal are described and preschoolers conceptual constructions are analyzed as a function of their explanations and representations. Analysis of children's actions in diverse physical situations offers deeper elements for understanding the construction of representations and scientific notions which could be reflected in a more adequate teaching of the sciences for small children.

KEY WORDS

Explanations construction, teaching, sciences, preschool

Résume

Ce travail présente les résultats d'une étude sur la construction entreprise par des élèves de niveau préscolaire relatives à leurs conceptions de la couleur, la lumière, la formation des ombres et des images sur un miroir plan, ceci grâce à l'application d'une proposition didactique EduCienPre, à partir de laquelle les séquences didactiques comme les matériaux sont développés et introduits dans la classe sous des conditions normales. Les caractéristiques de cette proposition didactique y sont décrites et les constructions conceptuelles des enfants sont analysées comme une fonction de leurs explications et représentations. L'analyse des actions enfantines dans diverses situations physiques permet d'approcher d'autres éléments qui permettent de mieux comprendre la construction des représentations et des concepts scientifiques ce qui permettra de réfléchir sur une méthode plus adaptée d'enseignement des sciences aux jeunes enfants.

Mots Clés

Construction d'explications, enseignement, sciences, préscolaire

Introduction

How children construct their representations about scientific phenomena is a question that has been at the center of research about sciences learning. In fact, the alternative conceptions movement has shown through a large number of educational works (Duit, 2004; Flores et al., 2002), the diversity and complexity of the notions that children construct, from their daily experience and their socio-cultural environment. Even though little children (preschoolers) were the first subjects of such research, as with the work of Piaget ([1926]1984), there is currently not much research carried out about their scientific notions. Research on small children's ideas (between three and six years old) about processes and physical concepts is rare, and most of the time the suggested teaching processes don't go beyond playing or the classification of objects and living beings. In this work, the explanations that preschool children (three to six years old) give about combination of colors, recognizing light in order to see, formation of shadows, and identification of images formed by plane mirrors are analyzed before and after the student participated into a teaching proposal oriented towards the construction of explanations and representations.

Theoretical Framework

Teaching of natural sciences at preschool

There are few educational proposals focused on learning sciences aimed at preschool. In most of the cases, classroom intervention processes are directed toward achieving the construction of certain scientific notions in children (Ravanis, 1994; Ravanis & Bagakis, 1998; Ravanis, Koliopoulos & Boilevin, 2008). Other proposals (French, 2004; Gelman & Brenneman, 2004) incorporate learning of science only addressing some particular aspects such as language in children's investigation process and the influence of teachers' explanations on them (Peterson & French, 2008).

In general, the proposals focus on different aspects that range from the teacher-student accompaniment in the non pre-defined notions about basic phenomena to activities centered on abilities and general competences that the child should develop in order to approach, with the aid of the teacher, the beginnings of scientific knowledge. However, the representational constructions in children's explanations do not seem to be clearly inserted into the learning proposals, for example Kallery, Psillos & Tselfes (2009), on analyzing the kinds of activities that are favored during a didactic process in the teaching of sciences at preschool, found that scientific activity is preferably confined to descriptions, without the use of didactic materials, and scientific investigation is poorly promoted. The use of ideas or concepts are not related with previous activities or with experiences the children have had, thereby not establishing a relation between new knowledge and knowledge which was previously acquired. Since some of the necessary abilities to promote a relation between the material world and the representations of phenomena were present in some of the experiences, in general the manipulation of variables is not promoted (Kallery et al., 2009). In conclusion these authors point out that the activities do not establish the relationships between the three entities, the Cosmos, Evidence, and Ideas (Hacking, 1992), in order to develop scientific investigation in school science lessons.

Other studies (Eshach & Fried, 2005) indicate that the teaching of sciences at this school level support cognitive development in children and the formation of a standard of reference that will help children understand phenomena and scientific concepts that will be studied in subsequent grades.

The Preschool education curricular program in Mexico (PEP, 2004) incorporates the teaching of science with a focus centered on competences and where the main objective is that children (from three to five years old) develop abilities and attitudes that characterize reflexive thinking through experiences that allow them to represent the natural and social world. Unlike the previous program, this program does not establish specific content and leaves it to the educator to design didactic situations starting from specified competences in which challenges for children are implied and which help children learn more about the natural world.

Ideas about color, light, and shadow in preschool children

One of the themes frequently found in the teaching proposals for small children relates to light, especially colors and shadows. Research shows the complexity about children understanding such themes and the lack of adequate didactic proposals.

In particular, the research on the ideas of children (older than preschoolers) about color reveals that their ideas are similar to the pre-Newtonians. The research done by Feher and Rice (1992) shows some of the ideas that children (8-13) construct about light, colored objects and colored shadows. Their study was carried out in a museum and consisted of two tasks: 1) the effect of colored light on objects and, 2) the formation of colored shadows. Their results report that, for children, dark is an ingredient of color, that is, darkness is not interpreted as the absence of light. They also identified different types of explanations about the qualities of colored light and its propagation. In another study, Guesne (1985) identifies that when children observe colored objects under a white light, they take the color to be a quality of the object, independent of the source of light or the receiver. In tasks where a colored filter is placed in front of a white light, the children explain that the filter modifies the white light beam adding color to it (Anderson & Kärrqvist, 1983; Watts, 1985, cited in Feher & Rice, 1992).

What preschool and primary school children think about light and shadows is reported in the work of DeVries (1986), which identified four levels and eight sub-levels in children's reasoning about shadows. The results for children from 0 to 5 years of age are described herein. The author locates in *level 0* children who are characterized by not being able to recognize their own shadow, or that of others.

Level 1 is defined as that where children find a correspondence in form between objects and shadows. This level is subdivided into two sub-levels, in *1A,* children still have some difficulty observing shadows and their identification with an object and they think of the shadow as a property of the object. In *level 1B,* children believe that the shadows are produced by approaching a certain screen; they don't attribute any relationship to the light. In *level 2,* children are conscious of the role of light and it is made up of three sub-levels. In *2A,* children recognize light as an important factor in the formation of shadows, but they can't determine the relationship exactly. In *2B,* children think that to generate a shadow it's necessary to move the lamp in what can be interpreted as a first approximation of the light-object relationship and trial and error activities are produced. In *2C,* children consider that light plays an active role in the formation of shadows. The following levels imply much clearer relationships between light, object, and shadow, and as they pass from *level 3* to *4*, the causal relationships are fortified. However, there are no corresponding preschool children that reach these levels and, in fact, few children from 6 to 9 years of age make it to these levels. The majority of them are located in *level* 2, mainly in sub-levels *2b* and *2c*.

Likewise, Ravanis (1999) finds that five year old children establish a relationship between light and its sources, but they haven't constructed the notion of light as an independent entity that travels through space, which makes it difficult for them to describe the propagation of light in all directions and understand formation of shadows. To summarize, small children may find conceptual difficulties when building a representation of the construction of shadows, which may be listed as follows: a) the recognition that light plays an active role in the formation of shadows and, b) no longer attributing shadow as a property of objects or a relationship between the object and the screen or surface where the shadow is formed.

The research carried out does not provide any information either on its own construction or on its possible transformation process. To frame what has been said within the educational context of children's constructions, we ask: how can conceptual development be supported with an educational process that starts with these problems and takes preschoolers to a level of establishing relationships and clearer, more precise explanations of physical phenomena?

The EduCienPre proposal

EduCienPre (Preschool Science Education) consists of an educational proposal that we have designed for the purpose of developing explanation and representation construction processes in various areas of science for younger students. The focus of the proposal starts by considering that small children play a fundamental role in the construction of their knowledge and that this is achieved not only through their participation in educational play activities, but also should provide the structuring of conceptual elements that help establish causal relationships or making explicit the relationships in child's representations. This development is achieved in an educational process that favors a rich interrelationship with the teacher, as well as with their peers. EduCienPre begins with three central elements: a) favor the development of "explanation mechanisms" used by children in the construction of their representations around scientific concepts, b) favor the development of the student's and teacher's experimental abilities within a conceptual environment that involves description and the establishment of causal relationships, and c) support the approach and curriculum objectives. These three elements combine in teaching sequences that organize the development of concepts and the interpretation of natural processes through activities with didactic materials designed *ex professo*. A detailed description of this didactic proposal can be found in Gallegos, Calderón, Albornoz and Flores (2008).

One of the aspects that is taken into account during the development of the intervention proposal has to do with the consistency and congruency of the themes dealing with a determined sequence. In the case of light, we articulate the theme of the combination of colors, the formation of shadows, and the formation of images by plane mirrors. These three aspects have a close conceptual relationship. We note three objectives for preschool children. These objectives are: a) establish relationships between colors and some system of auxiliary organization (the use of the chromatic circle), b) the comprehension of the necessary elements in the formation of shadows (the presence of light and its trajectory, as well as the difficulties in structuring the light-object-shadow relationship), and c) the functional explanation of the formation of images in plane mirrors starting with considering the previous idea that the image is found within the mirror itself.

Methodological Framework

Intervention process in the classroom

The process of intervention was carried out in the kindergarten annex to the Normal School for Kindergarten Teachers of the Ministry of Public Education in Mexico City. All of the children in the preschool center (first to third grade, 254 children in all) participated in the intervention over a six month period in which all the themes were worked on (colors, light, shadows, and images). The intervention process was done in weekly sessions for each theme. For the theme of colors, five sessions were used and 24 subjects were interviewed for the study (12 girls and 12 boys). For the theme of shadows, five sessions were used and 29 children were interviewed for the study (15 girls and 14 boys). For the theme of images, three sessions were used and 28 subjects were interviewed for the study (15 girls and 13 boys). Table 1 shows the distribution of interviewed sample.

Table 1

Distribution of interviewed children

Type of Activities	*Pre-test*	*Post-test*	*Total Number of Children*
Colors	12	12	24
Shadows	17	12	29
Images	16	12	28
Total	45	36	81

In all cases the teacher of each group directed the activity, and these were videotaped and observed by the research team. Prior to the classroom activities, all the teachers attended a course to learn the sequence of activities (structure, materials, activities, etc.) and to review all the related physics concepts (colors, sources of light, propagation of light, how a shadow is formed, and the formation of images in mirrors).

Sequences and didactic material

Attention was centered on children identifying the processes involved in simple activities, starting with the handling of different materials and distinct situations about the same physical process, with what we seek to support an interaction and reflection process in different contexts on the part of the child.

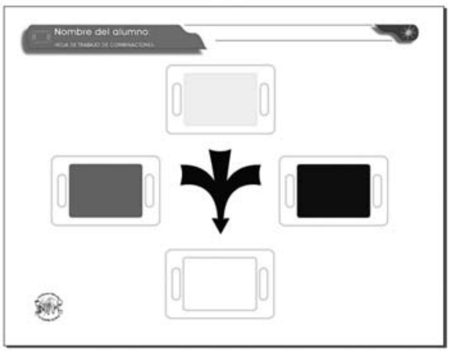
The materials constitute an important point in the development of the sequence, since above all in small children these represent the objects of knowledge. At these ages children cannot easily make inferences and generalizations, for which precision of processes that are carried out with the used materials may mean the strategy's success or failure. On the other hand, we find in the documented literature that children's conceptual constructions are anchored in the concrete materials with which they interact (Krnel, Watson & Glazar, 1998), which is why we consider it important to vary the materials for the observation of the same process. The materials used are shown in Figure 1, they include:

1. Finger paints, trays.
2. Colored filters, colored figures such as laminated plastic filters.
3. Dark-light transition viewer with background figure (butterfly).
4. Set of laminated plastic opaque figures (hippopotamus and girl), figures with opaque and transparent areas (girl) and figures with transparent areas (transparent hippopotamus silhouette) for forming shadows.
5. Battery powered lamp.
6. Plane mirrors.
7. Record book with figures for each activity.

FIGURE 1

Materials for use in the sequence of activities

FIGURE 2



Page from record of color mixing

In the development of the sequence the record of children's observations is important since it is a cognitive resource that allows them to show their ideas again with a more stable representation. That's what the pages of the record books in which children note their observations are used for (see Figure 2, example of color mixing activity), these pages are always within their reach, and they contain elements children can either select or draw.

Development of preschoolers' representations and explanations throughout the sequence

In order to know the construction of the children's representations and explanations about the mixture of color, the formation of shadows, the role of light, and the formation of images, we carried out the following:

Design

The study involved three phases: pre-test, pedagogical intervention, and post-test. Both the pre-test and the post-test were done by individual interviews of children. The post-test interviews were done six months after the intervention.

Procedure

For both the pre-test and the post-test a semi-structured interview was applied during which the following tasks or activities were carried out: A1) color mixing with paints and B1) color mixing with filters, A2) observation with the light-dark viewer, and B2) formation of shadows, and lastly, A3) formation of images by plane mirror. Each of the participants was interviewed individually (30 to 40 minutes for each theme of the sequence of activities), each interview being videotaped. The interview used in the post-test followed the same objectives of the initial interview. The tasks outlined in the interview were similar to the activities that make up the intervention proposal. The categorizing of the interview results in what we call "explanations" were validated by three researchers.

Description of tasks

<u>Color mixing: Task A1. Paint mixing.</u>

The interview begins with a recognition question, what colors do you know? This is for subsequent identification of the colors that will be used during the task. The participant is then shown two colors (yellow-blue) and is asked what would happen if we put these two colors in a container and mix them. If the child doesn't respond to the question he/she is given options: nothing would happen, one of the colors in the container would remain, or we would get a different color. The child then puts the colors into the container and mixes them. On observing the result, the child is asked what happened to the colors and why. The child notes the resulting color mix on his page in the record book. This same activity is carried out with the rest of the combinations (blue-red, yellow-red), all the results being noted by the student in the record. On finishing the three previous combinations the child is asked about what he/she believes would happen if he/she mixes all the colors that he/she had available, and when he/she finishes mixing all the colors he/she is asked to give an explanation of the result.

Color mixing: Task B1. Color mixing with filters.

During this part of the interview the same questions are asked and the same combinations are done as in *Task A1,* but in this case the colored plastic filters are used. The child is shown a plastic plate with a printed object of a determined color (yellow, red, blue), they are given a colored filter (yellow, red, blue), and are asked, what color would the object look if we observe it with one of the filters? The participant observes the combination and is asked for an explanation for what happened. All possible combinations are done with the filters and the objects, and in every case an explanation is asked for, that is, why the object looks a different color. The results are duly noted in the record book.

Light trajectory and shadow formation: Task A2. The identification of light as a necessary element to see objects.

The interview begins with an everyday question, what would happen if you covered your eyes? Once the child responds, the light-dark viewer is used. This is initially kept closed so the child won't see the figure inside, the child responds to whether something can be seen in the bottom and is then asked, what can we do to see inside the viewer? After responding, the child opens the door in the device allowing light to enter and then observes again. The child is asked to explain what he/she sees and why he/she thinks this has occurred (In the bottom of the viewer the drawing of a butterfly can be seen). In conclusion, they are asked to note on the page of the record book the option that corresponds to what they observed.

Light trajectory and shadow formation: Task B2. The construction of a shadow.

To begin, the interviewer asks the child if he/she knows what shadows are and how they are formed. He/she is shown a plate with an opaque figure and is asked if with this a shadow could be formed and what we would have to do to form one. He/she is later asked how he/she believes this shadow would look and he/she is given three options to choose from on an answer page. Once the prediction is made the shadow is formed on the wall and the child is asked what he/she observed and to indicate it. He/she is asked to choose on the page from the record book the option that is the same as the shadow he/she observed on the wall and to explain his/her choice.

Image formation in plane mirrors: Task A3. The observation of images in plane mirrors. The first part of the interview consists of determining if the child knows what mirrors are and what they're for. He/she is then asked what he/she believes might happen if we placed an object in front of the mirror, the object is placed, and he/she is asked if he/she knows why we can see ourselves in the mirror. To continue the interview, the object is removed and he/she is asked what happened to the object in the mirror, the object is brought close then pulled back, moved from left to right, all in order to determine if the participant can establish the difference in the image on different positions and recognize some of its characteristics such as symmetry, orientation, movement, and size.

Results of the Intervention Process

Framework of analysis. The construction of explanations and representations

Can preschool children elaborate causal explanations? Since the studies of Piaget (1960) it has been demonstrated that children between 3 and 6 years of age can both infer and elaborate relations between events that lead them to construct causal explanations, though limited as far as the transference of their elaborations into distinct themes. More recently, Hickling and Wellman (2001) have shown and classified the possibilities that children from the age of three have to elaborate causal explanations and, even though they recognize that the language used by children doesn't necessarily reflect their conceptions, they establish that "when verbal expressions are adequately analyzed, they are revealers of children's comprehension" (Hickling & Wellman, 2001, p. 668). Blomm and Capatides (1987) also refer to how children can establish causal relationships between objects, but they can't express these physical relationships among themselves.

It has also been found that small children can have an abstract thought (Metz, 1998) within a specific dominion of knowledge, and Gelman and Markman (1986) show that children between 4 and 5 years of age are capable of selecting relevant information in the construction of inferences, and thus respond to questions.

In this study we consider that the relationships among notions can be established to the extent that the construction of representations that have passed through an elicitation process is achieved, moreover, it is very convenient to use objects that function as external representations for preschool children. The above is justified in that external representations fulfill two basic functions: a) a communicative one, they help to clarify the meaning of internal representations and make consciousness possible and, b) consider their representations like a knowledge object, they help make meanings explicit for a reorganization of the same representation, giving form to a causal or explicative comprehension.

Categories of analysis

For the analysis of the students explanations we have started from the categories elaborated by Hacking (1992) and applied by Kallery et al. (2009) for the analysis of children's expressions which are: Cosmos (C), Evidence (E), and Ideas (I).

Cosmos includes materials, artifacts, devices, measuring instruments, samples and reading instruments which constitute the data. Evidence includes entities which have been derived, whether from the senses, or from a systematic processing of the data where, implicitly, the students representations and conceptions are. Ideas include specific theoretical entities, notions, models or concepts, methodological entities which include questions and hypotheses. It's worth mentioning that in the Ideas category the representations the subjects have about the world can be transformed as a function of the Cosmos objects and the evidence of processes that the subject can possibly interpret are all taken into consideration. The group that is made up of the three categories (CEI) constitutes a network of possible relations that allows for an analysis of children's expressions. Table 2 presents the relationships among the categories and the characteristics that define them, starting from the proposal of Kallery et al. (2009). From our point of view, the three elements (CEI) are always present in children explanations. The way in which the children analyze the evidence and the objects action are regulated by these three elements.

TABLE 2

Connections among categories starting from the CEI model

Connection possibilities among C, E, I	***The connection appears when:***
C→E	The Cosmos relates with the Evidence when what happens with the objects is conceived of as the cause of the Evidence.
E→C	The relationship that is established from the Evidence to the Cosmos allows beginning from the description of the event or object. In this case, the description of the processes and objects are at the center of attention of this relationship.
I→E	That Ideas relate with the expected Evidence implies predictions of evidence based on the Ideas. That's why the construction of predictions and hypotheses is identified with this relationship.
E→I	The Evidence that is related to the Ideas is identified when Evidence is explained in terms of the Ideas. This is why the Explanations, (possibly not causal), can be found in these relationships.
I→C	In this case the Ideas are superimposed on the objects of the Cosmos. The implicit representation determines the interpretation of the Evidence.
C→I	On occasion the Cosmos supports the transformation of the Ideas. In this case, doubt about the Ideas allows observation of the Cosmos and with it, the reconstruction of the Ideas.

Preschooler's explanations

What follows is a presentation of the different types of explanations children give in a comparative form, both pre-test and post-test. "Explanations" are considered verbal expressions and actions that children establish, and together constitute an enunciation that completely reports on an idea which allows inference of the existence, or not, of a relationship between factors or of a causal relationship. Though this implies making some inferences, these are justified as a function of other actions and answers given by the children. These inferences, or explanations allow the establishment of relationships among the analysis categories (CEI) according to the possible relationships established in table 2. The results are presented first with a brief description of the characteristics of children explanations supported with interview sections in which the presence of the analysis categories stand out. Tables and graphs of the type of explanation identified for each of the distinct tasks are then shown.

Explanations about the mixing of colors

In this case, the two tasks corresponding to the combination of colors (A1 and B1) have been grouped. There are four explanations that represent the set of the interviewed students' ideas.

Explanation 1 (E1)**.** The colors are combined, mixed, or blended. Some students conserve the idea that one of the colors persists after mixing and others say that a new one appears. All these explanations present the C→E relationship given that the action of mixing the paints (C) is the cause of the observed color change (E) (*Post-test. Five year old student*).

> Researcher (R): Do you think that if I put a little blue drop and a little yellow drop something will happen? What do you think could happen?
> Marco: *[yes] they combine (E).*
> R: And what happens with the color?
> Marco: -*The colors combine (C→E).*

Explanation 2 (E2). The results of the mixes are due to the objects, whether paints or other nearby objects. These explanations reflect a type I→E relationship since they concern predictions about what will happen after the action of mixing the paints.

> R: I have to mix this (yellow) with this (red), another color will come out, what color will come out?
> Moisés (Post-test. Five year old student): - *orange (I→E).*
> R: If we mix the three colors [what will happen].
> Moisés: *all of them will come out because you put so much (I→E).*

Explanation 3 (E3). Certain colors combine together to make a third. These ideas establish an E→I relationship since the child explains evidence as a function of their ideas (something magical).

R: Why did it become orange?
Emmelin (Pre-test. Six year old student): *because the red became orange (E→I).*

R: If I put a little red with yellow, will it come out?
Alejandro (Post-test. Four year old student): *it changes to the devil's color (E→I).*

Explanation 4 (E4). They change because one of the colors is stronger or clearer than the other. All the explanations correspond to an I→E type since the idea of the color's strength is imposed on the observation of the evidence.

R: And if I put this filter on it, will it look clearer or more intense?
Carlos (Pre-test. Six year old student): *darker; this (red filter) helps it to look stronger (I→E)*

In table 3, a comparison is presented between the pre-test and post-test results by explanation and task for the color mixing exercise. In each explanation, the type of relationship between CEI categories is also presented.

TABLE 3

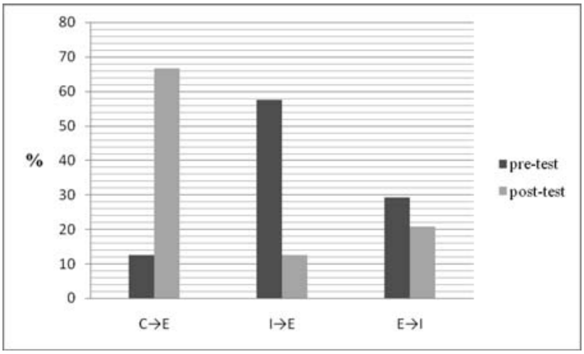
Color mixing comparison of percentages between pre-test and post-test

Pre-test								
	E1 (C→E)		E2 (I→E)		E3 (E→I)		E4 (I→E)	
Task	A1	B1	A1	B1	A1	B1	A1	B1
%	16.6	8.3	25	66.6	50	8.3	8.3	16.6
Post-test								
	E1(C→E)		E2(I→E)		E3(E→I)		E4(I→E)	
Task	A1	B1	A1	B1	A1	B1	A1	B1
%	58.3	75	8.3	0	25	16.6	8.3	8.3

The percentage is calculated independently by explanation and task since the same child can have more than one explanation throughout the interview.

In figure 3 the percentages from the answers of the CEI categories are shown. As we can see, the explanations during the pre-test are mainly answered with the I→E and E→I combinations, which begin from the students ideas elaborated as a prediction. After the intervention process, the students change the type of explanations which are practically the C→E type, that is, the causal explanation process is favored, since the cause (colors, quantity of color, the fact that they mix, etc.) of getting another color is recognized.

Figure 3



Categories found in the explanations for the color mixing tasks

As can be seen in the examples, explanations 1 and 3 correspond to the recognition that the union or mix of two colors produces a third, although no description of the process exists. In the case of explanation 1, the action of mixing is recognized as the cause of the evidence (C→E), while in explanation 3 the children resort to their ideas in order to do so (E→I). Explanation 2 (colors that are a result of mixing are due to external objects whether the paints or other nearby objects), and 4 (the strongest color is the one that remains after being mixed) obey those agents that the children think can produce the resulting color, for which both demonstrate an I→E relationship where the idea carries to the prediction of possible evidence. In explanation 2 the answers that stand out are those which center their attention on nearby objects "it's because of the bucket that's behind", or something anthropomorphic. In the case of explanation 4 an allusion is made to the concept of force which, according to Carey and Spelke (1994), is constructed from the first stages of the child's thinking, which means for the child more intensity of one over the other, without having a justification about what strong color means, that is, it can be any color the child decides which will be the one which is "imposed" by its force. These explanations appear both before and after the intervention process, though there are variants in terms of the percentages of their use.

There are two explanations in the pre-test that present the greatest percentage in the two tasks, explanation 2 (A1:25%; B1:66.6%), and explanation 3 (A1:50%; B1:8.3%). Explanation 2 assigns a causality to an external object, while with explanation 3 the results of the mix (evidence) take them to other types of ideas as explanations. These two explanations considerably reduce their answer percentage between the pre-test and post-test in which only explanation 1 appears (A1:58.3%; B1:75%), and which is related with the identification of the observation of a third color (evidence), which shows the incidence of the intervention process activities.

The two representations that are tied to an anthropomorphic causality or to the concept of intensity and that are distinguished by presenting an I→E type relationship diminish considerably after the intervention, which indicates that the process favors the search for mechanisms in the explanations of children, however, they still don't seem clear in their expressions.

Explanations about the formation of shadows

In Task A2. Identification of sources of light the objectives were to identify if the children recognize the need for light in order to see objects and distinguish different light sources in their environment.

Explanation 5 (E5). The objects can be seen if the window in the viewer is opened (explanation on the mechanical action, but there is no relationship with light as a necessary factor in order to see the object). These explanations establish a C→E category since an action about the Cosmos produces Evidence.

R: Why can you see the butterfly now?

Leonardo (Pre-test. Four year old student): -*because we lifted It (*the viewer door) (C).

R: Is something else needed so it can be seen?

Leonardo: *no* (C→E).

Explanation 6 (E6). The objects can be seen if there is light. The child can identify one or many sources of light. This explanation corresponds to the C→E type category, where an element of the Cosmos (light source) is identified in order to obtain Evidence.

R: What would have to be done in order to see?

Emilio (Post-test. Four year old student) (: -*turn on the light or if there's a little hole put it inside (C→E).*

R: And where is the light?

Emilio: – [The child indicates the bulb of the lamp, takes it and turns it on to show the light to the R. Even though the R asks about other sources of light, no answer is given] (C→E).

R: And if I want to see what's inside, what do I have to do, what do I need?

Yoali (Post-test. Four year old student): – *use light (C→E).*

R: And where do I get light?

Yoali: – *could be from the sun*, – [the girl indicates the lamps on the roof], – *with a lamp (C→E).*

The following presents the explanations the children give about the Task B2. Formation of Shadows, and an example of each one. Note that explanation 8 appears only in the pre-test.

Explanation 7 (E7). The shadows are identified as objects. In this explanation a relationship is established between the Evidence (the presence of shadows) and an implied object or action, which is an E→C type relationship.

R: Andrea, do you know what a shadow is?
Andrea (Post-test. Five year old student): – *it's a boy or an animal or a dog or a tiger or a cat (E).*
R: What is a shadow?
Andrea: – *people (E).*
R: People are shadows?
Andrea: – *because when they walk, walk and their shadow is there (E→C).*
R: How could they make a shadow?
Andrea: – *walking (E→C).*

Explanation 8 (E8). Shadows are reflections, formed by reflected light. In this case the children's explanation establishes light (generally from one source as shown in the example) as cause (C) of the formation of shadows (E) which is a C→E type relationship.

R: How could we make a shadow from this hippopotamus?
Axel (Pre-test. Four year old student): – *like this, lying down,* [the boy again puts the plate on the table, in fact. The R separates it but the boy says that it should be the way he showed him] (C).
R: And where is the shadow?
Axel: – [the child indicates the light that is seen reflected on the plate, the light from the lamp, and in fact moves the lamp so more can be seen] (C→E).
R: If I turn off the light will we still see the shadow?
Axel: – *no*.
R: If you didn't have the lamp, what else could you make a shadow with?
Axel: – *with nothing.*

Explanation 9 (E9). Shadows acquire the color of the object. In this case the children have an idea about the shadow being the color of the object that forms it, thereby establishing an I→E type relationship in which the Idea is imposed on the Cosmos.

R: And can I make a shadow with this hippopotamus?
Yoali (Post-test. Four year old student): – *yes (E).*
R: And what color do you think it will be?
Yoali: – *blue (I)*.
R: Why blue?
Yoali: *the [hippopotamus] is blue* (I→E).

Explanation 10 (E10). A shadow is formed when an object does not allow light to pass. In this case a clear representation is established of how a shadow is formed resulting in an I→E→C relationship.

R: Do you know what a shadow is?
Karen (Post-test. Five year old student): – *a figure you put light on like this… – and you have to grab* (the child takes the materials and correctly makes a shadow) (I→E).
R: Do you think it can be seen here [on the table]?
Karen: – *yes* [the child projects the shadow of a spider onto the table] (E→C).
R: Where is the shadow?
Karen: – *here.*
R: Show me where the shadow is.
Karen: – *here (correctly indicates the shadow).*

Table 4 includes the two tasks about the formation of shadows. Note that explanations 5 and 6 correspond to task A2 and explanations 7 to 10 correspond to task B2. (In the post-test there were fewer children in the study due to a change of schools, for which the relative percentages are presented at each sample in a way that allows them to be compared).

TABLE 4

Shadows: comparison of percentages between pre-test and post-test

Pre-test						
	E 5(C→E)	E 6(C→E)	E 7(E→C)	E 8(C→E)	E 9(I→E)	E 10(I→E→C)
Task	A2	A2	B2	B2	B2	B2
%	41.1	47.1	17.6	17.6	41.1	7.6
Post-test						
	E 5(C→E)	E 6(C→E)	E 7(E→C)	E 8(C→E)	E 9(I→E)	E 10 (I→E→C)
Task	A2	A2	B2	B2	B2	B2
%	16.6	75	8.3	-	16.6	75

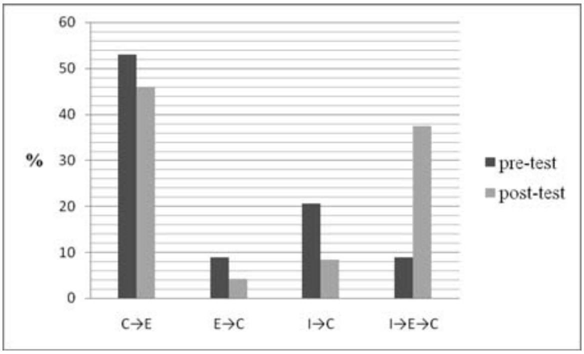
Two distinct types of answers are observed in the shadow task (A2), in both cases C→E causal relationship types are established. These explanations show the children's need to find an explanation for the phenomena, on the one hand, the object itself as the source of explanation (explanation 5), and on the other, the recognition of the presence of the other sources of light (explanation 6).

Explanation 5 identifies the possibility of observing the phenomena through some action applied to the object. Explanation 6 establishes the identification of light as a necessary element in order to see objects. Here one or more sources of light are recognized which indicates that generalization is found in the process of construction. Apparently, the majority of children with the intervention and as a function of the activities, focus on the presence of light and stop mentioning the variety of distinct sources of light.

In the second task (B2), most of the children's explanations are again focused on the objects, in this case because they produce the shadows starting from one of their characteristics. Explanation 7 (pre-test: 17.6%; post-test: 8.3%) alludes to the form of the objects and explanation 9 (pre-test: 41.1%; post-test: 16.6%) to the color of the objects. The appreciation for the need of light, which appears in explanation 8 (pre-test: 17.6%; post-test: 0%), shows that the children pay exclusive attention to one element. Curiously, this type of explanation can be interpreted as a preamble to explanation 10, since how reflected light doesn't pass is what forms the shadow. Only explanation 10 establishes a clear relationship between the object and the presence of light for the formation of shadows, and links the three elements of the CEI (I→E→C) framework in a complete sequence.

Figure 4 shows the percentages of the categories used by the students in their comparative explanations between the pre-test and the post-test. As we can see, the category with the largest percentage of explanations, both pre-test and post-test, is C→E, which corresponds to the establishment of a causal relationship. It's very interesting to see, however, the presence of I→C category in the pre-test, this is the way in which ideas the are imposed onto the objects, and the I→E→C relationships which appear in the post-test with a high answer percentage and which corresponds to a more complete and abstract explanation from the children.

Figure 4



Categories found in the explanations for the formation of shadows

The explanations that appear with a higher percentage in the pre-test are: 5 (41.1%), 6 (47.1%), and 9 (41.1%) of which the first two have to do with the identification of a cause in the Cosmos, and the third with the idea that the color of the object is the same as the color of the shadow. The explanations that appear with a higher percentage in the post-test are explanations 6 (75%) and 10 (75%), in the first case recognizing the light constitutes an antecedent to explanation 10, in which various elements are articulated to explain the formation of a shadow. It should be noted that children have explicitly identified, corresponding to the pedagogical intervention, the function of light as the source of illumination that, on acting on the objects, allows them to be seen, and when these intervene in the lights trajectory, a shadow of the intervening object is formed.

This presents a much more complete logical structure that relates the three elements of the CEI framework.

Explanations about the formation of images in plane mirrors

The following is a presentation of the children's explanation about the images observed in a plane mirror.

Explanation 11 (E11). The object and the image are different but mutually dependent on one another. These are I→E category.

> R: Hey, is that bear that we see in the mirror the same as this, or is it a different one [indicating the image in the mirror]?
> Fernando (Post-test. Five year old student): – *let me see; – the same* (E).
> R: [The child turns over the big plane mirror together with the bear, then looks behind the mirror to make sure there's nothing there] (I→C).
> Fernando: – *it's the same because if I move it, it also moves* (I→E).
> R: Why is that: if you move it, it also moves?
> Fernando: – *because it's just a reflection* (I).
>
> In this case, the child's action of confirming that no object exists behind the mirror allows the affirmation of his idea, which he later uses to explain the Evidence.

Explanation 12 (E12). The object and the image are different, however the image can exist without the object. These can be categorized as I→E type explanations.

> R: If we take the bear from the mirror, can it still be seen?
> Frida (Pre-test. Four year old student): – *yes, it will stay like that* [the object is removed] (I→E).
> R: Why can't we see it now?
> Frida: – *because it's looking for its friend [but there it is]* (I→E).

Explanation 13 (E13). If an object is seen in a mirror, its image can also be seen in another mirror. These explanations are more complex, and are based in Ideas, as well as the Cosmos and the Evidence, I→E→C and I→C→E.

> R: Jessica, the bear has a spider on his back [the bear is in front of the mirror], how could he realize that?
> Jessica (Post-test. Five year old student): [the girl turns the bear over, turning its back to the mirror] (E→C).
> R: If the bear wants to see his back [the bear is facing a mirror]what does he have to do?

Jessica: -*not like that* [returns the bear to its initial position and takes another mirror and puts it behind him and observes] *like this* (I→C→E).
R: What did you do?
Jessica: – The bear *is looking at this mirror* [the one facing him], *and his back is in this mirror* [puts a mirror behind the bear] (I→E→C).
R: How does that happen?
Jessica: – *because the mirror is looking at me* [it's in front of her], *because I'm seeing the mirror and my back is in the other mirror* [explains that she sees her back reflected in the mirror behind her], *because this mirror* [in front] *is in the other mirror* [the one behind]*and I'm in this mirror* [the one in front] (I→E→C→E→C).

Table 5

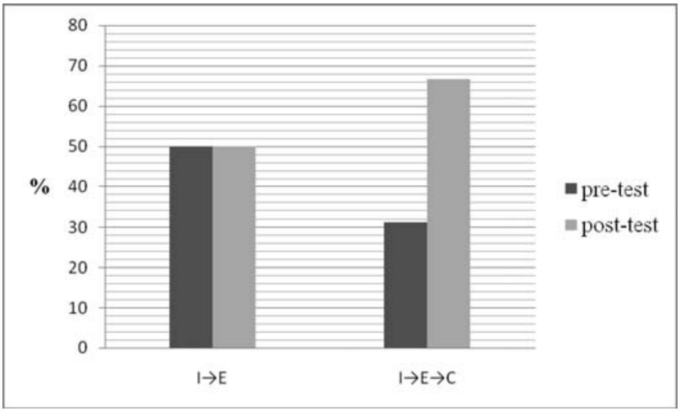
Plane mirrors: comparison of percentages between pre-test and post-test

Pre-test			
Task	E 11(I→E) A3	E 12(I→E) A3	E 13(I→E→C) A3
%	50	50	31.3
Post-test			
Task	E 11(I→E) A3	E 12(I→E) A3	E 13(I→E→C) A3
%	83.3	16.7	66.7

Table 5 shows the answer percentages for the three explanations found for the plane mirror tasks. All the children from the sample responded that mirrors "are for seeing". This is a functional idea about images in mirrors and is the base of the three explanations presented previously. In explanation 11, (pre-test: 50% ;pos-test: 83.3%) children think that the image and the object that is reflected are not the same, but are mutually dependent, an idea which increases after the intervention process and establishes in the children a notion of implicit image. In explanation 12 the object and the image can exist independently (pre-test: 50%; post-test: 16.7%), which implies that for the children the image has a concrete and independent existence, which is maintained even after the classroom intervention, though in a lesser percentage. These same ideas have appeared in higher grade school students (Hierrezuelo & Montero 1989), which speaks to the complexity of the construction of the images notion. Explanation 13 is more complex in that it is recognized that an image can be reflected. Though these explanations are observable before the intervention, the percentage increases in the post-test (66.7%).

Figure 5 presents the answer percentage for CEI categories of the three explanations shown. There are two relationship types, I→E and I→E→C, that are used at a high percentage in the pre-test as well as the post-test, which indicates that the imposed task about the images in the flat mirrors implicitly uses an idea (I) about the characteristics of the images (C), and what is required for them to be observed (E). These ideas have been constructed by the children starting with their continued activities with the mirrors (at home), and this implicit idea they maintain about the images now seems to be imposed on the evidence and allows for the managing of the Cosmos, as can be seen in explanation 13.

FIGURE 5



Comparison between categories for images in plane mirrors

What conceptions are present in the representations of the children and how do they permit them to approach each one of the presented themes?

The explanations described are conceptual entities that generically permit the establishment of basic characteristics of representations which, over a certain phenomenological range, construct the subjects, and therefore allow children to interpret phenomena.

Starting from the analysis of the set of the children's elaborated explanations, it's possible to infer the conceptions that underlie their explanations and actions and that, as Flores and Valdez (2007) have described, are constructed in order to realize an underlying structure in the implicit representations of the subjects in a way that corresponds with the observed processes. These conceptions go beyond the specific explanation, representing a certain level of generalization. They are:

1. Colors are the product of the combination or mix of other colors.
2. The presence of light allows objects to be seen.

3. Shadows are non-illuminated regions due to an object intervening in the light's trajectory.
4. Images depend on objects but are not the same as them.
5. Images can be reflected as objects.

The first conception establishes that the colors we observe in paints are the product of the combination of certain colors, the second shows the need to illuminate objects in order for them to be seen; both are conceptions which are seemingly associated with the children's development itself (older children do this much more easily), and to which the possible influence of EduCienPre's activities seem to contribute. The recognition of paints or filters and light as acting factors, but without a specific relationship, is established in these representations. Both are related to the construction of C→E causal relationships. We identify them as constructions that we will call "in transition", since they will lead to more complex functional processes.

The fourth conception is associated with the construction of the notion of an image in a mirror which is found in the disassociation process of the object itself and its characteristics, which is a more elaborate conception than the previous one and which emphasize the importance of the children's implicit ideas in the notional construction process. It's the justification for the image's existence as an "object" that shows the need to assign corporeity to the images as an indispensable element in the representation construction, previously described by Piaget (1960) and DeVries (1986). This conception is characterized by an I→E type relationship and can also be considered transitional, just as the first two.

The third and fifth conceptions are the most complete. In the third the light-object-shadow relationship is clearly established, which is reached by older children (see DeVries, 1986) than on the present study. The presence of a trajectory of light is implicitly recognized, for which the source of light is identified as relevant and its obstruction is what contributes to the formation of shadows. In this case, the integration of task A2 of this section can be observed as a substantial part of the children's explanations since the presence of light as one of the central factors in the formation of shadows is recognized, but a form of propagation is assigned as well. It's worth noting that, though it can't be deduced from the expressed ideas of the children, with the recognition of a rectilinear propagation of light, it is possible to establish a causal relationship between the absence of light from the interruption of its trajectory, and the shape of a shadow corresponding to the shape of the intervening object. As far as the fifth conception, the image is focused in the children's minds as an object when given the chance to reflect as the objects do, but at the same time leave clearly established that they are not the objects. This conception is complex and abstract in its construction process and, as with the third, shows a clear influence of the classroom intervention process.

Conclusions

The children's physical representations

In the actions that the children carry out in the classroom and during the interview when working with notions of color, light, shadows and images previously described, we can observe how the preschool students elaborate a wide diversity of representations about their action, beyond the interest, enthusiasm, and coordination among them to do such activities. These representations can be characterized as initial elements of a physical thought. Of course they present diversity and levels of representation, determined by the explanations which have been located and shown throughout this document. Though the relation that is established is direct, at no time can it be thought that there are causal networks that make up clear and coherent representations that do provide a base for analyzing the beginnings of a more complex relational construction.

The representations described, on the other hand, give indications about the children's implicit representations (Pozo, 2001) and which recover and synthesize all their previous phenomenological experience. Finally, it should be noted that these conceptual elements are not mutually exclusive and that it is the older children that carried out the activities proposed in EduCienPre who had the most complex representations which allowed them to determine functional relationships, and therefore better descriptions of physical processes, as can be observed in the relationships established in the CEI categories.

What were the effects of the pedagogical intervention?

As has been described, EduCienPre's didactic strategy is based on a semi-open knowledge construction sequence where phenomenological situations are found which are equivalent, but contextually distinct, that allow the children to have experiences that help them interpret the same physical phenomena in different situations; they also count on recording systems to serve as an external memory that helps with the reinterpretations that the students will be making in their activities throughout the school cycle.

The results show that the strategy has played an important role in the construction of more complex explanations (I→E→C) as a percentage increase is deduced that the children receive from the activities. It is possible to state, then, that the children's explanations, after the classroom intervention, have become more extensive and explicit regarding elements that intervene with phenomena. The results show important advances in the children's notions and forms of expression about physical phenomena even months after having applied the strategy.

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