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Precursor model and preschool science learning about shadows formation

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ABSTRACT

Background: This work is based on the idea that young children benefit from early introduction of scientific concepts. Few researches describe didactical strategies focusing on physics understanding for young children and analyse their effectiveness in standard classroom environments.
Purpose: The aim is to identify whether didactical strategies referring to a precursor model can be used to help children construct explanation of physical phenomena.
Sample: We present results that test children's capacity (aged 5-6) to build knowledge within a precursor model in order to describe, explain and predict the phenomenon of shadow formation.
Design and methods: The teaching intervention's efficiency is tested in a standard classroom setting. Data were collected through individual interviews, using identical tasks before and after the teaching intervention.
Results: The analysis of children's ideas shows that the use of a constructivist didactical strategy referring to a precursor model of shadow formation by teachers has a positive effect on children's understanding and ability to identify shadows as a physical phenomenon.
Conclusion: Such results support the importance of science teaching in preschools. In particular, the didactical strategy focuses children's attention to a critical aspect of their understanding and destabilizes their previous representations. It has implications for preschool teacher professional development.

KEYWORDS
Preschool; shadow formation; precursor model; children's representations; teaching intervention

Introduction

There is a general agreement that an introduction to science education should be done as early as possible for all children (Eshach and Fried 2005; Klaar 2016). The rational supporting this claim can be found in the literature in relation to children early cognitive development or discussions on educational systems and the forms of pre-primary education available. For instance, results from PISA 2012 highlight the benefits that students get from attending preschool in terms of future school performance (Eurydice 2014). As such, there is a growing

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interest for children's learning between the age of 3 to 6 and the role it seems to play as a foundation for lifelong learning (Ibid). Moreover, the curiosity of young children favours scientific activities (Eshach and Fried 2005). Children are interested in finding explanations of natural phenomena occurring around them. Further instructional settings can then produce interesting ways of reasoning and conceptualisation of natural phenomena (Havu-Nuutinen 2005; Ledrapier 2010).

Despite the interest for early science education, European curricula for early education give little place to scientific concepts or reasoning. These choices add up to the difficulty for teachers who often feel they do not have sufficient time to focus on science concepts; they lack confidence to teach science or they consider their pupils might not be capable of learning science concepts (Saçkes 2014). Early science education often finds its place as a way to develop children cultural and social skills. Such perspectives reinforce the importance of science educational research focusing on an early development of science activities at preschool, and in particular regarding physical science concepts, often neglected in preschools (Saçkes 2014). Nevertheless, it was shown by different authors that the construction of the physical world in young children's thought can be influenced by interaction situations (Bowker 2004; Blake 2005; Fleer and March 2009; Ravanis 2010; Papandreou and Terzi 2011), facilitated by the teacher acting as a mediator (Weil-Barais 1994; Fleer and March 2009). However, science activities for young children (3–6 years old) often emphasise the introduction of properties of entities and objects, or the description of phenomena of the physical world, rather than the concepts of physics. In addition, through everyday life experiences, children acquire ideas about things and phenomena (Eshach and Fried 2005; Sikder and Fleer 2015). Various authors insist on the importance of taking into account children's first representations as a starting point of instruction in order to improve pupils' understanding (Siry and Kremer 2011; Boilevin 2013).

In such perspectives, the present study explores the possibility to introduce physics concepts at an early age by the introduction of a precursor model on shadow formation. The precursor model is described as an intermediate mental scheme between children's representations and a scientific explanation (Lemeignan and Weil-Barais 1994) and, in the case of shadow formation, it founds its grounds in the underlying scientific model of light propagation and interaction with matter. It leads us to study the efficiency of a teaching intervention with constructivist grounds. The aim of the study is therefore to identify whether didactical strategies referring to such a precursor model can be used to help young children construct explanation of the physical phenomenon of shadow formation in early science settings.

Conceptual framework

From children's representations to the construction of a precursor model

The construction of a mental representation of the physical world for young children has been widely studied on a psychological and epistemological point of view. Many studies explore the origin of children's representations and, in particular, the social conditions of the construction and modification of representations during development (Piaget 1975; Karmiloff-Smith 1992; Baillargeon 2002). In physics education, the problem of the construction and the evolution of representation at school age is also prominent (Driver et al. 1994;

Johsua and Dupin 2003). Representations are seen as the product of the individual and social history of a child, in constant interaction with the sociocultural and educational environment (Sikder and Fleer 2015). As such, they present dynamic characteristics. In many cases, the representations used by children to give an interpretation of the physical world are not in harmony with some aspects of the scientific model (Duit and Treagust 2003). As a result, there is a prevailing idea in physics education research leading to the construction of teaching interventions that are likely to foster the transition from naïve, implicit, local and non-conscious representations of phenomena to conceptions and explanatory mental forms. For the last 20 years, it leads to a constructivist and socio-constructivist research trend that aims to develop, apply and validate activities focusing on children's change of representation and the construction of coherent conceptual scheme to go beyond discovery activities and introduce children to the physical world (Duit and Treagust 2003; Havu-Nuutinen 2005).

Many studies demonstrated that children are not passive learners (Lautrey et al. 2008) and use physical and social interaction with their environment to develop science understanding (Allen and Kambouri-Danos 2017). Their sensitive experience of the world results in the fact that they 'do not come into science instruction without any pre-instructional knowledge or beliefs about the phenomena and concepts' (Duit and Treagust 2003, 671). However, such pre-instructional knowledge may be incorrect and becomes obstacle to new learning and conceptual change. In the tradition of science education, conceptual change is a progressive process during which, initial conceptual structures, based on children's interpretation of everyday experiences in a natural and social environment, are constantly enriched and restructured (Strike and Posner 1982). It is still a prevalent trend in science education (Allen and Kambouri-Danos 2017) with, in particular the idea that taking into account children's ideas in teaching is more likely to initiate rich and permanent conceptual change (Çalık, Ayas, and Ebenezer 2009; Papandreou and Terzi 2011; Ergazaki et al. 2016).

Focusing our interest in the cognitive progress of young children, we place our work in such perspective of conceptual change. Within this framework, we make the hypothesis that the concept of precursor model, proposed by Lemeignan and Weil-Barais (1994), is a powerful tool to develop children's learning in science. 'These "precursors" are cognitive constructions (…). They constitute the moulds for subsequent cognitive constructions, which, without their help, would be difficult or impossible' (Weil-Barais 2001, 188). A precursor model includes several characteristics of the underlying scientific model. It is considered 'precursor' in the sense that it prepares for the definition of other models (Lemeignan and Weil-Barais 1994). Such intermediate entities between first children's representations of the physical world and physics models offer several perspectives. They 'explicit and systematise personal representations, to identify their domain of validity in order to make them representations in the sense of models. These models can, in some cases, be established as precursor to scientific models.' (Lemeignan and Weil-Barais 1994, 98). This framework is connected to the concept of zone of proximal development (Vygotsky 1978) in the sense that the transition from a naive representation of a phenomenon to the construction of a precursor model is not spontaneous (Weil-Barais 1994). Such transition requires a mediating role played by the teacher through didactical strategies specifically designed to target the development of preexisting intellectual possibilities (Fleer and March 2009).

Within this theoretical framework, several researches have been conducted for children aged 5–7 regarding the appropriation of these precursor models such as the association of temperature fluctuations with the expansion or contraction of metal objects (Ravanis, Papandreou et al. 2013) or the rolling of an object (Ravanis, Koliopoulos, and Boilevin 2008), the construction of an inter-object interpretation of the phenomena of shadow formation (Weil-Barais and Resta-Schweitzer 2008), the recognition of the substance of a compact object as a factor allowing to predict whether it floats or sink (Canedo-Ibarra et al. 2010), the model of a linear causal effect relative to the concept of energy that allows the description of divers natural phenomena (Koliopoulos and Argyropoulou 2011), the use of the metaphorical concept of 'travel' in order to identify light as an autonomous entity (Ravanis, Christidou, and Hatzinikita 2013) or the biological contribution of both parents to a child's creation (Ergazaki et al. 2016).

Research on shadow formation with pre-school children

The present study is based on a series of researches concerning teaching and learning of the physical phenomena of shadow formation with children aged 5–6. From what is already known on that matter in the literature, we propose a constructivist approach to destabilise children's representations and build a precursor model about shadow formation. A shadow is a natural phenomenon for which children have often built their own naïve representation in everyday experience (Chen 2009). However, according to Ravanis (1996), these naïve representations may generate difficulties to identify a non-transparent object as an obstacle to a light beam. According to Weil-Barais and Resta-Schweitzer (2008), the issue is to design didactical strategies that allow children to progress in their interpretation of reality. Within such didactical strategies, the teacher's role is to help children accept foreign forms of thoughts going beyond an understanding based on pure perception (Weil-Barais 1994). Children should therefore be encouraged to build observables to develop an understanding of physical phenomena (Weil-Barais and Resta-Schweitzer 2008).

First, we consider implications for the definition of didactical strategies in the domain of shadow formation. Dumas Carré et al. (2003) highlighted the influence of adult-children interactions in a preschool context concerning shadow formation. In particular, they examine the way a teacher guides children's activity and the effect produced on children in terms of scientific learning. Some interactions seam specific to scientific education and the phenomena of shadow formation and influence scientific conceptualisation done by children. Weil-Barais and Resta-Schweitzer (2008) study the role of scientific education in the intellectual development of children from 5 to 6 years old. Their study uses a conception of development based on psychological grounds with: (1) a piagetian model explaining the transformation of explanations of the world during genesis, and (2) vygotskian conceptions stressing the importance of adult mediation and guiding in a socio-cultural perspective. Such studies are based on the design of didactical strategies supported by research in order to confirm the idea that a good knowledge of children's representations significantly contributes to their development (Weil-Barais and Resta-Schweitzer 2008; Fleer and March 2015; Fragkiadaki and Ravanis 2016). Didactical strategies based on naïve representations and the development of teacher's experimental abilities can lead to significant improvements of intellectual constructions of preschool children in shadows formation and various physical concepts related to light (Gallegos-Cázares, Flores-Camacho, and Calderón-Canales 2009). In another perspective, it has been highlighted that a body-based approach, using direct experience with shadows and preschool children's own body, shows a positive effect on learning (Herakleioti and Pantidos 2016).

Secondly, we focus on the phenomena of shadow formation and associated learning difficulties. Based on a historical and epistemological analysis of the knowledge involved with the explanation of shadow formation, Parker (2006) stresses the critical characteristics linked to a qualitative explanation of shadow formation. In particular, he reminds that 'it requires a complex synthesis of knowledge including: light as an entity produced by a light source; light as an entity propagated in space; reflection and absorption of light as it interacts with an object; shadow formation as an area of darkness that varies in intensity according to how much light is reflected from the area into the eye; and the role of the eye as a receptor' (Parker 2006, 1551). As such, the critical point is that the shadow itself has to be understood as an anti-image, or an absence of light resulting from the geometrical blocking of rays of light (Delserieys et al. 2017).

However, Chen (2009) reminds the lack of study on children's conception of shadow formation for children below 6 years old. They mainly confirm Piaget's findings that 'children think shadows belong to the object, and that light is for shadows to push out or to be seen by' (Chen 2009; 61). Similarly, Gallegos-Cázares, Flores-Camacho, and Calderón-Canales (2009), in a study from first to third grade (254 children in total), highlight difficulties in the way young children identify shadows as an autonomous entity sometimes coloured like the corresponding object or as a reflection of the light off the object. After sets of activities proposed during six months, a majority of children (approximately 7 out of 10) do consider that 'a shadow is formed when an object does not allow light to pass' (Gallegos-Cázares, Flores-Camacho, and Calderón-Canales 2009; 64). However, other qualitative and quantitative researches with preschool children (Dumas Carré et al. 2003, Ravanis et al. 2005; Herakleioti and Pantidos 2016) come to the conclusion that the main difficulties in young children's thinking are linked to their understanding of the interactions between light and opaque objects. Children tend to attribute to shadows the properties of an object and do not recognise the role played by light. According to these researches, the intuitive estimations made by children regarding the position and shape of a shadow are caused by their difficulty to consider light interaction with an object and the blocking role of an opaque object. As a result, in the research presented in this paper, we considered that a major challenge is linked with a difficulty for children to explain the phenomenon of shadow formation by identifying the object that blocks the light path. Two consequences derive from this difficulty and have been previously observed (Dumas Carré et al. 2003). The first one is that young children have trouble to define the place of a shadow with respect to the place of the light source and the obstacle. The second one is that it is difficult for them to identify the correspondence between the number of light sources and the number of shadows. The difficulties identified here are considered critical obstacles to children understanding of shadow formation. As such, they were used to build a precursor model of the phenomenon of shadow formation and consequently used throughout the present study to structure the content of the pre- and post-test and the didactical strategy described in the methodological framework.

A precursor model of the phenomenon of shadow formation

The definition of a precursor model requires a communication between the scientific model and children's ideas. From the different elements presented previously (children's representations, precursor model and previous researches on shadow formation with young children), we draw a map to position the precursor model within a system of explanation (Figure 1).

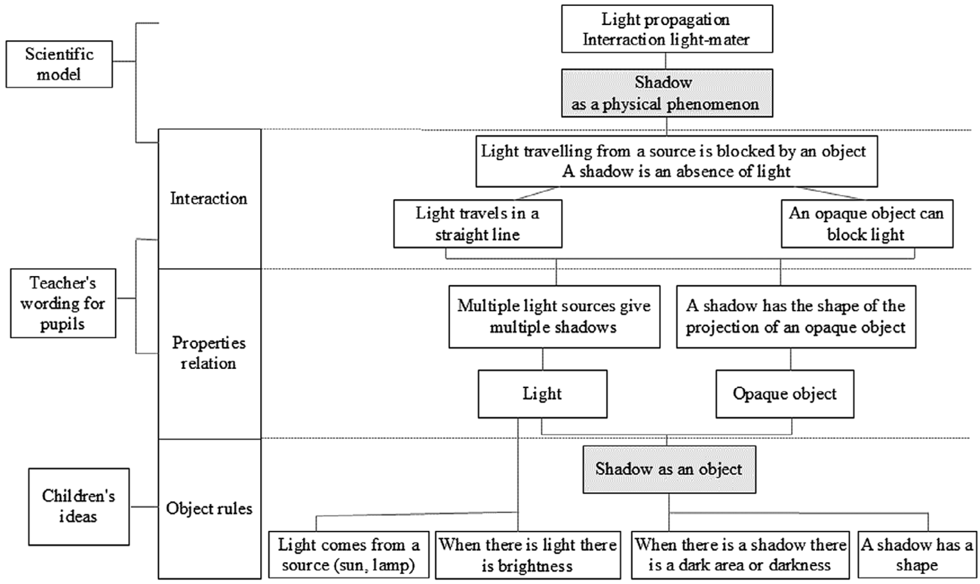

Figure 1. Presentation of the precursor model on shadow formation and the steps identified in children's representations, from the shadow seen as a material object to a first understanding of shadow as a physical phenomenon.

This map, inspired by the work of Canedo-Ibarra et al. (2010) on flotation, illustrates the transitions from the enumeration of different elements where shadows are seen as objects to a relational system defining a precursor model on shadow formation. In a controlled experimental context, it has been previously demonstrated that young children (aged 5–6) are capable of building knowledge within a precursor model that allows them to describe, explain and predict the phenomenon of shadow formation (Ravanis et al. 2005). As a result, the present study was driven by the following research question:

What is the efficiency of a teaching intervention based on a constructivist didactical strategy to trigger the evolution of children's ideas in a standard classroom setting? The didactical strategy refers here to a precursor model on shadow formation to describe, explain and predict the phenomenon of shadow formation.

Methodological framework

Sample

The study was conducted in three classes (equivalent to year 1, KS1) in three public kindergartens in France. Fifty-two children (29 boys and 23 girls) aged 5–6 years old and three teachers were involved in the study. The children had not studied the topic of light and shadow at school before. The three kindergartens were situated in large cities in districts with similar socio-economic features. Regarding ethical issues working with young children, the parents were informed about the objectives and method of the study and we involved only children whose parents gave their agreement. Moreover, the study was conducted within the standard classroom organisation and fell within the objectives of the national curriculum. All teachers were introduced to the didactical strategy based on a constructivist approach using a precursor model of shadow formation described in Table 1. The teaching material and required equipment were provided in each school. Researchers were involved at different levels: they supported the teachers 'activities regarding the constructivist didactical strategy and they conducted semi-directive interviews during pre-tests and post-tests.

The three teachers involved were experienced (more than 10 years), engaged as well in teacher education. They were accustomed to conduct self-analysis of their practice, but had no specific training in science education or research in education other than regular training for all teachers. These teachers were given a script (4 pages) detailing the constructivist didactical strategy and its theoretical grounds. From that, they derived a teaching intervention that was implemented in their standard classroom organisation. We consider 'standard' an organisation that did not require any specific modification for the teacher in terms of classroom organisation, other than the nature of the activities (Delserieys et al. 2014). In this organisation, the class was divided in groups of 5–6 children. Each group did the activity on shadow formation in the classroom with the teacher while the others were doing other activities in autonomy. The teaching intervention lasted 15 to 20 min with each group.

Description of each step of the study

For each group, the same procedure was implemented and similar choices were made regarding the teachers and children involved in the study. It consisted in three steps: pre-test, teaching intervention and post-test with two weeks between each step. The teaching intervention was under the responsibility of the teachers involved in the study and was part

Table 1. Description of the main activities in the constructivist didactical strategy on shadow formation.

Activity	Pupil's work	Teacher's work
A	Form a shadow with the equipment provided (1 lamp and 1 vertical stick)	Provides a lamp and places a vertical object on the tableAsks each child to form a shadow with the lamp and give an explanation
	Explain the phenomenon of shadow formation	Focuses children's attention on where the object is lighted by the lamp and asks children if the light can go through the object
B	Form the shadow of the stick at positions predetermined by the teacher	Asks children to predict the position of lamp and object to form a shadow at designated places
C	'Impossible activity': try to form the shadow of the stick between the lamp and the stick	Brings children to an agreement on the fact that the shadow is form on the other side than the lamp with respect to the object Asks children to realise the 'impossible activity' Engages a discussion on why the activity is impossible
D	Form several shadows of the stick	Provides several lamps to the group (at least one per child) Asks children to form more than one shadow Asks children to predict the number of shadows with 2 lamps
E	Predict the position and the number of shadows of the stick according to the position and the number of lamps	Guides children in successively turning on and off the different lamps while predicting the results of these operations Helps children making the correspondence between number of shadows and number of lamps

of teacher's regular science practices with the children in their class. The pre- and post-tests were organised by the researchers outside of standard classroom organisation.

A constructivist didactical strategy on shadow formation

The teaching interventions set up by the teachers all derived from the didactical strategy on shadow formation based on a constructivist approach. The main theoretical underpinning relies on the importance to take into account children's previous knowledge in the learning process of scientific phenomena. Furthermore, the didactical strategy is organised to focus on targeted concepts which have been identified as critical obstacles to children understanding (Ravanis 2010). In particular, it focuses children's attention on the role played by an opaque object to block the path of light. Moreover, it considers the difficulty that young children can have to define the position of a shadow with respect to its corresponding light source and object, and to identify the correspondence between the number of shadows and the number of light sources. The aim of the teaching intervention lies in overcoming these predetermined obstacles (Ravanis, Christidou, and Hatzinikita 2013). Therefore, the intervention is designed to target specific elements of the underlying scientific model aimed to destabilise children's representations and help them construct a precursor model explaining the formation of shadows. In this precursor model, a shadow is defined as the absence of light and the phenomenon explained by the fact that light travelling from a light source is blocked by an opaque object (Figure 1). The teaching intervention was organised through a set of five activities described in Table 1. Each group of 5 to 6 children were first invited by the teacher to express their previous knowledge through an open activity where they formed shadows using a lamp and a blocking object (Activity A). In a second step, the children were asked to predict the position of the lamp and the object to form a shadow at places designated by the teacher (Activity B). This second step led to an impossible activity where children were asked to form a shadow of the blocking object between the lamp and the object (Activity C). Throughout these activities of prediction, children were encouraged to verbalise over the role of the object and then to discuss on why the impossible activity is actually impossible to do. The fourth and the fifth activities involved several light sources. Similarly, children first expressed their previous knowledge through an open activity where they had to form several shadows (Activity D). Then they were guided by the teacher to make predictions on the positions and number of shadows depending on the positions and number of light sources (Activity E). In this intervention, the teacher plays a role of mediation to help children interacting with each other and with simple experiment in order to develop ideas about shadow formation. He/she provides scaffolding to the children to help children engage in the learning activities within a zone of proximal development (Weil-Barais 2001; Fleer and March 2009) where learning is understood as a product of social interactions focusing on targeted concepts (Dumas Carré and Weil-Barais 1998).

In Table 2, we propose an analysis of the didactical strategy with respect to the theoretical underpinning of such a socio-cognitive approach: the knowledge linked with the precursor model, the nature of the interaction between the children and the teacher and the cognitive functions developed by children (Venville et al. 2003; Ravanis, Christidou, and Hatzinikita 2013).

Table 2. Analysis of the constructivist didactical strategy on shadow formation.

Activities	Precursor model	Interactions	Cognitive functions
(A) Form the shadow of the stick	*Light travelling from a source is blocked by an object*	Taking into account previous knowledge Bringing new knowledge	Explaining
(B) Form the shadow of the stick at positions predetermined by the teacher	*A shadow has the shape of the projection of an opaque object*	Helping to formulate knowledge	Formulation of predictions Testing experimentally
(C) *Impossible activity* : Form the shadow of the stick between the lamp and the stick		Encouraging comparisons Synthesis of different conceptions	Identifying and managing disagreement Explaining Adopting new ideas
(D) Form several shadows of the stick	*Multiple light sources give multiple shadows*		Thinking and working collaboratively
(E) Predict the position and the number of shadows of the stick according to the position and the number of lamps		Synthesis of different conceptions	Formulation of predictions Testing experimentally

Pre-test and post-test protocol

The research protocol included identical pre- and post-interviews within two weeks of the teaching intervention. Semi-directive interviews were conducted with each child by researchers in a separate classroom allocated for these tests within each school (Delserieys et al. 2014). Three tasks were defined from the difficulties identified in children's explanation regarding shadow formation. These tasks were used to collect each child's ideas before and after the teaching intervention in order to test the efficiency of the didactical strategy described above to trigger the evolution of children's ideas. These tasks used everyday objects (pencil pots, bedside lamps …). In task 2 and 3, the lamps are never lit.

- Task 1: The child is invited to observe the shadow of an object formed by sunlight, and to describe and explain how shadows are formed.
- Task 2: A lamp and an object are placed in front of the child. He/she is asked to predict where there would be shadow if the lamp was lit and explain his prediction.
- Task 3: Two lamps and one object are placed in front of the child. He/she is asked to predict where there would be shadow if the two lamps were lit simultaneously and explain his prediction.

Data collection

All three steps of the protocol described above were videotaped. For this article, the data collected consisted in the videos of the individual interviews during the pre-test and post-test. In total, about 7.5 h of video were analysed. The data analysis was based on verbal and non-verbal language used by each child regarding shadow formation. The non-verbal consisted in all the moments were children did not express themselves verbally and used gesture instead: pointing the objects used in the tests (pencil pots, bedside lamps …), or pointing presumed location of the shadow on the table, etc. Data from the pre- and post-test were analysed and treated statistically. In order to evaluate the improvement in class performance following the teaching interventions, a goodness-of-fit test (χ^2) was performed.

Results

The present study focuses on the analyses of the children's mental constructions during the pre- and post-test, since a qualitative analysis in the teaching intervention has been made in another article (Impedovo et al. 2016). We present here the results in terms of performance and progress after the teaching intervention. We start with the categorisation applied to produce the results from the interviews of the pre- and post-test.

Data analysis: categorisation

The analysis is based on the scientific meaning and not on the linguistic form of the answers. In Table 3, we present the way children's answers were categorised with respect to the precursor model previously defined (Figure 1).

In the following, extracts from children's answers illustrate the ways the categories were used. An adequate answer (AA) refers directly to an explanation of the phenomenon based on a spatial relation between light-source, object and projection-plan and identifies shadows as the absence of light (Figure 1):

- Task 1: children recognise the mechanism of shadow formation: '*… the chair prevents the light … it cannot go through and a black chair is formed on the wall …*'
- Task 2: children recognise and correctly explain the position of the shadow of an object with respect to the light source: '*… anywhere we put the lamp … it gets created behind the object …*'
- Task 3: children recognise the correspondence between the number of light sources and the number of shadows: '*… for us to see two shadows … we need two lamps*'.

Non-relational answers (NRA) were considered when:

- Task 1: children do not mention the relation between the light and the object for the formation of a shadow: '*… there is the lamp and my hand; that's why the shadow is like my hand; the shadow gets created from my hand*'
- Task 2: children do not explain the position of the shadow, the object and the light source: '*The shadow is … in front … no … behind; I don't know; in front or behind*'
- Task 3: children do not recognise the correspondence between the number of light sources and the number of shadows: when the researcher asks where there would be

Table 3. Categorisation scheme for the description of children's understanding of shadow as a physical phenomenon.

Adequate answer (AA): the child explanation gives evidence that he is able to consider shadows as a physical phenomenon. He is able to establish a relation between a source of **light**, an opaque **object** and the formation of a **shadow**
Non-relational answer (NRA): the child explanation gives evidence of a partial understanding of the physical phenomena.
(a) Explanation only attributes the presence of a **shadow** to the presence of **light**
(b) Explanation only attributes the presence of a **shadow** to the presence of an **object**
Non-relevant and non-scientific answer (NSA)
(a) Explanation shows a confusion between shadows and darkness
(b) Explanation shows a confusion between shadows and spot of light
(c) The child does not mention any physical properties or gives incoherent answers
(d) The child does not answer or does not recognise the formation of shadows

shadow if two lamps are lit simultaneously, children point only one spot or one large area.

The answers were considered non-relevant or non-scientific (NSA) when:

- Task 1: children refer to elements or situations that are not linked in any way to the phenomena of shadow formation: *'… the shadow is in the villages …', 'the moon … it's a shadow …'*
- Task 2: children do not make any link between lamp-object-shadow: *'A shadow do not have colour … it is black …* [Researcher: Yes but where is it … I am talking about the shadow of the object] … *It is everywhere; in any part that is black'*
- Task 3: once again, children do not give explanations in terms of relation between lamp-object-shadow: *'We will see shadow … that reaches the wall …* [Researcher: and how is the shadow formed?]… *on the wall …'*

Efficiency of the didactical strategy

Table 4 presents the percentage of answers of children. The frequency of answers in each category indicates that the constructivist teaching intervention has an effect on preschool children and their ability to construct a precursor model on shadow formation. For all three tasks used in the pre- and post-tests, the results (Table 4) show that a large number of children give adequate explanation of shadow formation after the socio-cognitive teaching interventions based on the same didactical strategy. The difference between the results of the pre-test and the post-test is statistically significant. As such, these results are conclusive regarding the relevance of the didactical strategy shaping the teaching intervention and referring to a precursor model on shadow formation.

In task 1, the children exhibit significantly better results in the post-test than in the pre-test. For task 1, there are 16 children giving adequate answers in the post-test against 2 in the pre-test ($\chi^2 = 23.61$, $p < .00001$). This means that they are capable of recognising the mechanism of shadow formation with answers explicit and compatible with the precursor model on shadow formation in the post-test and were not before the teaching intervention. For task 2, 25 children give adequate answers in the post-test against 2 in the pre-test ($\chi^2 = 29.24$, $p < .00001$). Finally, for task 3, 18 children give adequate answers against 1 in the pre-test ($\chi^2 = 19.04$, $p < .00008$). Furthermore, it is interesting to stress the difference in performance from one task to another in the post-test. For task 1, the number of children giving completely non-scientific answers is reduced (7.7% of children) compared to task 2 (40.4%

Table 4. Frequency of answers of children at three tasks.

		Pre-test	Post-test
Task 1	AA	2 (3.9%)	16 (30.8%)
	NRA	28 (53.8%)	32 (61.5%)
	NSA	22 (42.3%)	4 (7.7%)
Task 2	AA	2 (3.8%)	25 (48%)
	NRA	4 (7.7%)	6 (11.5%)
	NSA	46 (88.5%)	21 (40.4%)
Task 3	AA	1 (1.9%)	18 (34.6%)
	NRA	5 (9.6%)	5 (9.6%)
	NSA	46 (88.5%)	29 (55.8%)

of children) and task 3 (57.8% of children). However, the majority of children do not reach completely satisfactory explanations of shadow formation with 65.4% of children still giving non-relational answers. Task 1 is found to be the task requiring the most advanced level of verbal explanation of the phenomenon. Moreover, the results in Table 4 also show that a majority of children (57.8% of children) are not capable of reaching any level of scientific answer in task 3, when more than one light source are introduced.

From the results shown above, it is observable that children, at the age of 5–6 years old, are capable of building knowledge within a precursor model whenever their teachers are introduced to didactical strategies that encourage overcoming obstacles regarding the comprehension of shadow formation by identifying the opaque object as a barrier that blocks the light path. In summary, the teaching intervention has a positive effect on children's attainment of the precursor model of shadow formation.

Evolution of children's explanations

The previous analyses are completed with a description of children's answers to qualify and propose an explanation of the evolution of their ideas on shadow formation. The following section highlights some answers from children in the first task that are considered representative by the researchers. We first present the progression observed amongst three children (Table 5), and then the case of two children that do not demonstrate any progression within our categories (Table 6). The case of children presented in Table 5 illustrates the nature of the progress accomplished in order to identify a binary relation between the obstacle and the shadow (child A), or a full relation light-object-shadow (children B and C). Child B demonstrates a particular progress between the pre- and the post-test with an increased level of abstraction. We note in particular the focus on the shadow only in the pre-test, then to its shape, with a correspondence with the pen-pot used during the interviews. The child finished the explanation considering that the more general category of 'an object' may produce a shadow when there is light, showing the capacity to abstract a variable in the physical situation proposed (Baillargeon 2002).

The answers of children D and E (Table 6) do not show apparent progress within the categorisation used (Table 3). However, differences can be pointed out in terms of the structure of the explanation between the pre- and the post-test. For child D, the researcher helps him to express a binary relation (light-shadow) to explain the presence of a shadow. In the post-test, this child is still not capable of expressing a full relation light-object-shadow, but gives awareness of the existence of two binary relations (light-shadow and object-shadow). The role of light in the shadow formation is also expressed with more details, implying also

Table 5. Examples of children's answers showing progress in task 1 from pre- to post-test.

Child	Pre-test	Post-test	Progress
	Researcher: 'Can you explain how a shadow is made?'		
A	*'It* (the shadow) *is made with paint, with pens* (points out a black pen)'	*'The shadow is made with the pot'*	NSA→NRA
B	Only capable of saying that he sees a shadow	*'It* (the shadow) *looks like the pen pot (…) it is made with light and an object'*	NRA→AA
C	*'Something else than the pen pot is required but I don't know what'*	*'The shadow is made with light and with a pot'*	NRA→ AA

Note: NSA→NRA: non-scientific answer→non-relational answer, NRA→AA: non-relational answer→adequat answer.

Table 6. Examples of children answers showing no progress in task 1 from pre- to post-test.

Child	Pre-test	Post-test	Progress
	Researcher: 'Can you explain how a shadow is made?'		
D	Researcher: *'Why is there a shadow?'* Child M1: *' because there is light'*	Researcher: *'What can you see here?'* Child M1: *'It is the shadow of the box'* (…) Researcher: *'How is it made?'* Child M1: *'The light from outside, it comes in and it makes a shadow.'*	NRA→NRA
E	*'Because here, there is sun* (points toward the window) *and if … When there is a thing, then, the sun, it is no longer there* (indicates the position of the shadow of the object) *because of the object.'*	'*Yes* (turns the head toward the window). *In fact, there is sun and then* (takes the object in her hand) *if this is removed* (removes the object), *there is still sun. If this is put back, there is a shadow.'*	AA→AA

Note: NRA→NRA: non-relational answer→non-relational answer, AA→AA: adequate answer→adequate answer.

the concept of propagation of light (child D: 'the light (…), it comes in …'), which is a complex concept for young children (Ravanis, Christidou, and Hatzinikita 2013). It is interesting to stress the support needed by child D to express his ideas based on the researcher's questions. The adult serves here as a mediator (Weil-Barais 1994). Child E finds this support in the available context (pointing toward the window or the shadow, touching the object) which seems to allow him to better express his thinking. This child particularly expresses causal relations using several conjunctions (because, then …). A focus on the phenomena associated to the absence of light (in presence of the object) and the presence of light (in absence of the object) is also interesting to point out. The causal relation seams constructed and stable for that child. It highlights the capacity of young children to evaluate evidence, experiment and draw conclusions (Piekny, Grube, and Maehler 2014).

This analysis emphasises the central role of language played in early science activities. Language can be therefore enriched from the expression of scientific concept, but also through scientific reasoning. Such consideration are important for pre-school where teachers tend to prioritise language and literacy practices and do not necessarily think of science to develop academic language (Henrichs and Leseman 2014).

Discussion

The study presented in this paper provides evidence to support the use of constructivist theoretical underpinnings to develop children's understanding of the physical world at an early age, and in particular understanding of the phenomena of shadow formation. Within the constructivist perspective, it was possible to build a precursor model. This precursor model is compatible with the characteristics of the underlying scientific model and adapted to the preschool age. It therefore allows young children (ages 5–6) to describe, explain and predict physical phenomenon, giving them access to scientific reasoning. This first general conclusion confirms the results of previous studies (Ravanis et al. 2005; Gallegos-Cázares, Flores-Camacho, and Calderón-Canales 2009; Herakleioti and Pantidos 2016).

In these previous studies, some authors propose to approach differently the question of the phenomenon of shadow formation at preschool. Gallegos-Cázares, Flores-Camacho, and Calderón-Canales (2009) describe a broad set of activities within a long period of time (six months) designed to change children's representation of light and shadows. However, they reach the same conclusion than us with 7 out of 10 children that managed to express the idea that shadows result from light being blocked by an object. Moreover, Herakleioti and Pantidos (2016) obtain similar positive results using a body-centred activity that 'explicitly incorporates the rectilinear movement of light into the process of shadow formation, while also providing learning through direct experience' (Herakleioti and Pantidos 2016; 21). In their research, the attention on the blocking object is provided with direct body experience. Finally, in a previous research, Ravanis et al. (2005) used similar didactical strategies than the one used in the present research (described in Table 1), but with a different approach in terms of the methodology employed. The previous results were obtained in a strict experimental setting comparing a control group using an empirical approach and an experimental group using a socio-cognitive approach. The results were obtained with a strong involvement of researchers in the classroom to directly assist the teachers. Furthermore, it involved teachers with a master's degree in science education that gave them an insight of how research in science education is conducted and wider knowledge of science in general. As a result, that previous research involved specific classroom settings that are not common to everyday preschool teaching and therefore are not replicable in real-life teaching (Ravanis et al. 2005). As a consequence, the results presented in the present article largely extend previous work in the sense that it shows that the didactical strategy based on a precursor model, passed on to teachers in a standard classroom setting, has the potential to trigger shifts in children's representation about shadow formation.

Moreover, the implications of our results engage discussions on two levels. The first one is linked to the precursor model as a support provided to children to assess their learning and evolving capacities. The second one is considered in a pedagogical perspective and linked to the role given to the teacher to provide scaffolding. According to our research findings, after the teaching intervention based on the use of a precursor model, a large number of children are able to identify shadows as a physical phenomenon and build causal relation (light-object-shadow). It is precisely these causal relations that allow a scientific way of thinking. They demonstrate that a precursor model is being constructed (Weil-Barais and Resta-Schweitzer 2008). This article highlights three main ideas in terms of didactical strategy that can have implications for teaching science at an early age using precursor models. First, the children's relationship to the obstacle in the formation of shadows is challenged during an impossible activity (forming a shadow in the same side than the light source with respect to the object, see Table 1, activity C). Such activity forces them to experiment and re-evaluate according to direct evidence (Piekny, Grube, and Maehler 2014) until they accept the impossibility of the activity. It focuses children's attention directly to a critical aspect of their understanding and as a result pushes them to destabilised previous representations. Secondly, the children's relationship with the equipment provided and the experimental set-up influences the way of apprehending the concept (Piekny, Grube, and Maehler 2014). Finally, we stress the importance of such science activities to develop language skills beyond scientific language (Henrichs and Leseman 2014), especially in the context of pre-school were the development of language skills is often the first goal (Eurydice 2014).

Finally we would like to come back to the way the teachers were introduced to the didactical strategies. A cognitive progress of the children is observed in our standard classroom setting, where only written instructions about the didactical strategy was given to the teachers. Implementation of a teaching intervention is a dynamic process where teachers are likely to adapt their actions. The didactical strategy, based on previous research evidences, and adopted by the teachers to implement in their classroom, gives positive results in terms of children's understanding of shadow formation. It is important to remind that the teachers involved were experienced, but did not have deep knowledge about teaching shadows. This work comes as an effective proposal to provide teachers with better knowledge of children's representations prior to teaching, and ways to take them into account to teach a new topic. It has been shown that this is a critical point for preschool teachers (Kambouri 2016). The present study relies on the bases that a teaching intervention strongly based on research should give better results (Tiberghien, Vince, and Gaidioz 2009). To go further, the activity of the teacher interacting with the children during the teaching intervention needs to be analysed in order to get a deeper understanding of the mediating role of the teacher and its relation to children's learning (Weil-Barais 1994). In this direction, we have shown in another paper (Impedovo et al. 2016) that this teaching intervention produces an interesting context to study the influence of gesture and interaction of children with artefacts.

In the perspective of teacher's professional development, this work shows that it is possible to introduce science concepts in early education with short and simple activities, creating more science learning opportunities (Fleer, Gomes, and March 2014). The activity proposed does not require extended material, time or complex class management. The effectiveness of the teaching intervention on shadow formation proposed here relies on a strong understanding by the teacher of two key dimensions, in relation to physics concepts and teacher–children interactions. First, it is important that teachers understand their practices to help children to identify non-transparent objects as obstacles to a light beam. In that sense, the impossible activity is seen as a way to focus pupil's attention on the object and the result of its interaction with light. Subsequently, the introduction of more than one light source raises the cognitive demand of the activity and engages children to identify each shadow and its corresponding light source, with respect to the object. Many teaching resources on shadows for young children tend to focus on the shadow and its size with respect to the position of a light source. When an object is targeted, the focus tends to be put on the shape of the shadow depending on the nature of the object. Rather than insisting on shadow properties, the teaching intervention proposed here focuses on the relations light-object-shadow with a concern that children can explain that a light source can produce a shadow in presence of an opaque object. The second dimension is the mediating role of the teacher in the system of interaction knowledge-learner-artefact which induces a change of teaching practices. Interactions teacher-learner and learner-learner play a major role (Dumas Carré and Weil-Barais 1998). A precursor model is accessible to young children only with the help of his teacher. Such a mediating system requires teachers to 'go from a vision of transmitting knowledge to one of being a mediator' (Lenoir 2011, 113). It therefore supports the idea of zone of proximal development seen as 'a process of construction carried out jointly with more skilled partners, and teachers in particular' (Weil-Barais 1994, 368).

As a conclusion, this study reinforces the possibility for research to 'serve the design of teaching resources and more generally contributes to improve science teaching' (Tiberghien, Vince, and Gaidioz 2009, 2276) in preschool science contexts. Such approach could bring perspectives to the definitions of learning progressions where the concept of precursor model could contribute to the definition of 'curriculum that is informed by conceptual research' (Allen and Kambouri-Danos 2017, 186). However, the use of precursor models is done under the condition of a clear theoretical framework to design the teaching intervention, and also requires working together with teachers communities to increase teaching effectiveness (Johnson 2006).

Disclosure statement

No potential conflict of interest was reported by the authors.

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